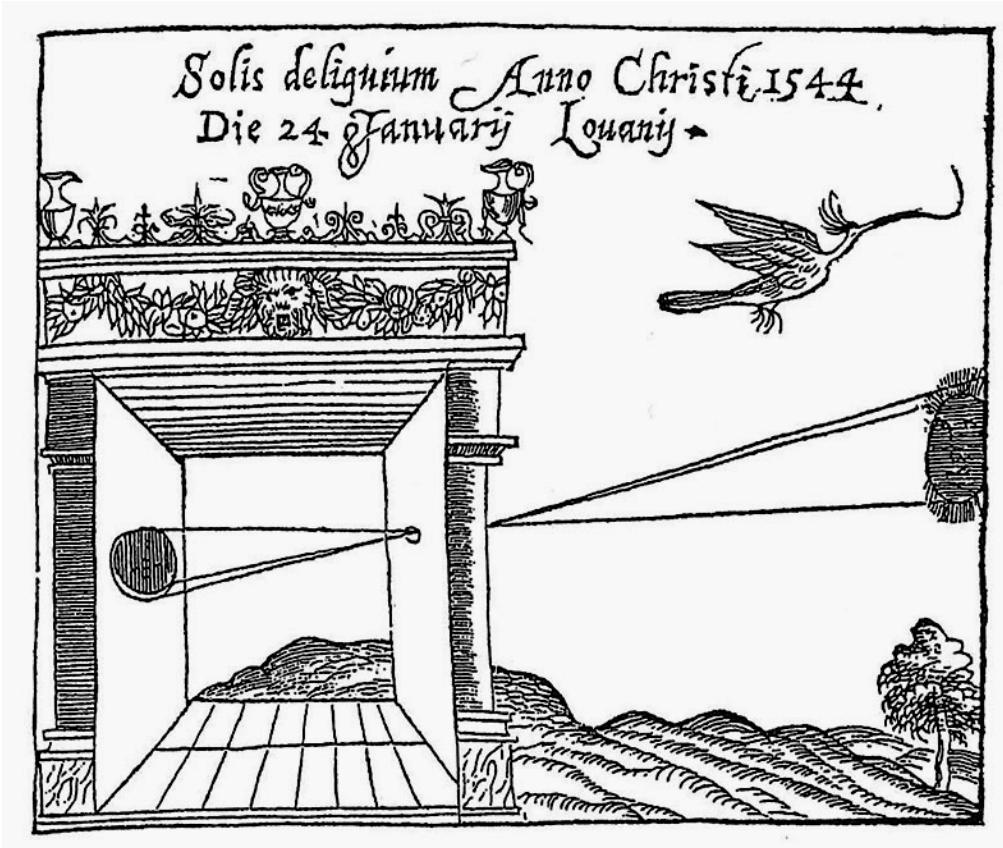


# Cameras

15462: Computer Graphics

# A Brief History of Images



*Camera Obscura*, Gemma Frisius, 1558

# A Brief History of Images

1558  
1568

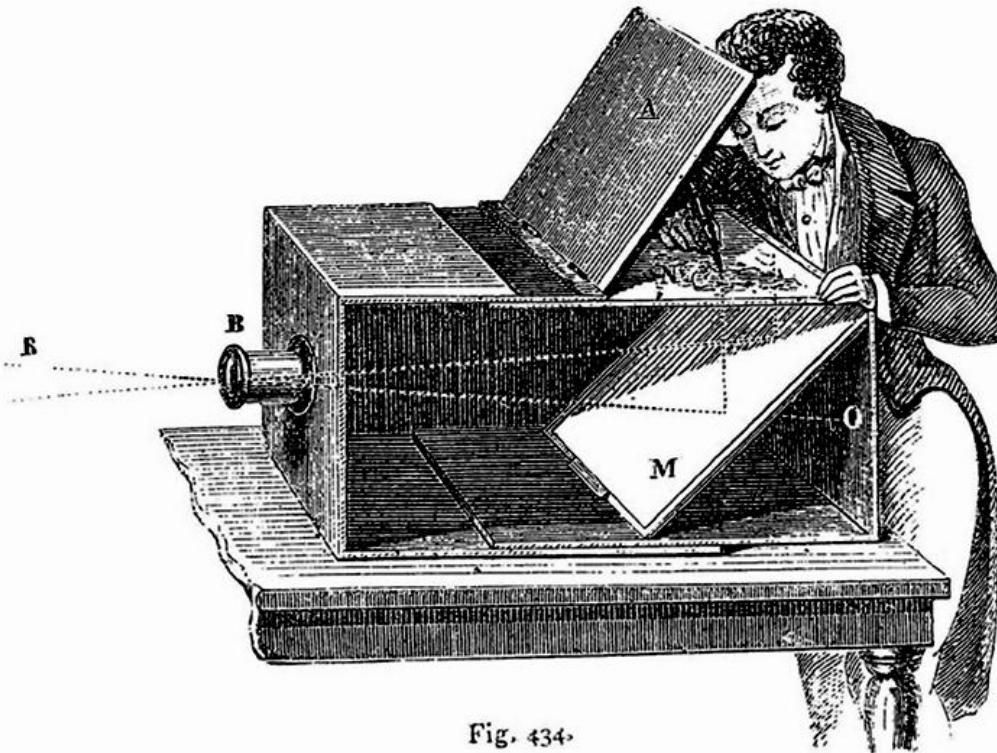
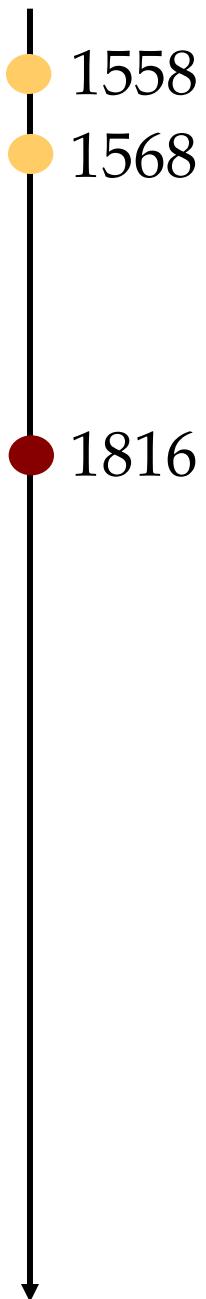


Fig. 434.

Lens Based Camera Obscura, 1568

# A Brief History of Images



Joseph Nicéphore Niépce (1765-1833)

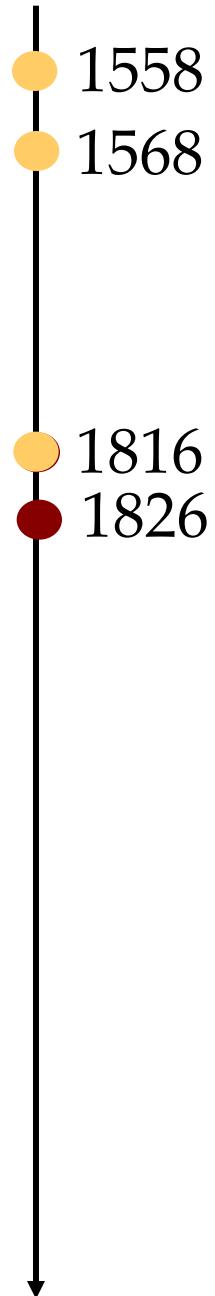


The first negative (not original)  
[Not fixed...quickly vanished]

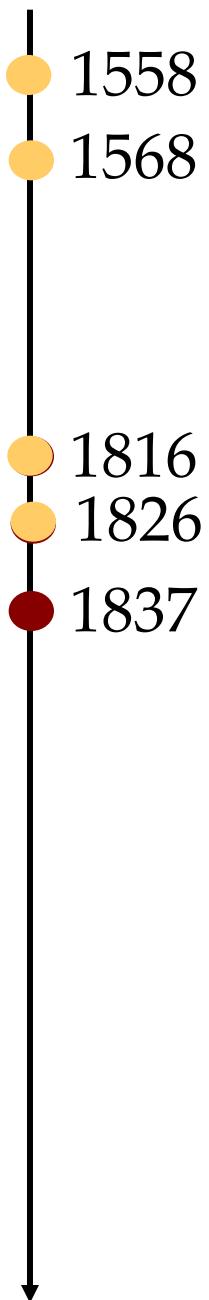
# A Brief History of Images



The first permanent photograph (8 hour exposure), Niépce

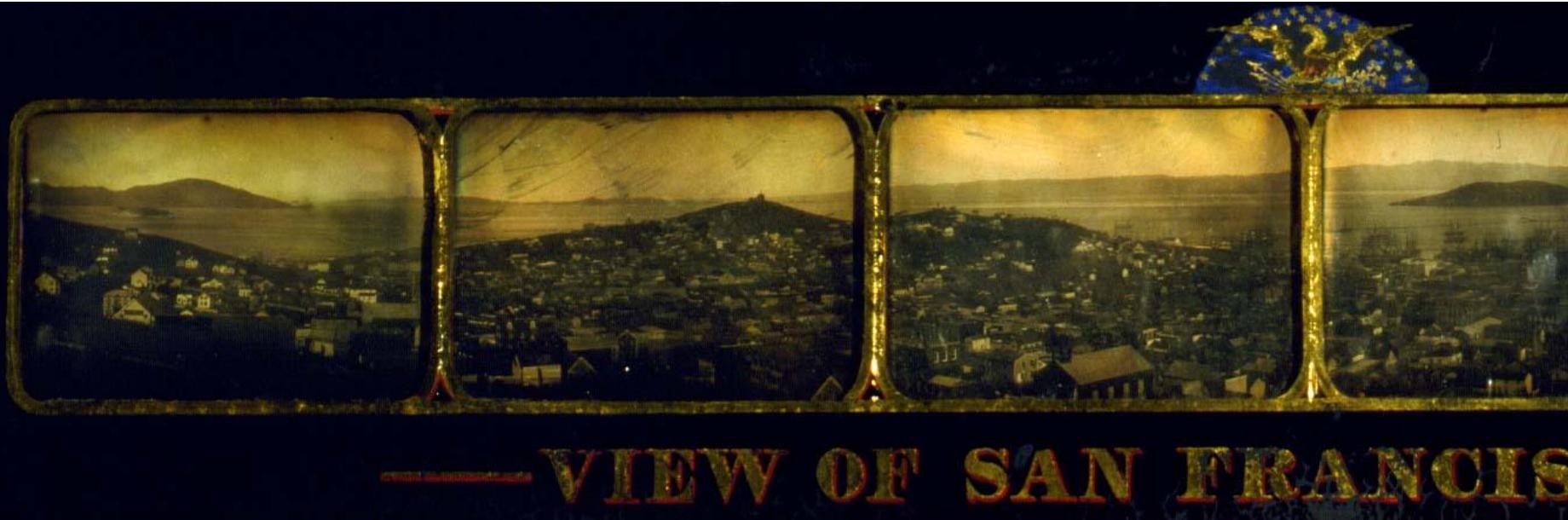


# A Brief History of Images



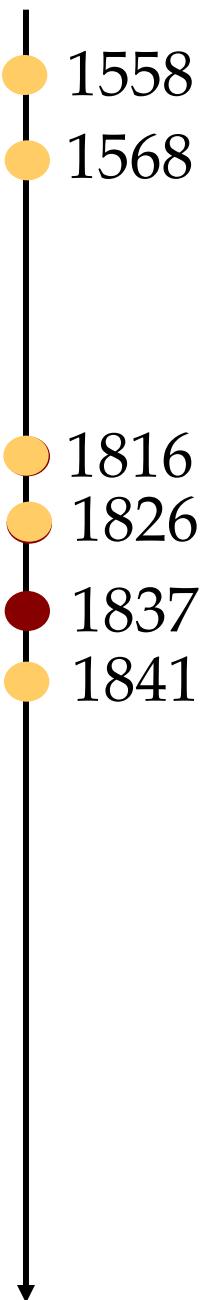
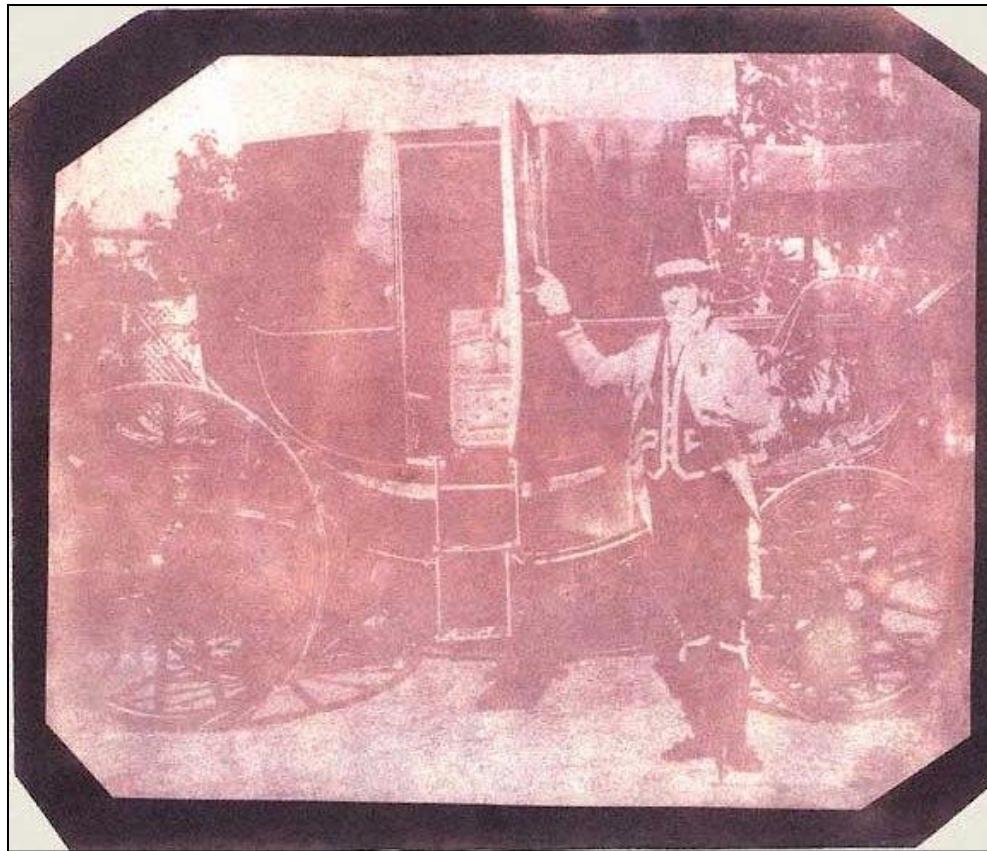
*Still Life*, Louis Jacques Mandé Daguerre, 1837

# A Brief History of Images



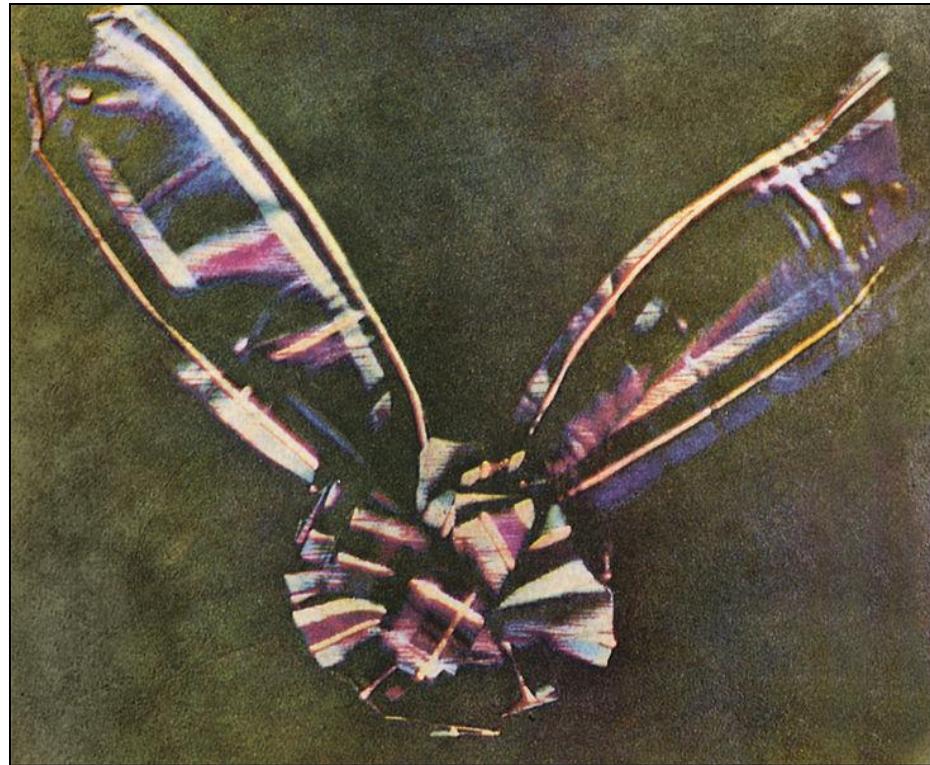
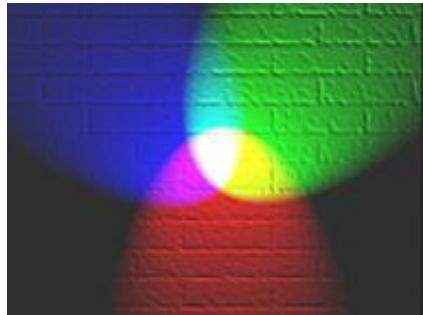
Daguerreotype Panorama (wiki)

# A Brief History of Images

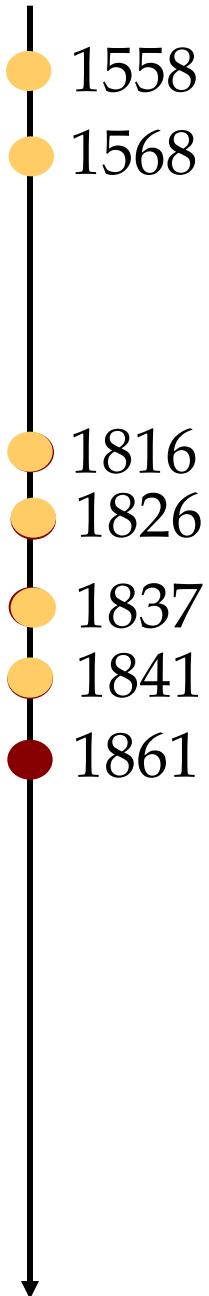


William Henry Fox Talbot , negative to positive photographic process

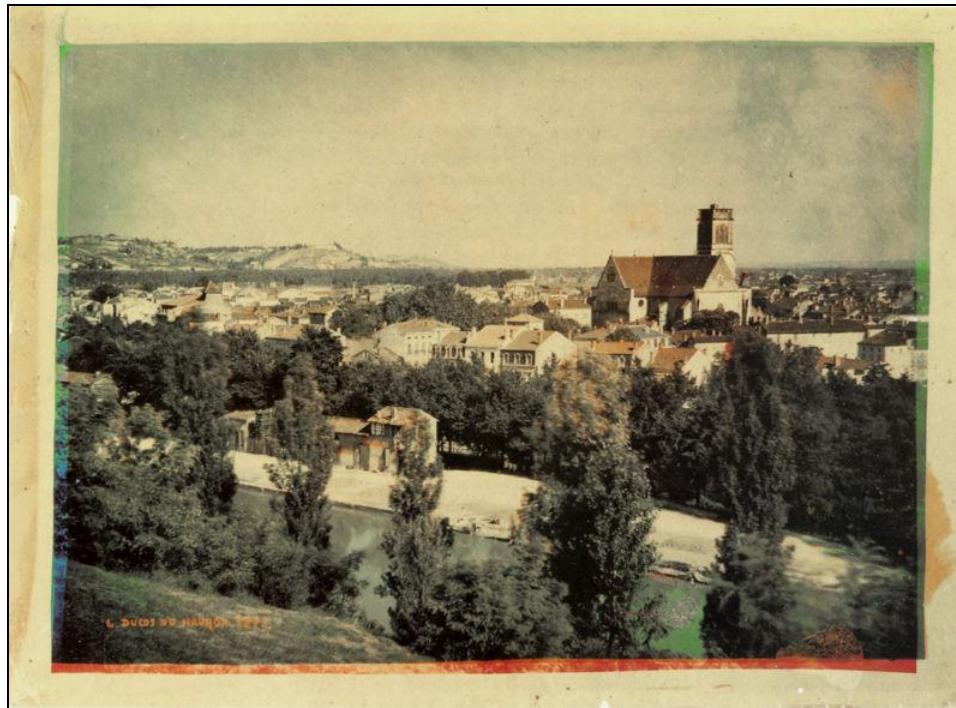
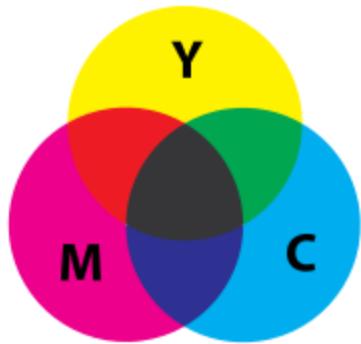
# A Brief History of Images



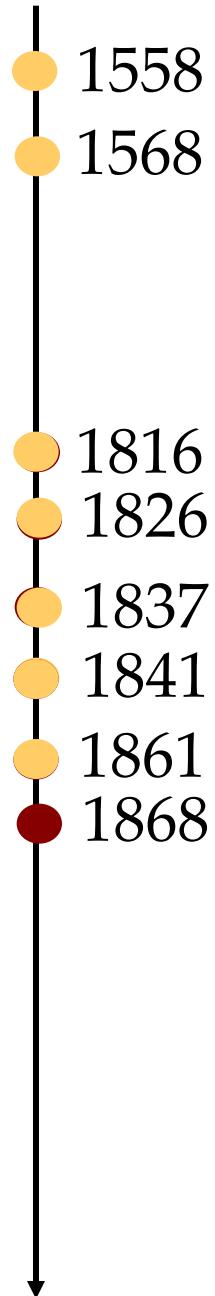
*tartan ribbon*, James Clerk Maxwell, additive color photograph



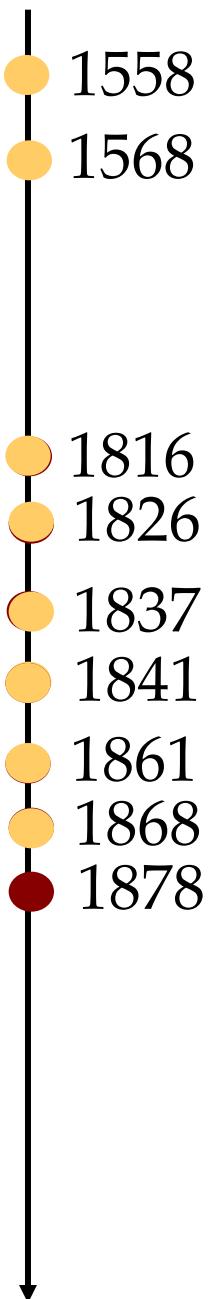
# A Brief History of Images



Louis Ducos du Hauron, subtractive color photograph



# A Brief History of Images

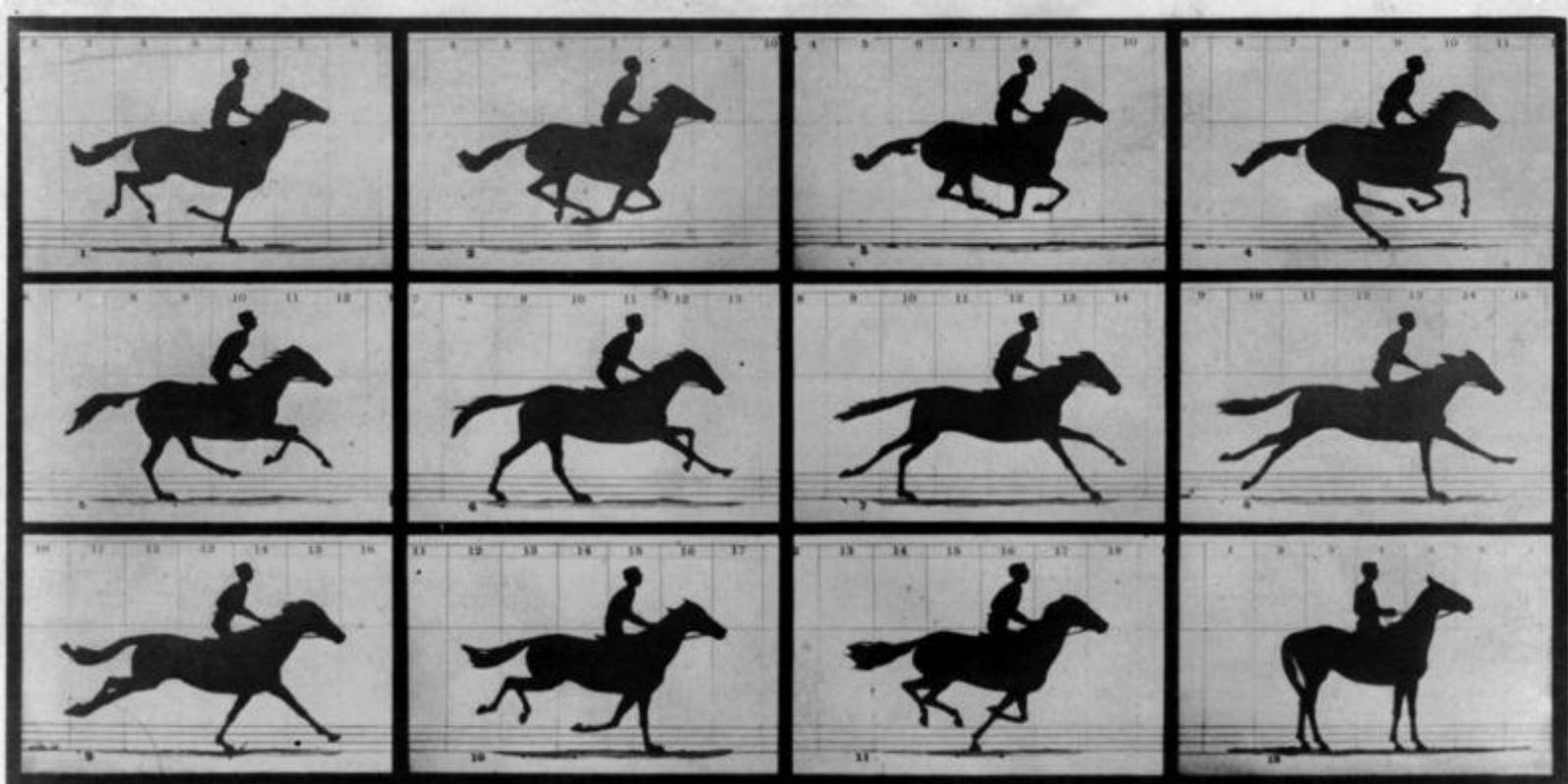


*The Horse in Motion*, Muybridge, fast motion using 24 cameras.

1558  
1568

# A Brief History of Images

1816  
1826  
1837  
1841  
1861  
1868  
1878



Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 437 Montgomery St., San Francisco.

## THE HORSE IN MOTION.

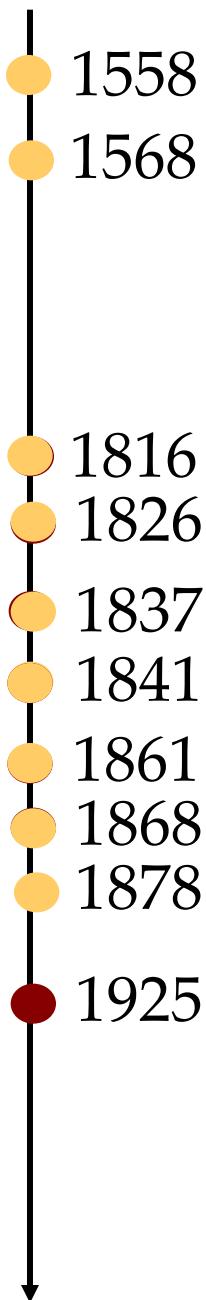
Illustrated by  
**MUYBRIDGE.**

AUTOMATIC ELECTRO-PHOTOGRAPH.

"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative was less than the two-thousandth part of a second.

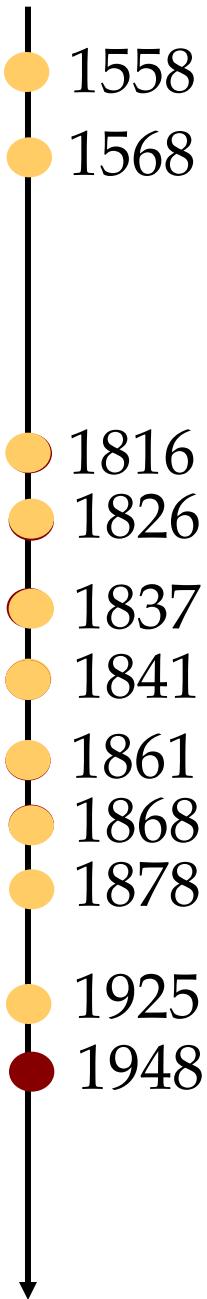
# A Brief History of Images



*The Leica, the 35mm format in still photography.*

The photographic film is cut into strips 35 millimeters wide.

# A Brief History of Images

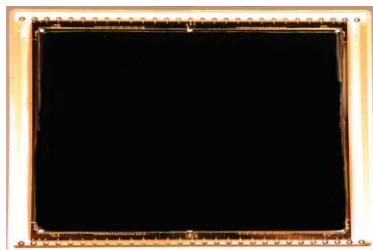


Edwin H. Land

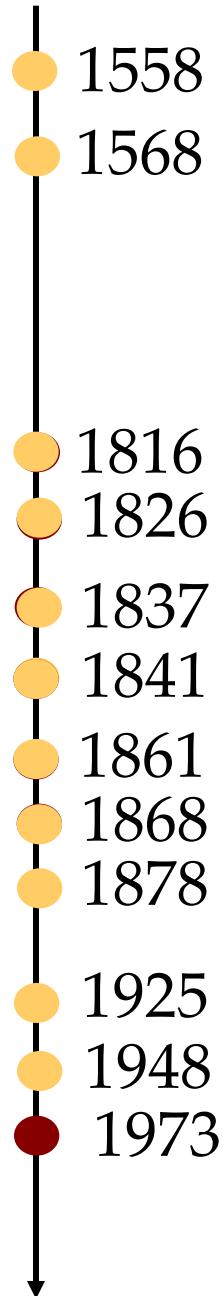


Polaroid instant image camera

# A Brief History of Images



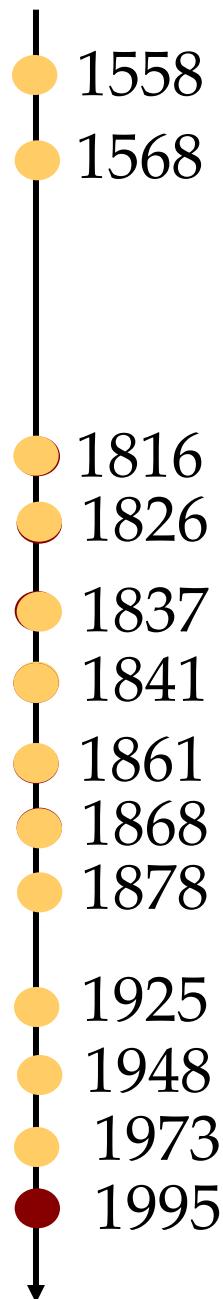
Silicon Image Detector, 1973



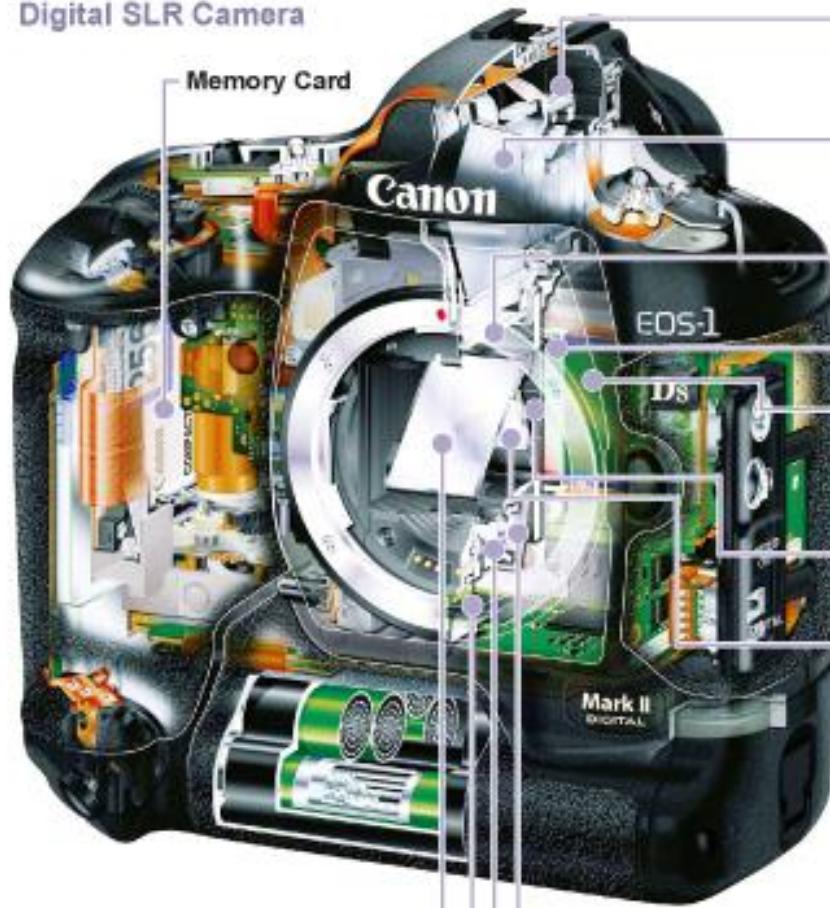
# A Brief History of Images



Digital Cameras



## Digital SLR Camera



### 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

### 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

### 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

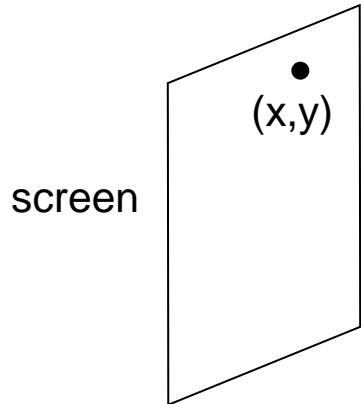
### Submirror

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

## 35mm SLR Film Camera

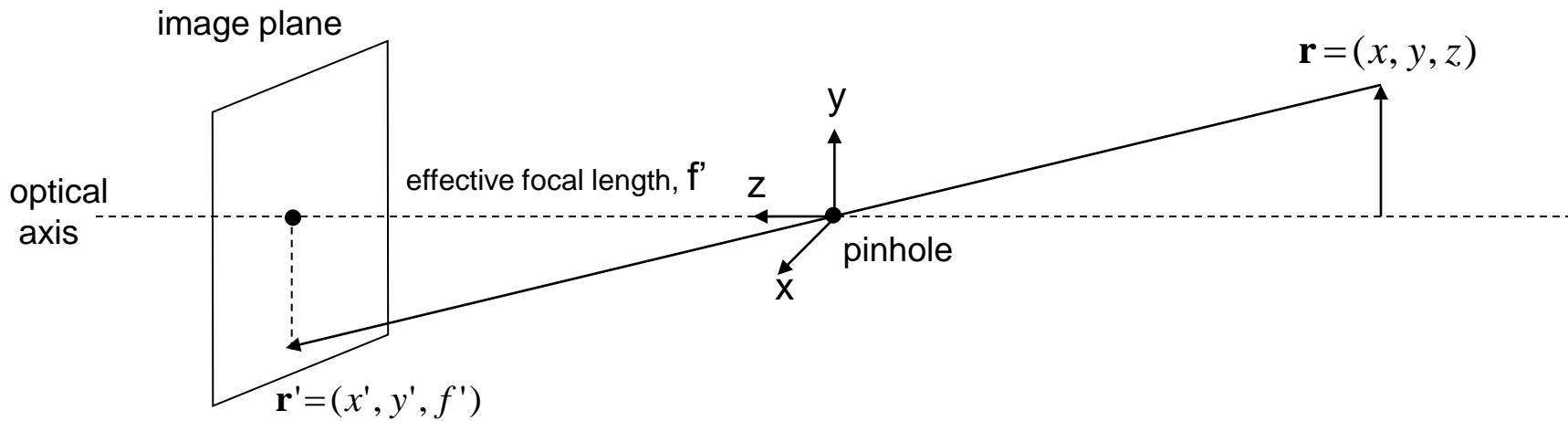


# Pinhole and the Perspective Projection



Is an image being formed on the screen?

YES! But, not a “clear” one.



$$\frac{\mathbf{r}'}{f'} = \frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'} = \frac{x}{z} \quad \frac{y'}{f'} = \frac{y}{z}$$

# Pinhole Photography

---



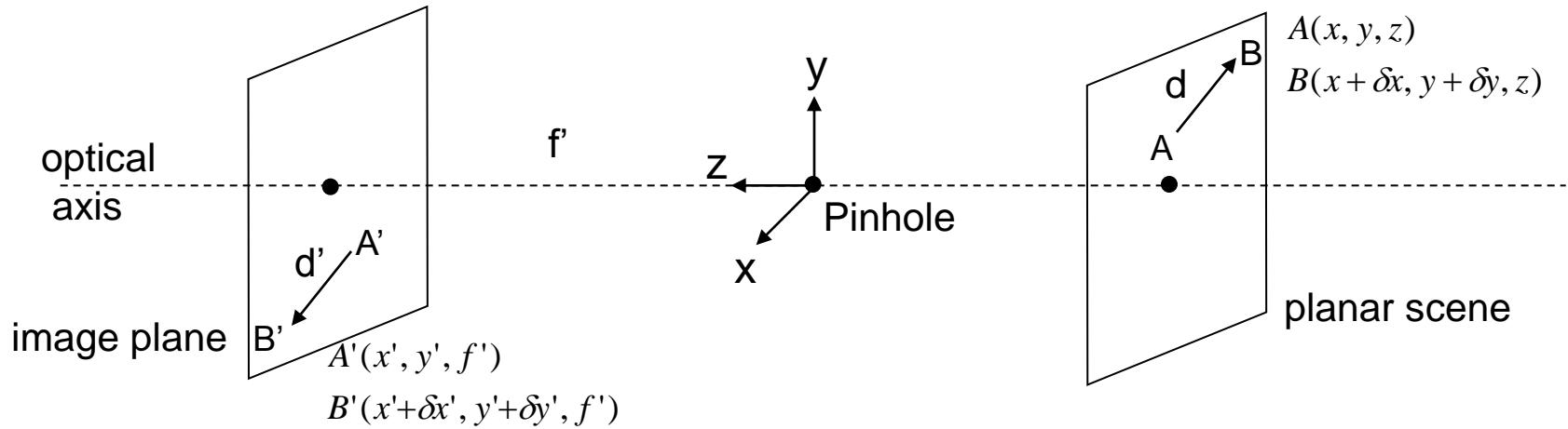
©Charlotte Murray Untitled, 4" x 5" pinhole photograph, 1992



Image Size inversely proportional to Distance

Reading: <http://www.pinholeresource.com/>

# Magnification



From perspective projection:

$$\frac{x'}{f'} = \frac{x}{z} \quad \frac{y'}{f'} = \frac{y}{z}$$

$$\frac{x'+\delta x'}{f'} = \frac{x+\delta x}{z} \quad \frac{y'+\delta y'}{f'} = \frac{y+\delta y}{z}$$

Magnification:

$$m = \frac{d'}{d} = \frac{\sqrt{(\delta x')^2 + (\delta y')^2}}{\sqrt{(\delta x)^2 + (\delta y)^2}} = \frac{f'}{z}$$

$$\frac{Area_{image}}{Area_{scene}} = m^2$$

# Pinhole Photography

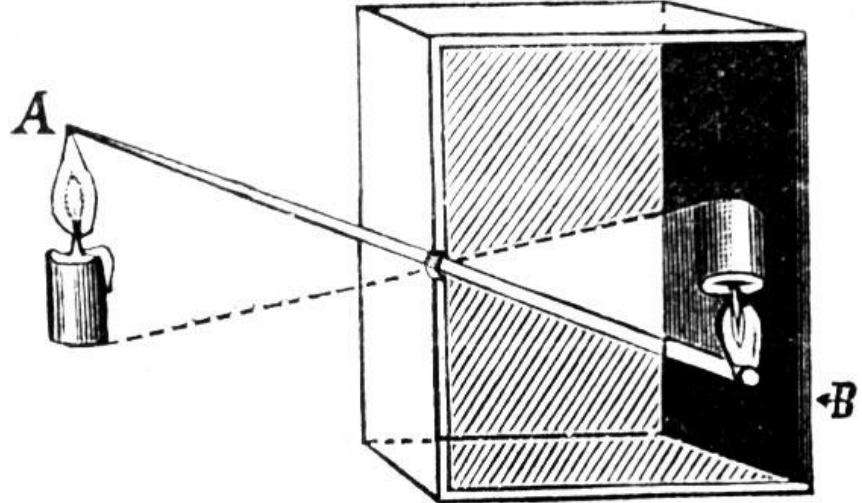
---



Wide Field of View and Sharp Image

# Camera Obscura with a Pinhole

---



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.

# Problems with Pinholes

- Pinhole size (aperture) must be “very small” to obtain a clear image.
- However, as pinhole size is made smaller, less light is received by image plane.
- If pinhole is comparable to wavelength  $\lambda$  of incoming light, DIFFRACTION blurs the image!
- Sharpest image is obtained when:

$$\text{pinhole diameter } d = 2 \sqrt{f' \lambda}$$

Example: If  $f' = 50\text{mm}$ ,

$$= 600\text{nm (red)},$$

$$d = 0.36\text{mm}$$

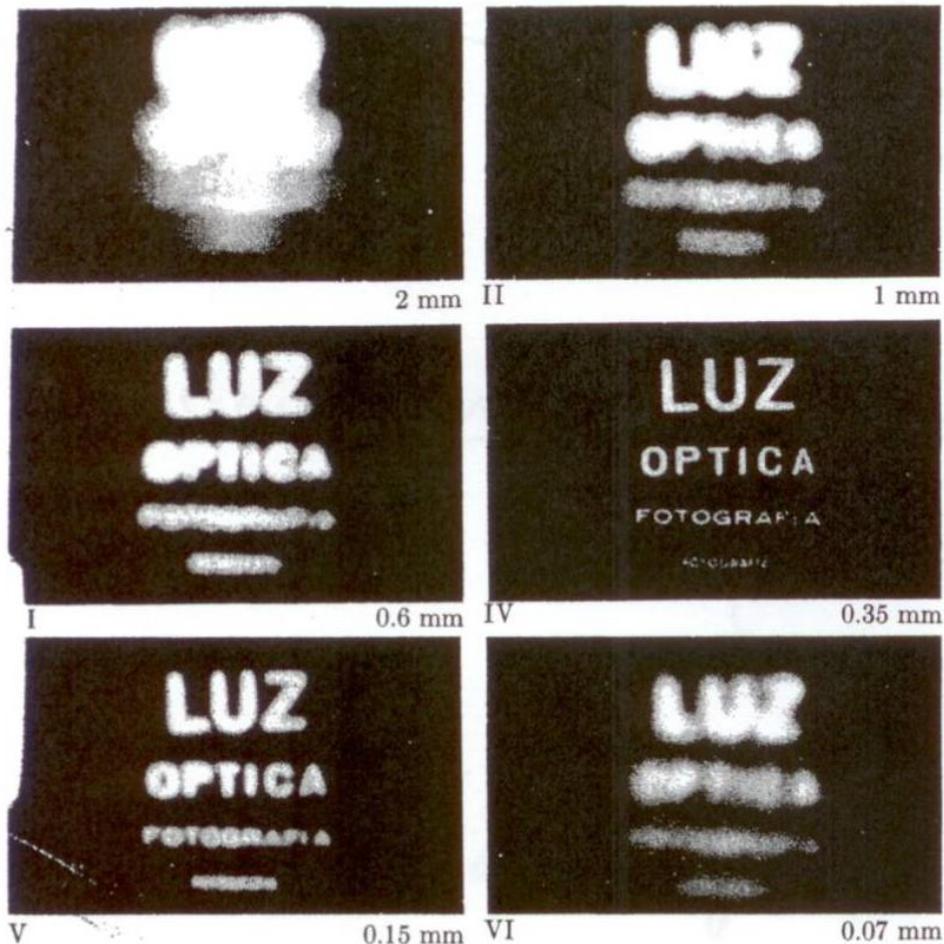
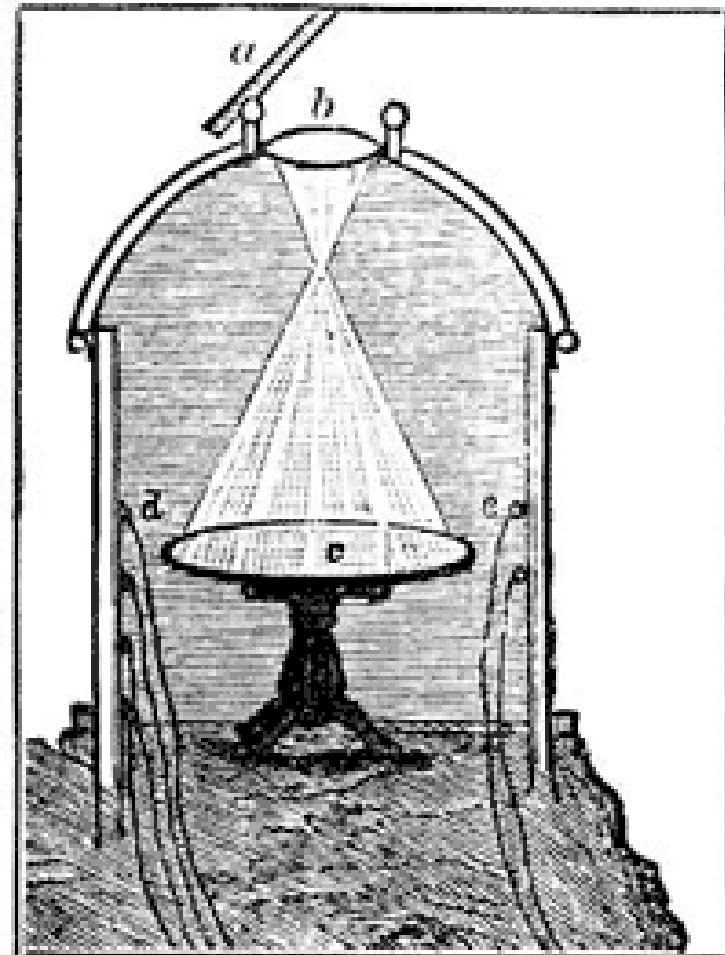


Fig. 5.96 The pinhole camera. Note the variation in image clarity as the hole diameter decreases. [Photos courtesy Dr. N. Joel, UNESCO.]

# Camera Obscuras with Lenses

---

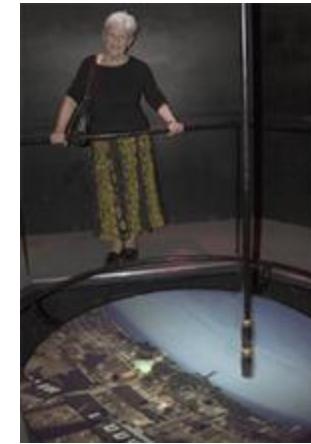




**Charles Schwartz Private Camera Obscura, New York City** The optics are housed in a copper turret on the roof and project through a hole in the ceiling onto a 42 inch round white table. At the side of the table are controls for the shutters, the tilt of the mirror and rotation of the turret. It is equipped with an 8-inch lens with a 12 1/2 foot focal length and a 12-inch mirror and brings in a 15-degree slice of the world outside. Sharp focus is possible from infinity to 400 feet. The optics were designed and built by George Keene of California.



**Eastbourne, England**



**Edinburgh, Scotland**



**Kirriemuir, Scotland**



**1836, Dumfries, Scotland**



Aberystweth, Wales



Knighton, Wales





Giant Camera, San Francisco, California



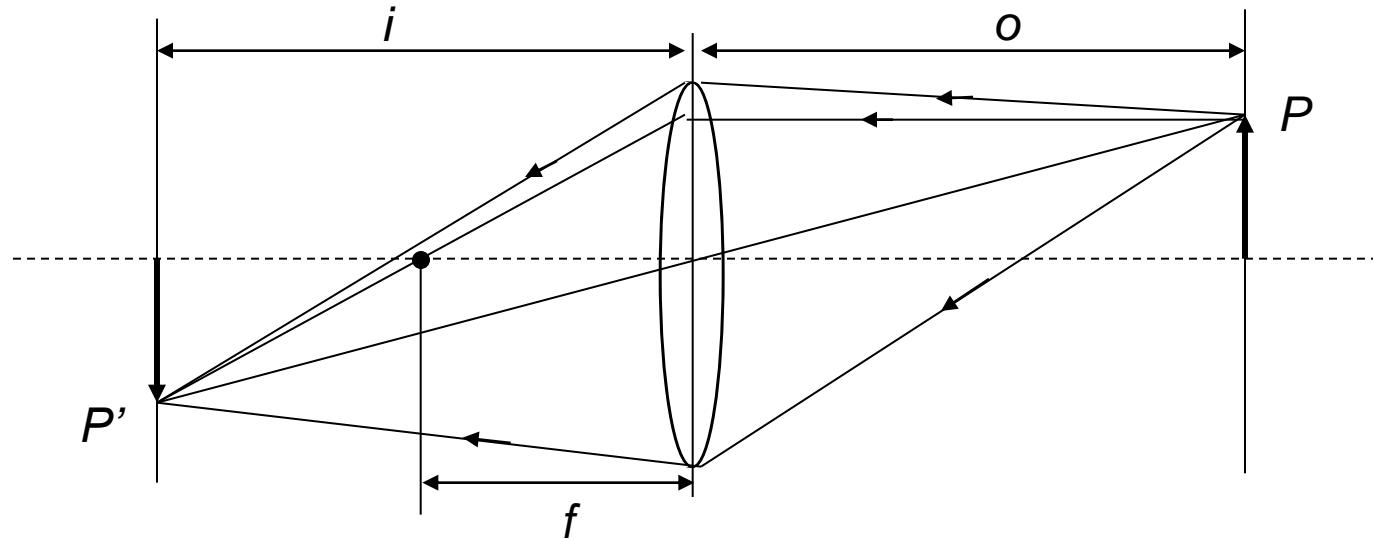
Discovery Park, Safford, Arizona



George Eastman House, Rochester, New York

# Image Formation using Lenses

- Lenses are used to avoid problems with pinholes.
- Ideal Lens: Same projection as pinhole but gathers more light!



- Gaussian Thin 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 refract light
- $f$  different from the effective focal length  $f'$  discussed before!

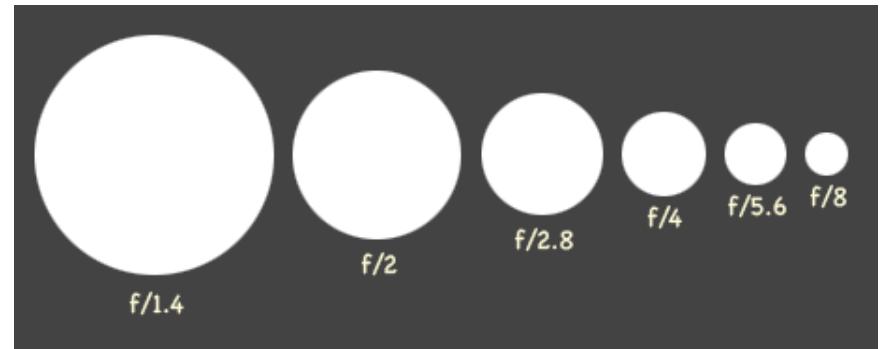
# Aperture, F-Number

---

- Aperture : Diameter  $D$  of the lens that is exposed to light.

- F-Number ( $f/\#$ ):

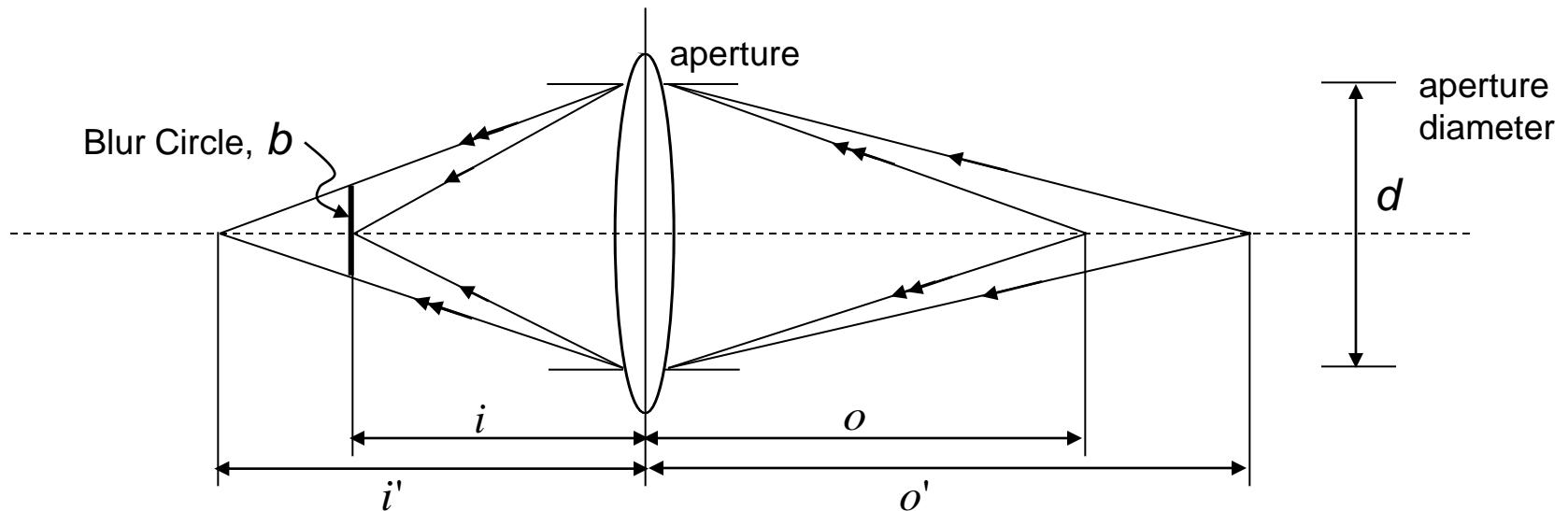
$$f/\# = \frac{f}{D} ,$$



Copyright: © Jared C. Benedict.

- For example, if  $f$  is 16 times the pupil diameter, then  **$f/\#=f/16$** .
- The greater the  $f/\#$ , the less light per unit area reaches the image plane.
- f-stops represent a convenient sequence of  $f/\#$  in a geometric progression.

# Focus and Defocus



- Gaussian Law:

$$\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$$



$$(i' - i) = \frac{f}{(o' - f)} \frac{f}{(o - f)} (o - o')$$

$$\frac{1}{i'} + \frac{1}{o'} = \frac{1}{f}$$

- In theory, only one scene plane is in focus.

# Depth of Field

---

- Range of object distances over which image is sufficiently well focused.
- Range for which *blur circle* is less than the resolution of the sensor.



# Depth of Field

---



DEPTH OF FIELD  
DEPTH OF FIELD

Both near and farther scene areas are blurred

# Controlling Depth of Field

---

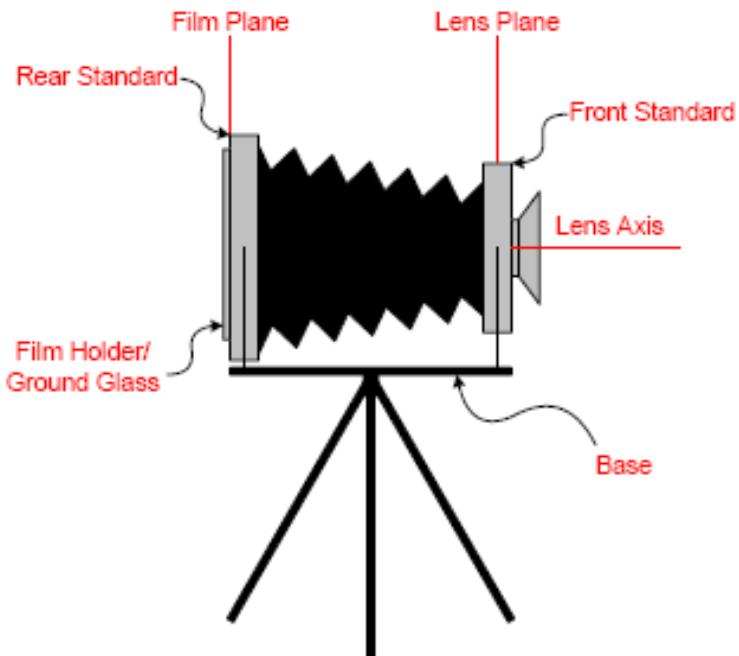


---

Increase Aperture, decrease Depth of Field



# Large Format (View) Camera



A black and white photograph of a highway interchange. In the foreground, a multi-lane road curves to the right. To the right of the road is a grassy embankment. A directional sign stands on the embankment, pointing towards a bridge. The sign has two columns of text: "Rockcliffe Promenade" and "Parkway Rockcliffe". Below each column are two arrows: a right-pointing arrow for "East" and an upward-pointing arrow for "West".

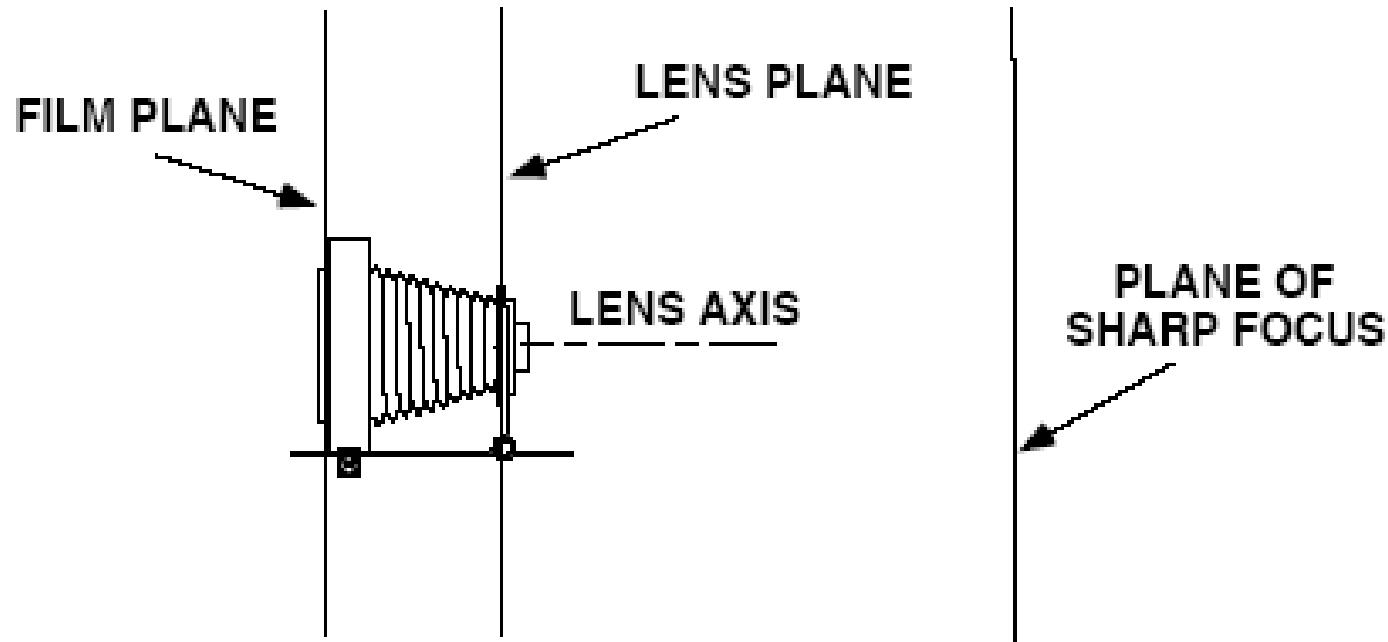
Rockcliffe Promenade  
Parkway Rockcliffe  
→ East      ↑ West  
                    ↓ Ouest



[Harold M. Merklinger]

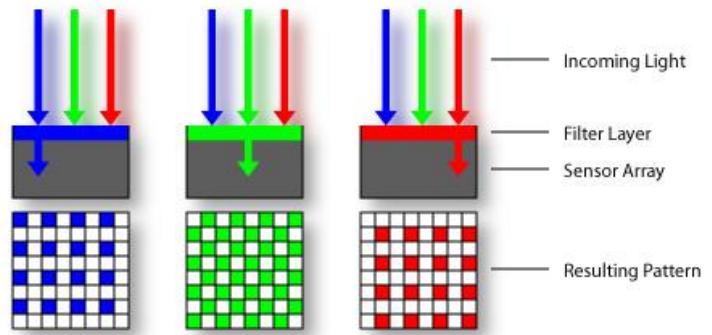
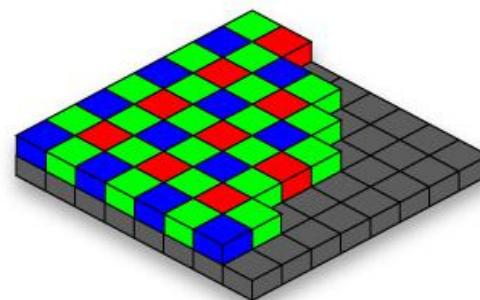
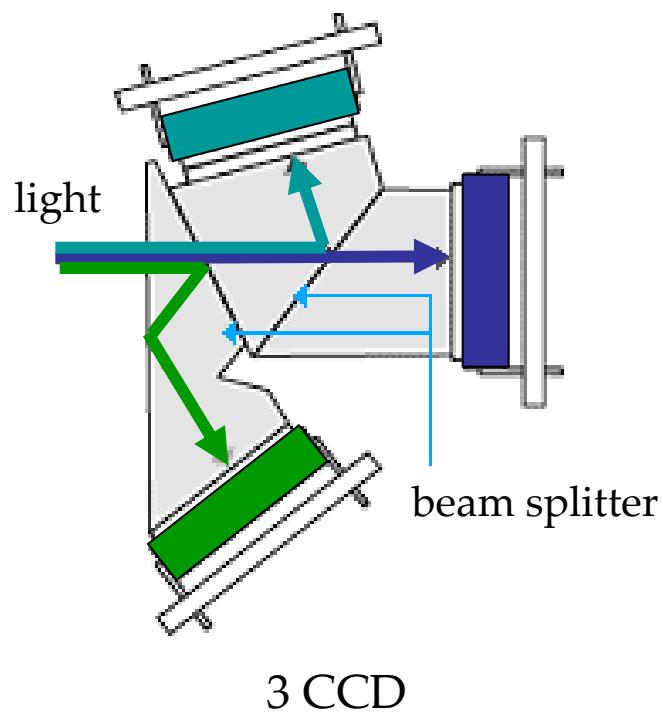


# Regular Camera: Image, Lens & Object Planes are Parallel

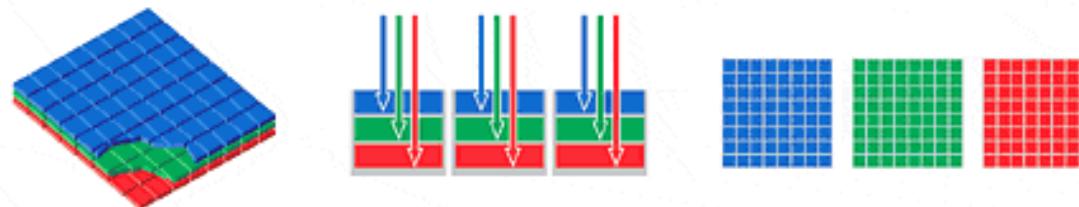


View camera: The image and lens planes can be shifted/tilted

# Sensing Color

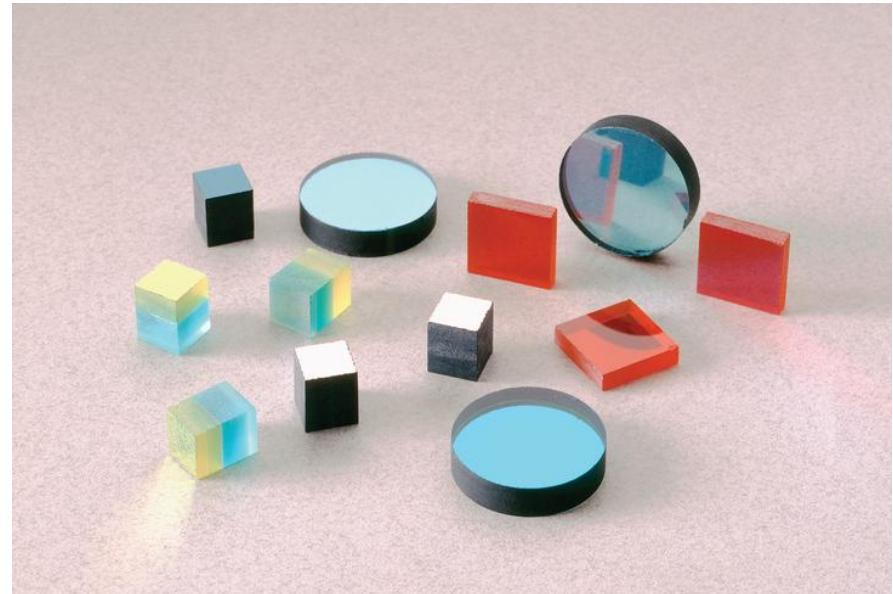


Bayer pattern



Foveon X3™

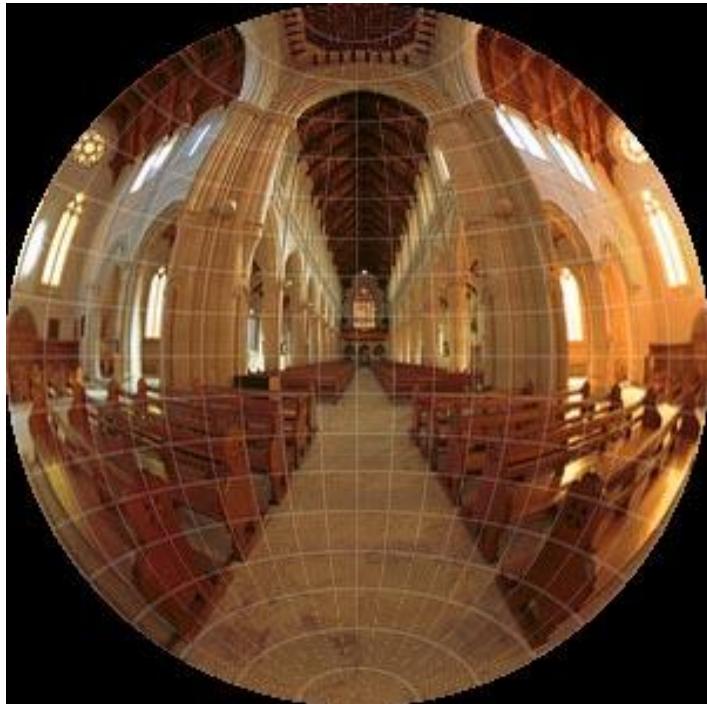
# Optical Elements in an Imaging System



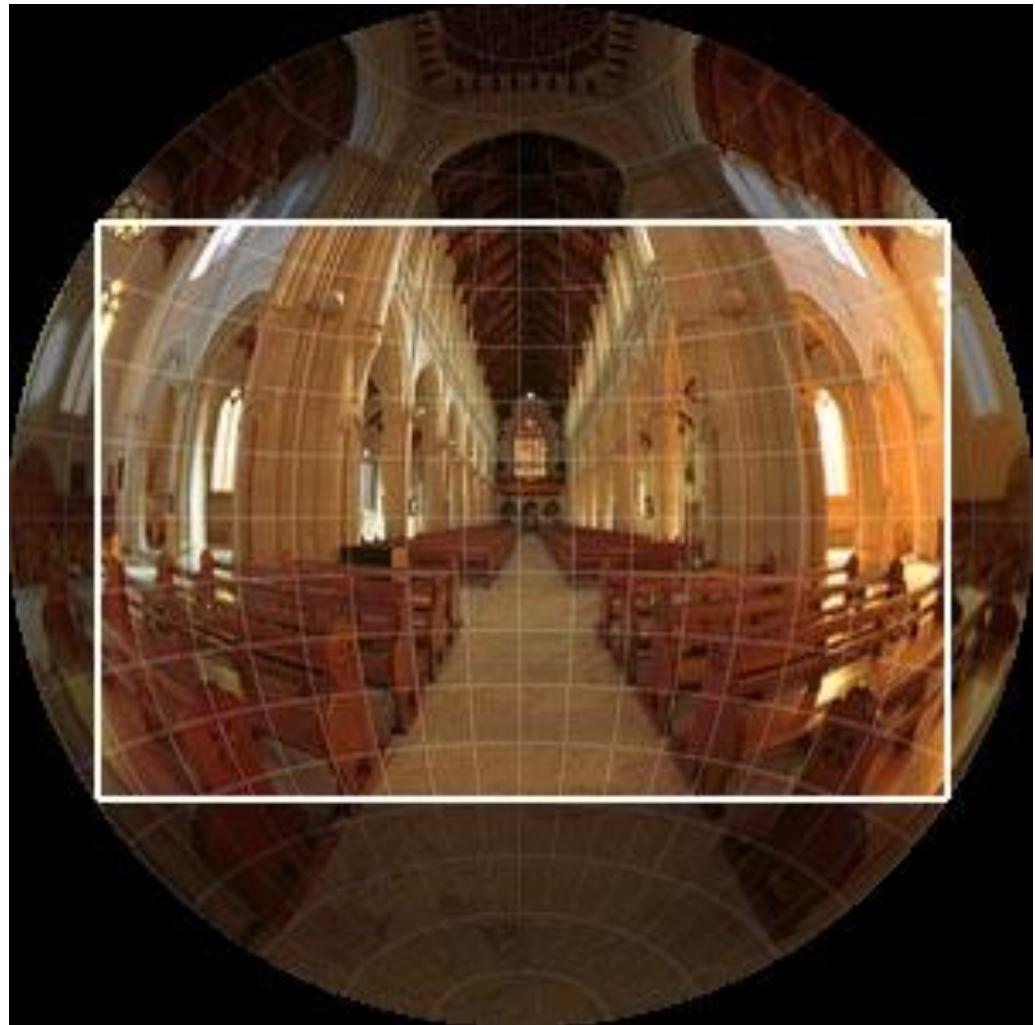
# Lens Distortions



# Wide angle Lenses



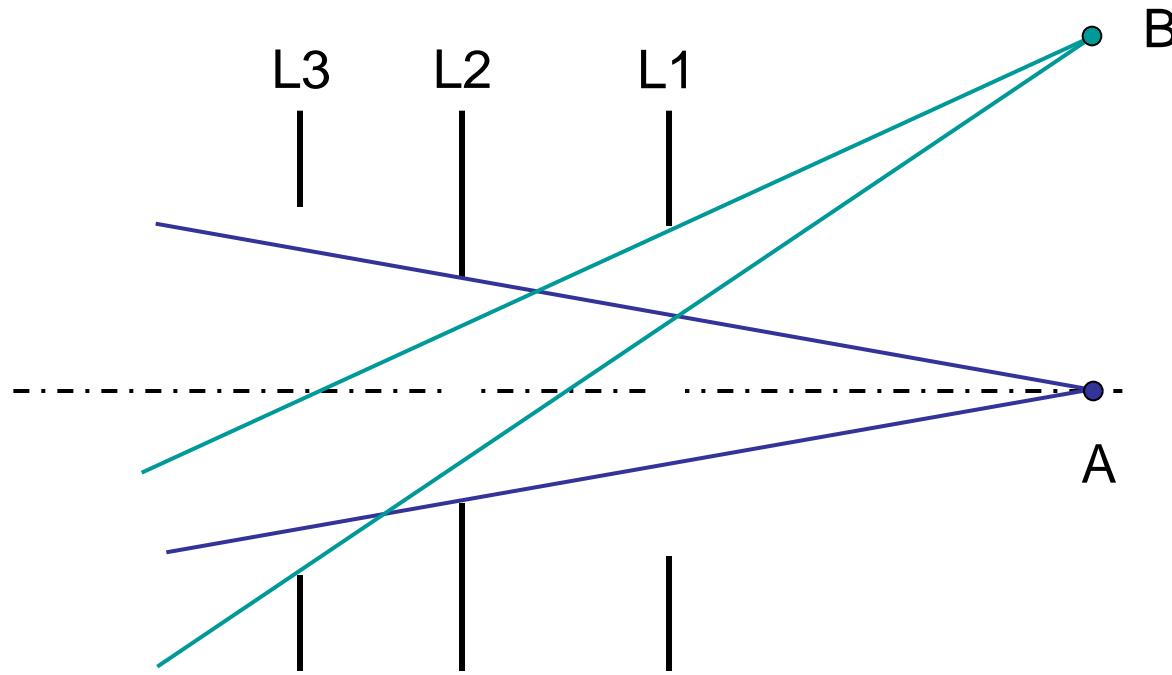
Circular Fisheye



Full Frame Rectangular Fisheye

# **Common lens related Issues**

# Vignetting



More light passes through lens L3 for scene point B than scene point A

Results in spatially non-uniform brightness (in the periphery of the image)

# Lens Vignetting

---



- Usually brighter at the center and darker at the periphery.

# Vignetting

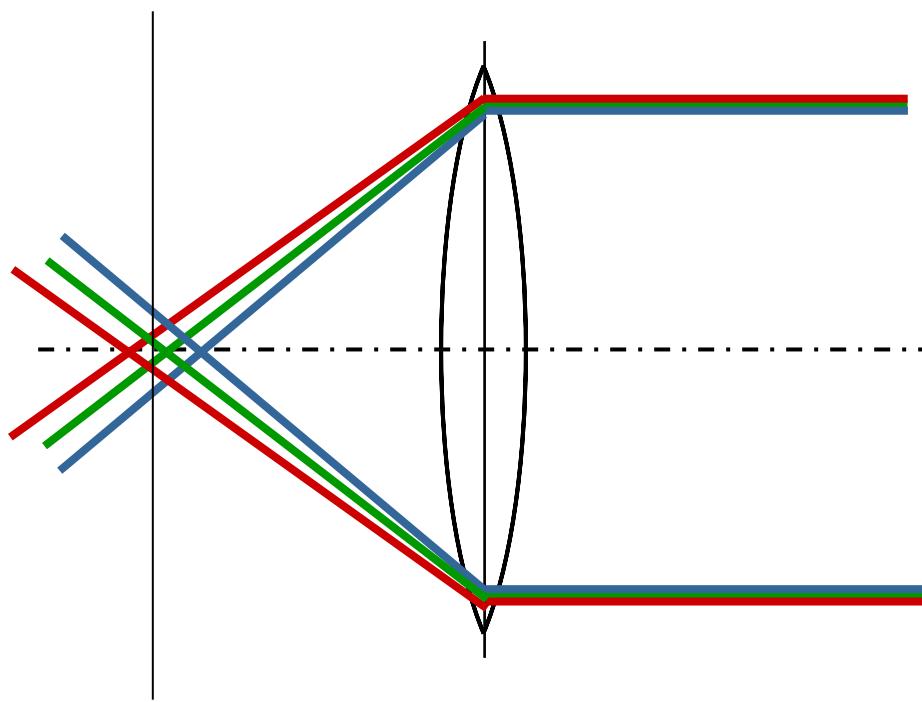
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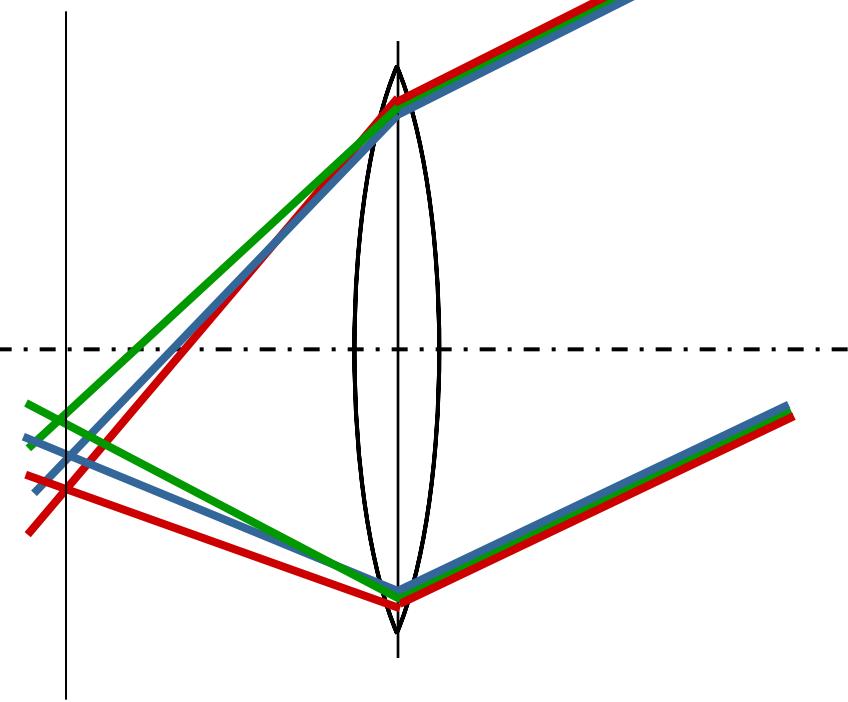
photo by Robert Johnes

# Chromatic Aberration

---



longitudinal chromatic aberration  
(axial)



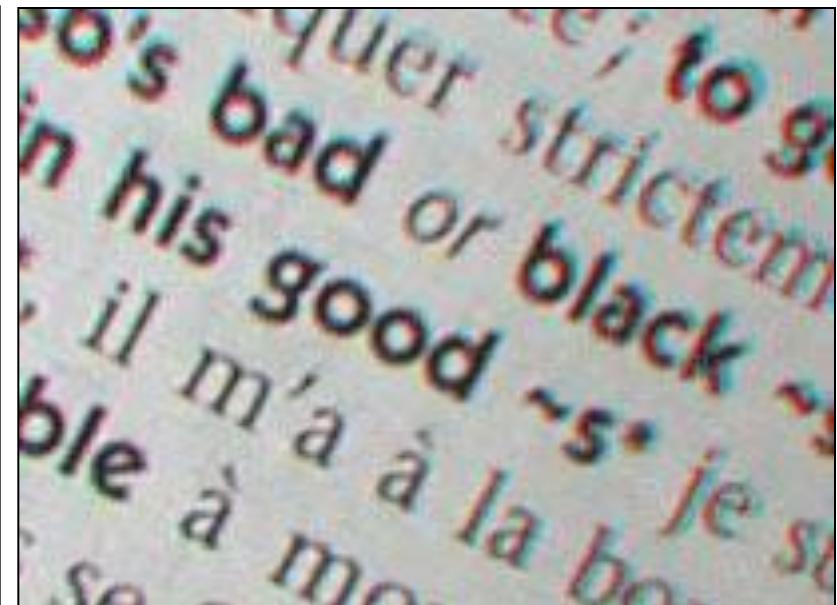
transverse chromatic aberration  
(lateral)

# Chromatic Aberrations

---



longitudinal chromatic aberration  
(axial)



transverse chromatic aberration  
(lateral)

# Chromatic Abberations

---



# Lens Glare

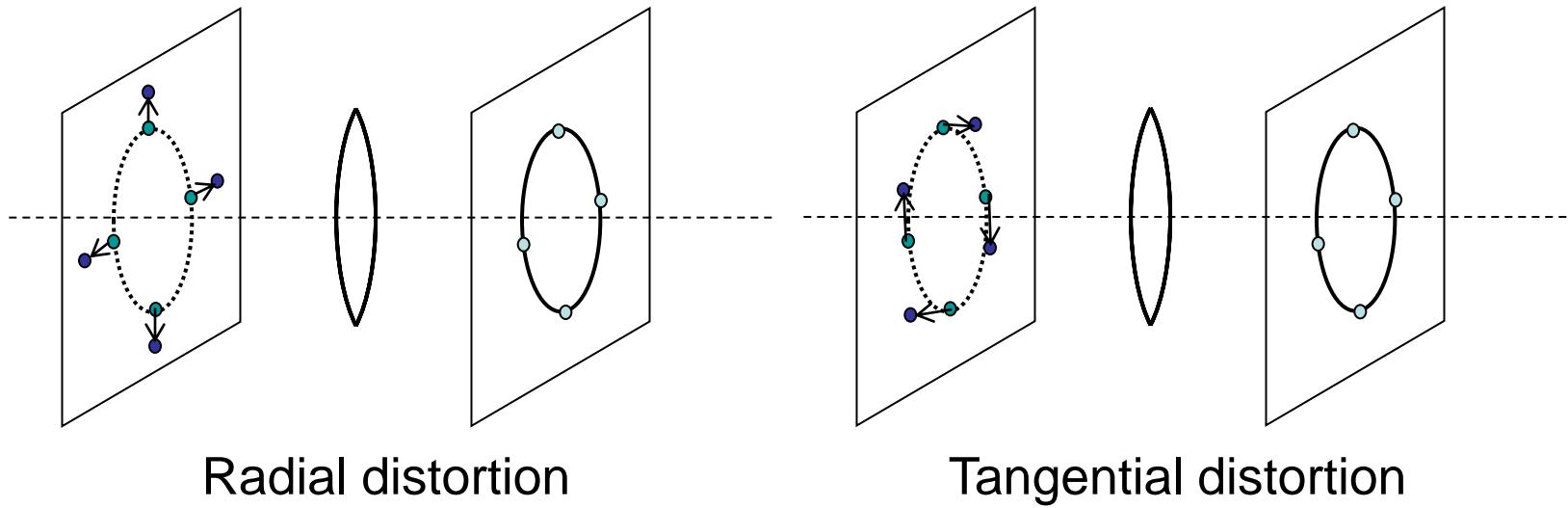
---



- Stray interreflections of light within the optical lens system.
- Happens when very bright sources are present in the scene.

# Geometric Lens Distortions

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Radial distortion

Tangential distortion

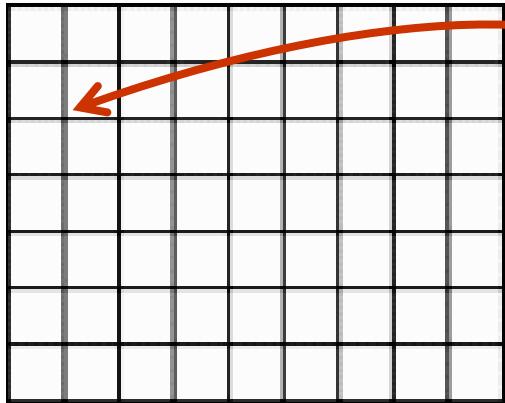


Photo by Helmut Dersch

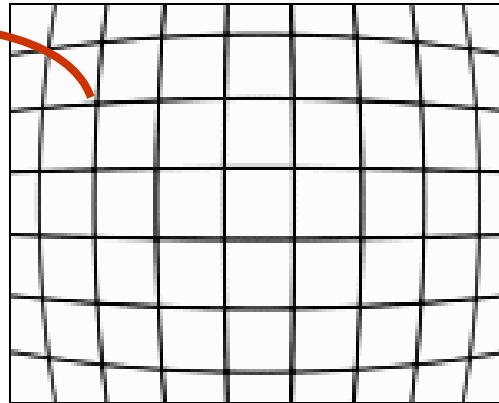
Both due to lens imperfection  
Rectify with geometric camera calibration

# Radial Lens Distortions

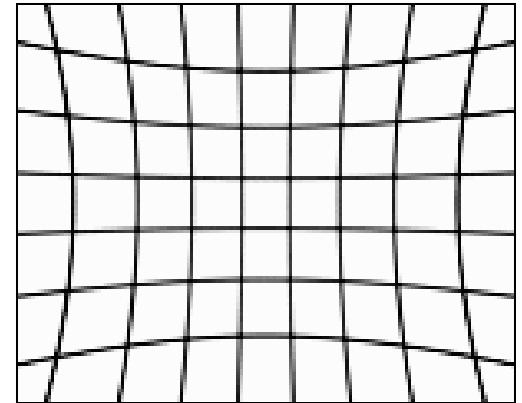
---



No Distortion



Barrel Distortion



Pincushion Distortion

- Radial distance from Image Center:

$$r_u = r_d + k_1 r_d^3$$

# Correcting Radial Lens Distortions

---



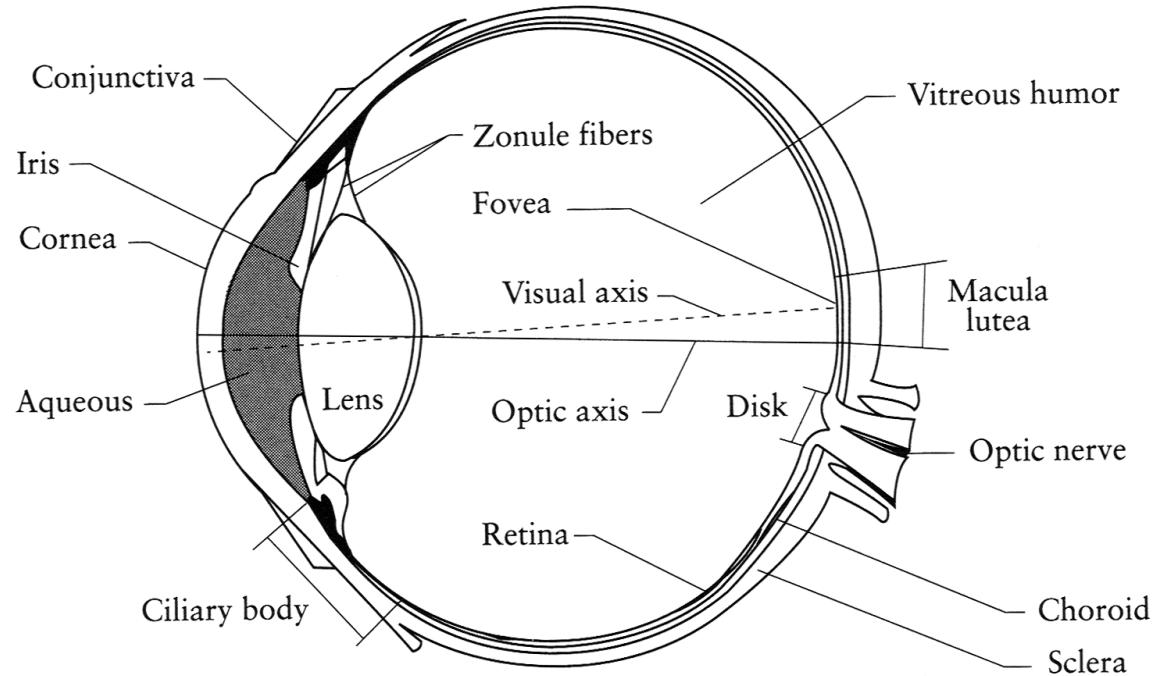
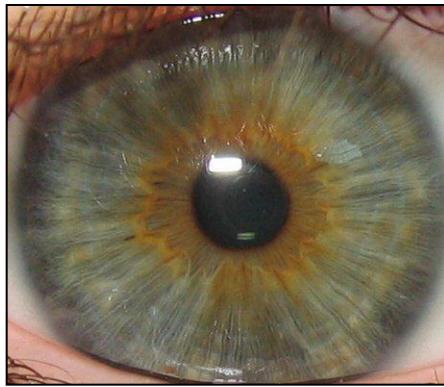
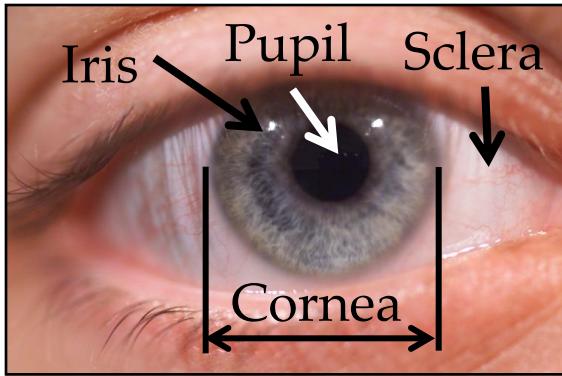
Before



After

# Our Eyes

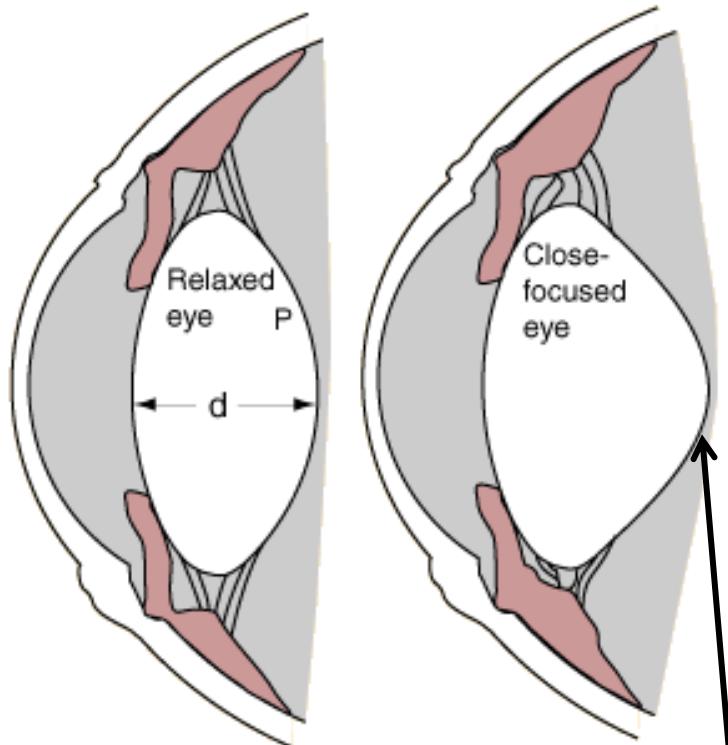
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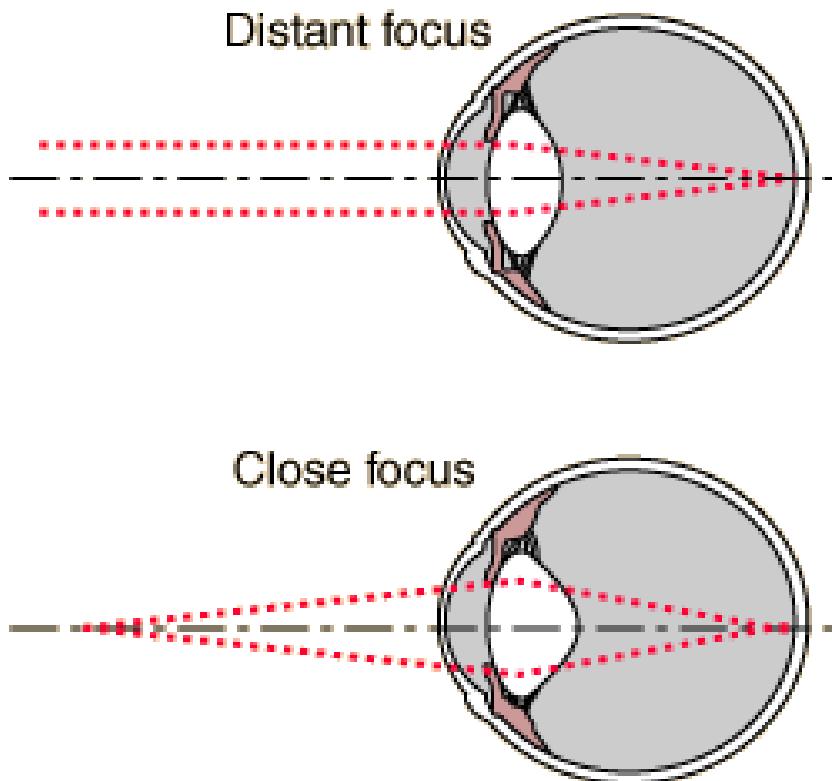
- Index of refraction: cornea 1.376, aqueous 1.336, lens 1.406-1.386
- Iris is the diaphragm that changes the aperture (pupil)
- Retina is the sensor where the fovea has the highest resolution

# Accommodation

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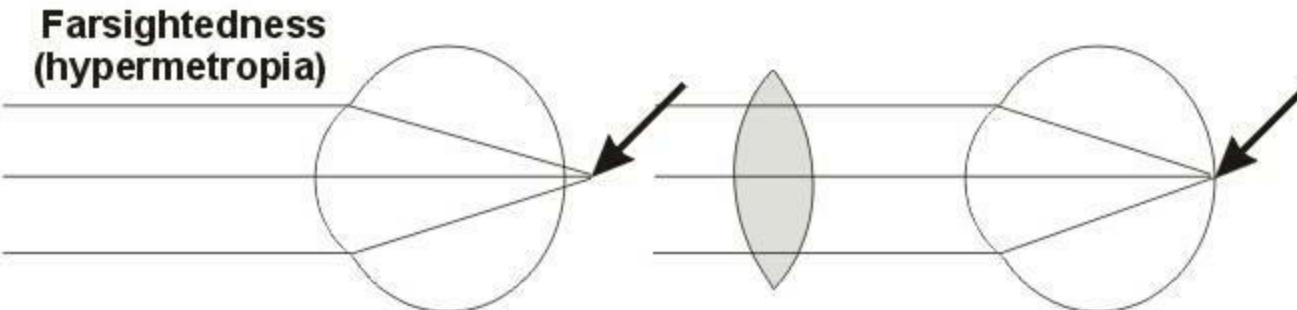
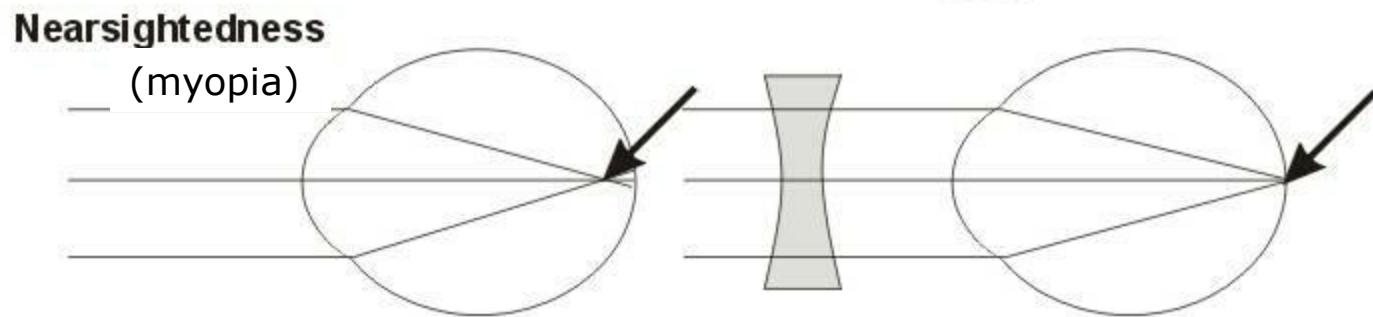
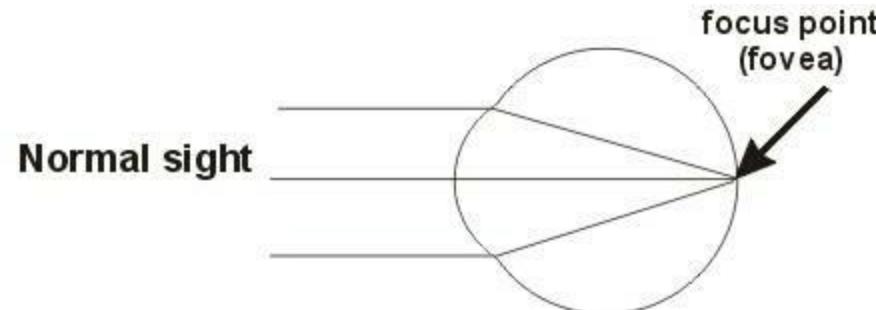
shorter focal length



Changes the focal length of the lens

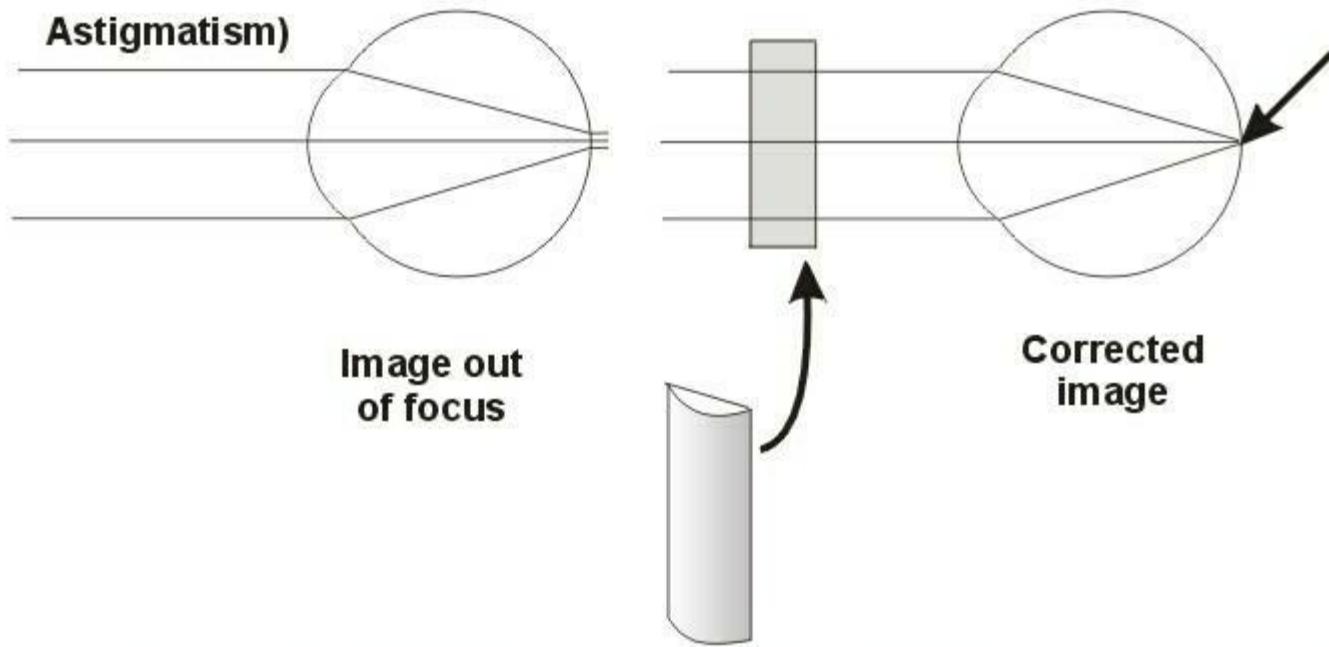
# Myopia and Hyperopia

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# Astigmatism

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The cornea is distorted causing images to be un-focused on the retina.

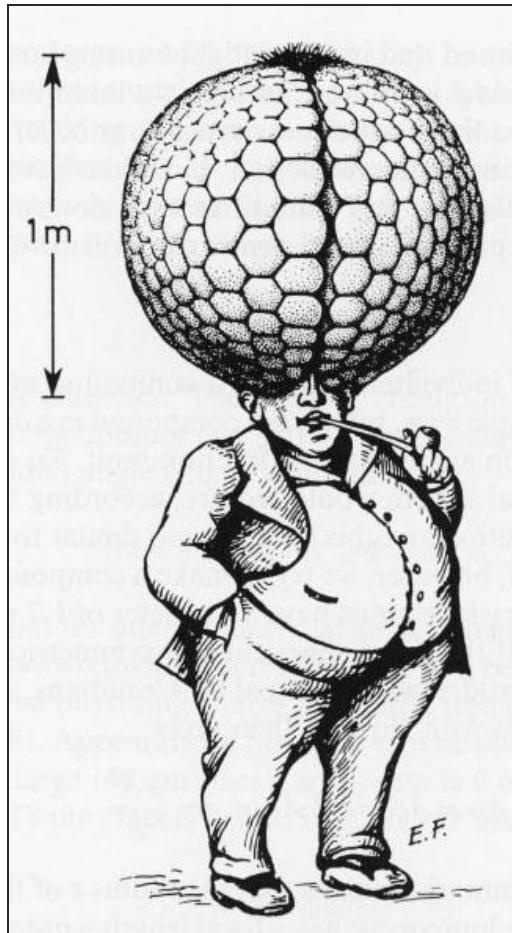
# Blind Spot in Eye

---



Close your right eye and look directly at the “+”

# Eyes in Nature

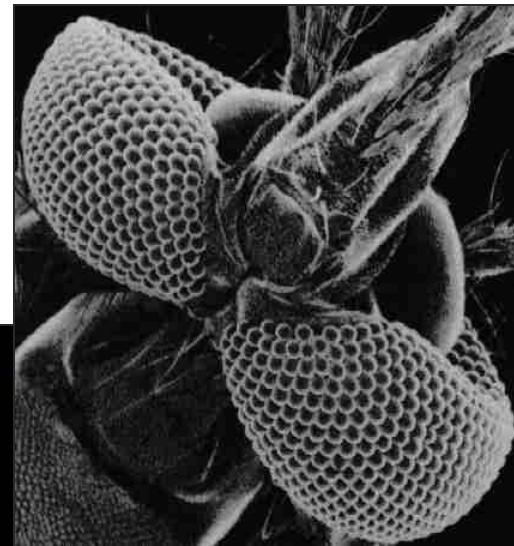


The Compound Eye  
of a Mosquito

one ommatidium

a compound eye  
with one quarter removed  
to show ommatidia

facets



Mosquito

<http://ebiomedia.com/gall/eyes/octopus-insect.html>

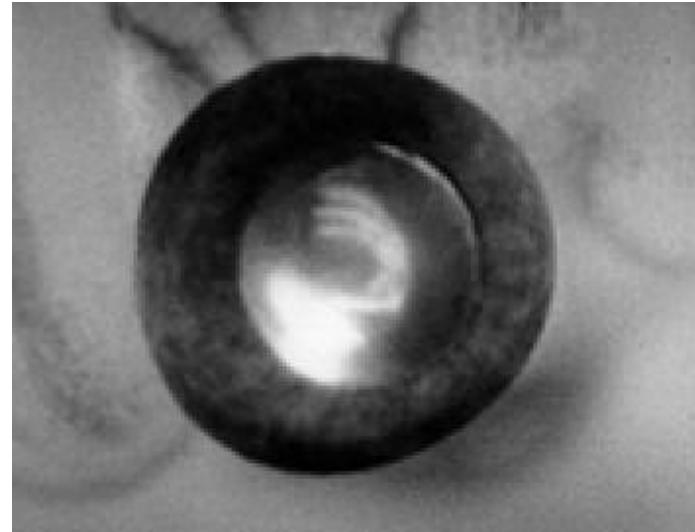
Mosquitos have microscopic vision, but to focus at large distances the eye would need to be 1 m!

# Curved Mirrors in Scallop Eyes

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Telescopic Eye



(by Mike Land, Sussex)

... More in the second part of the course

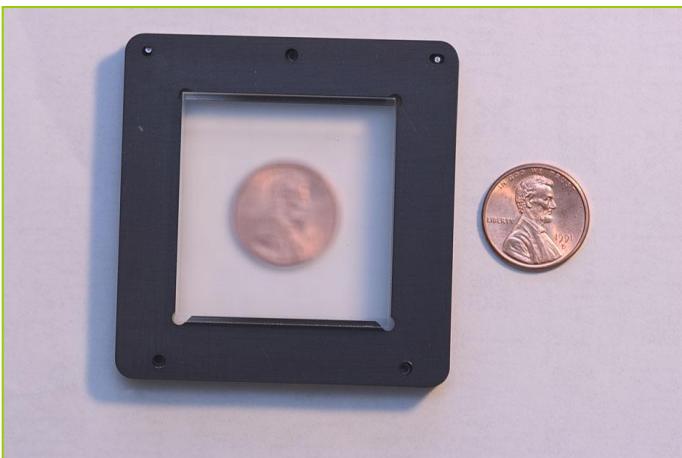
# Light Field Cameras - Lens Arrays



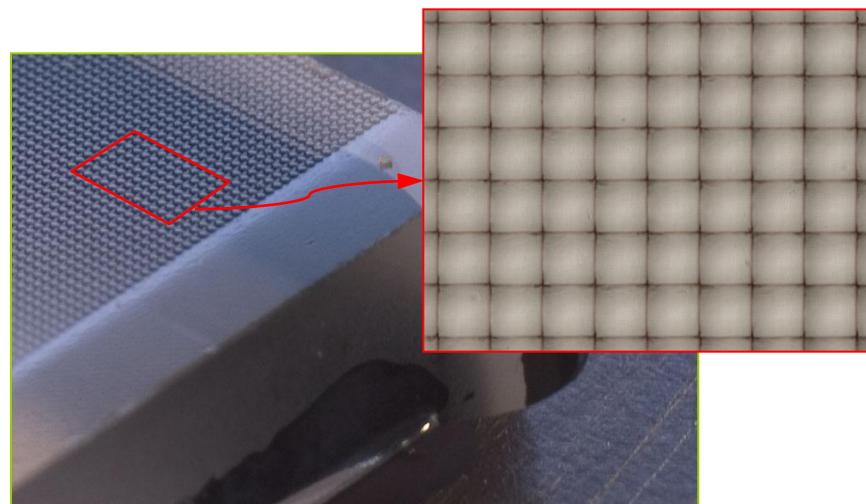
Contax medium format camera



Kodak 16-megapixel sensor



Adaptive Optics microlens array



125 $\mu$  square-sided microlenses

$$4000 \times 4000 \text{ pixels} \div 292 \times 292 \text{ lenses} = 14 \times 14 \text{ pixels per lens}$$

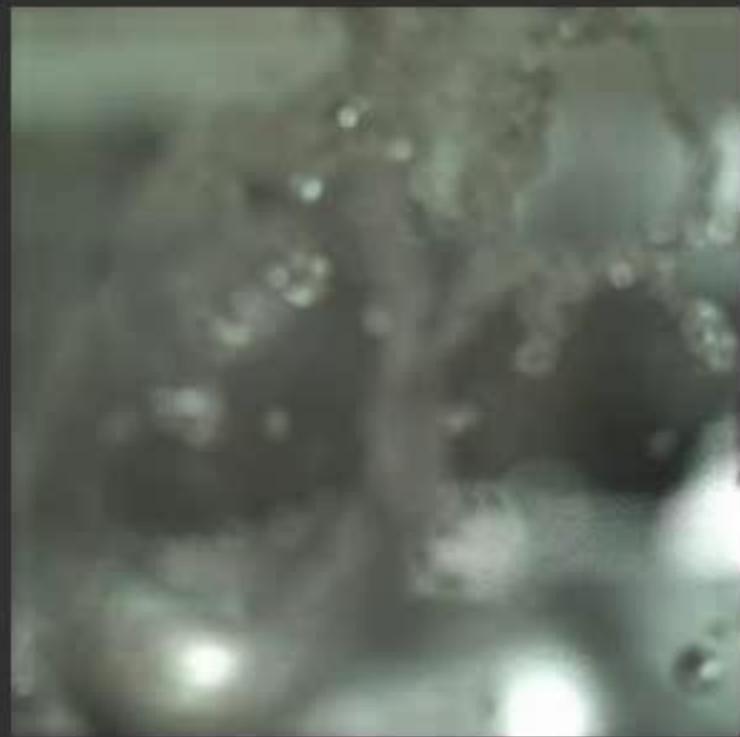
# Refocusing using Lens Arrays



# Refocusing using Lens Arrays

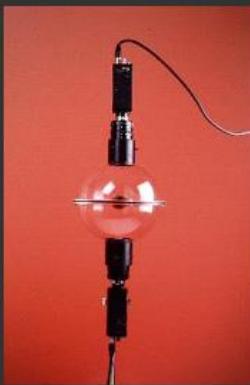


## Refocusing using Lens Arrays



**Focusing through a splash of water**

# Cameras with Lenses and Mirrors



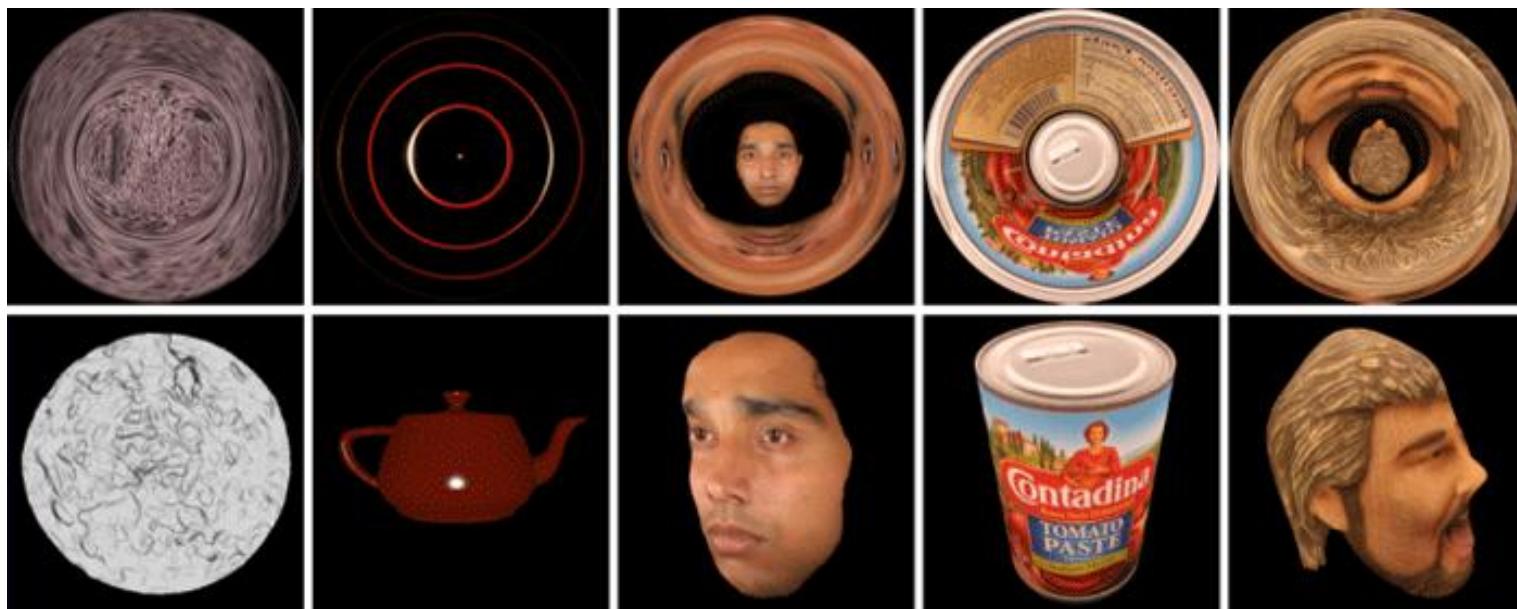






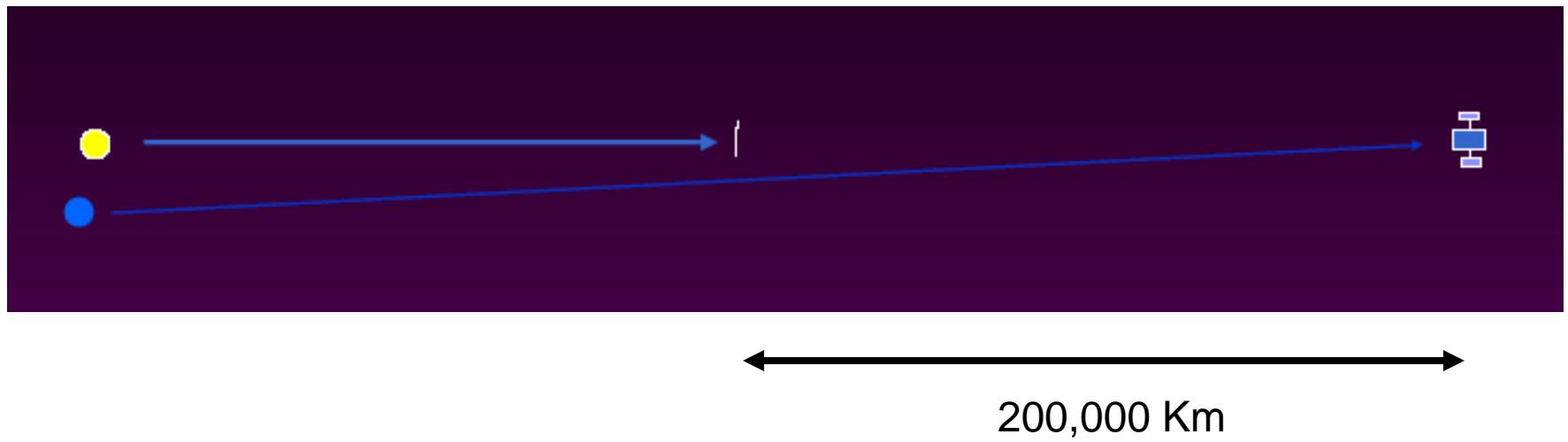


# Cameras with Lenses and Mirrors - Applications



# Astronomical Camera Obscura?

New World Mission - NASA



[http://en.wikipedia.org/wiki/New\\_Worlds\\_Mission](http://en.wikipedia.org/wiki/New_Worlds_Mission)

[http://www.nasa.gov/lb/vision/universe/newworlds/new\\_worlds\\_imager.html](http://www.nasa.gov/lb/vision/universe/newworlds/new_worlds_imager.html)