



UNIVERSITÀ DEGLI STUDI DI PADOVA

Real cameras

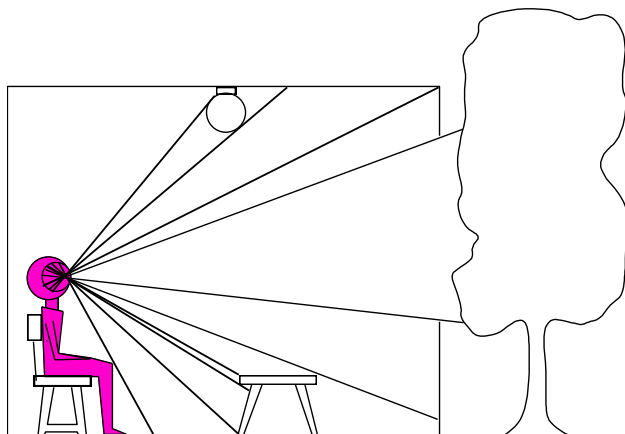
Stefano Ghidoni





- Camera: overview
- Sensor
- Focal length & focus
- Zoom & perspective
- Exposure, aperture and shutter
- Depth of field

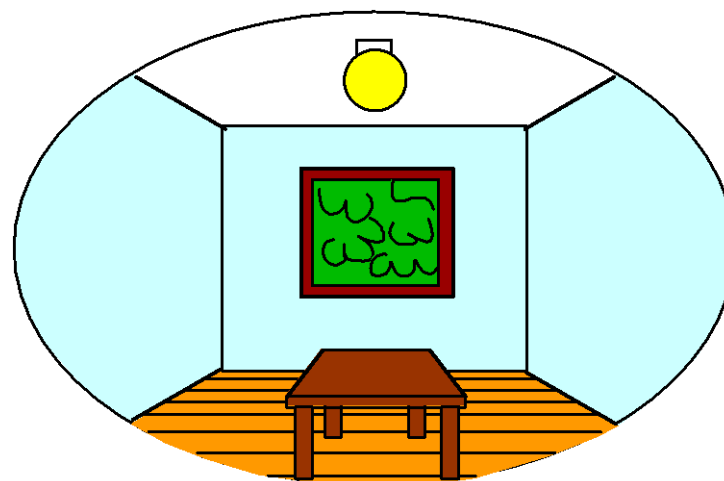
3D world



Point of observation

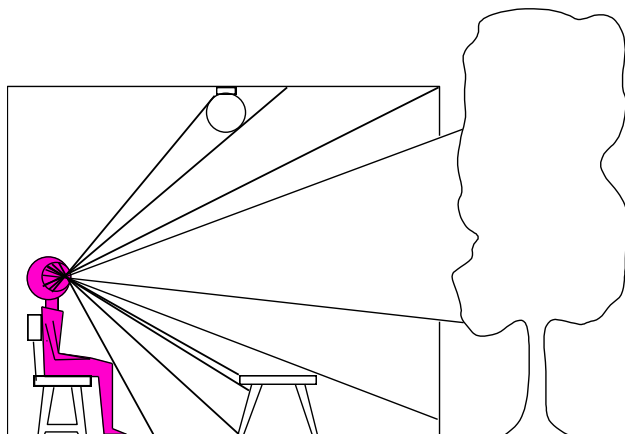


2D image



- Have we lost something?
 - Angles
 - Distances
 - Parallel lines
 - What about straight lines?

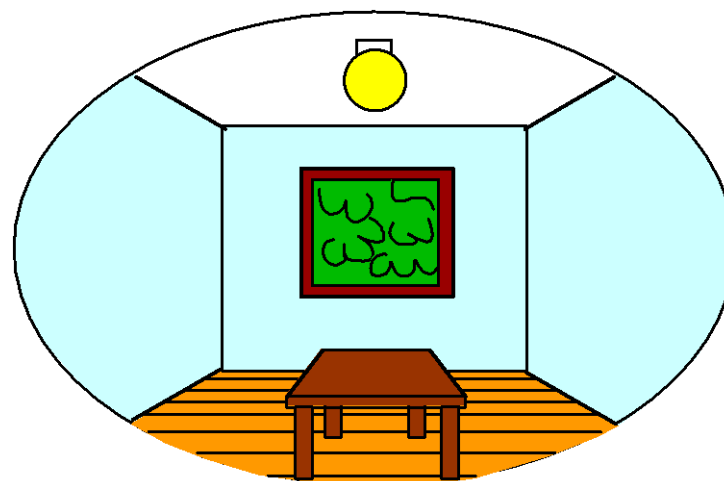
3D world



Point of observation



2D image



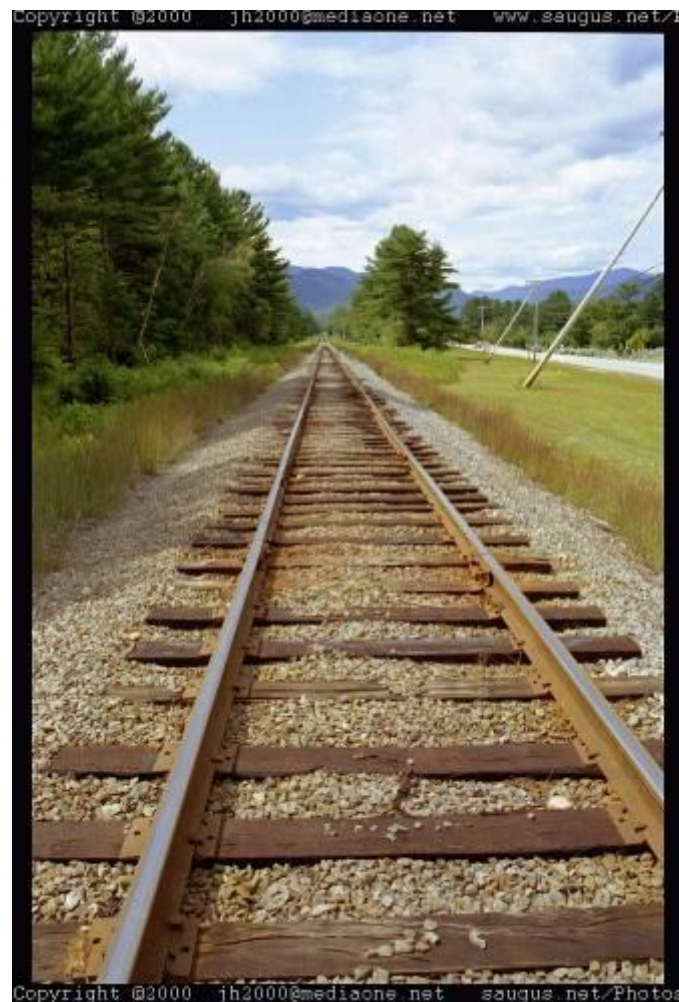
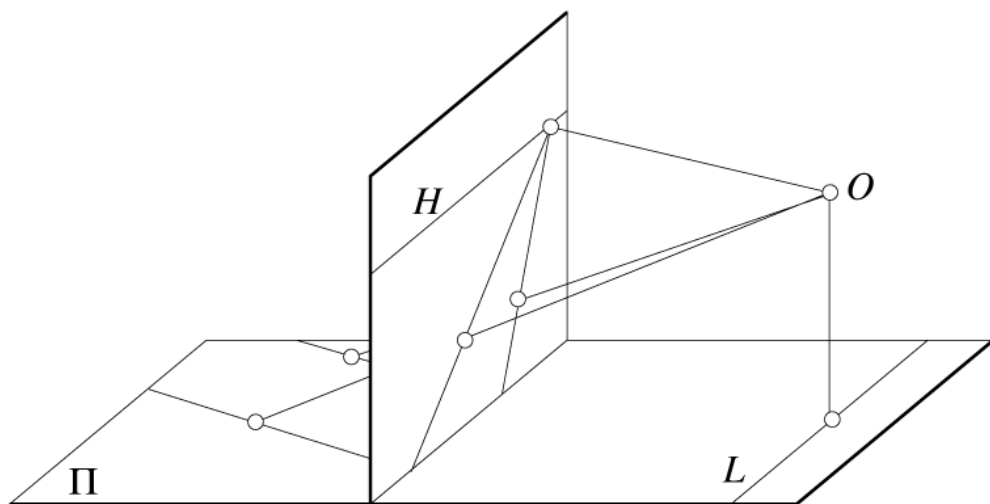
- Have we lost something?
 - Angles
 - Distances
 - Parallel lines
 - What about straight lines?
 - Straight lines remain straight



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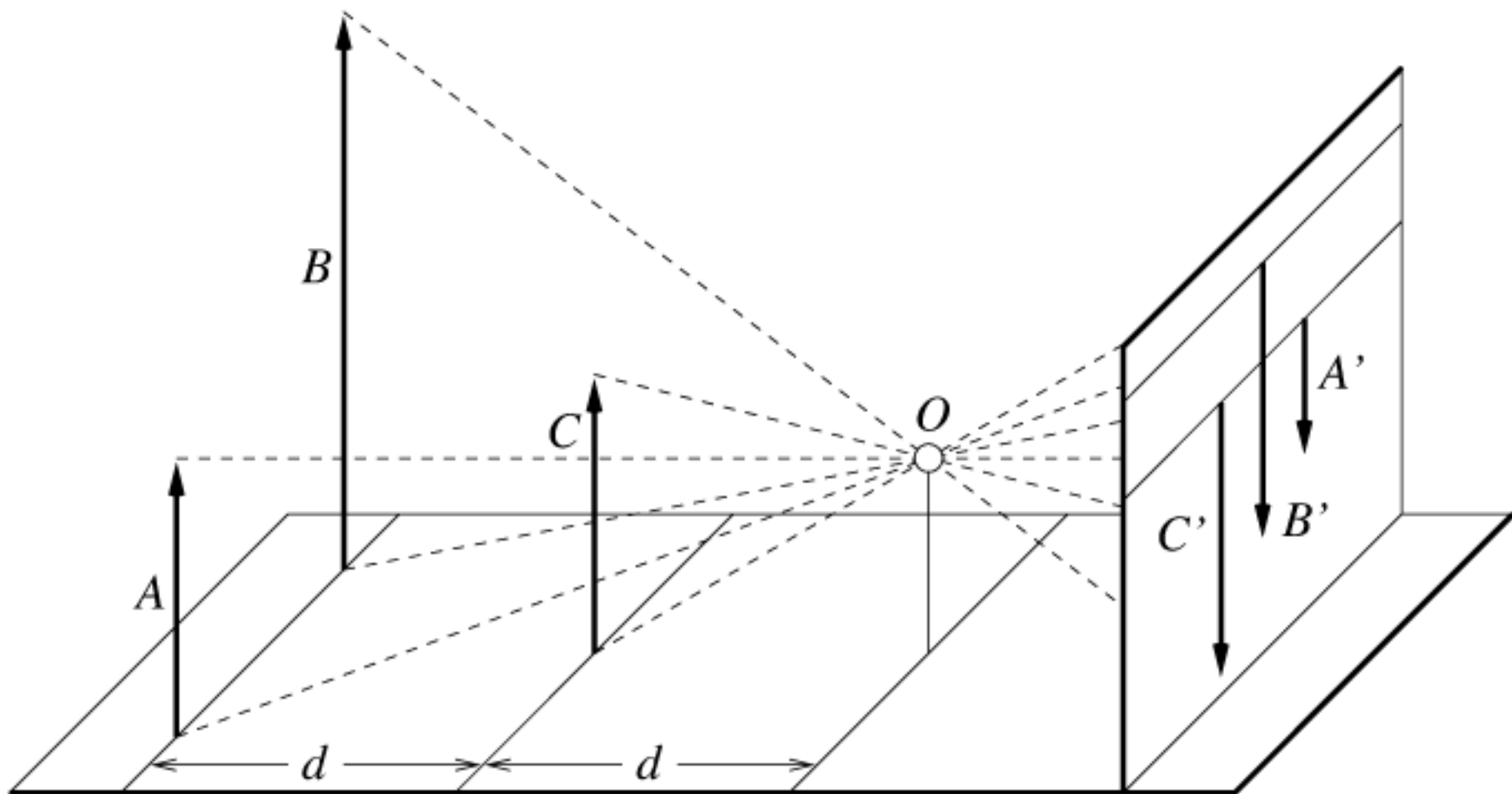
Parallelism is lost

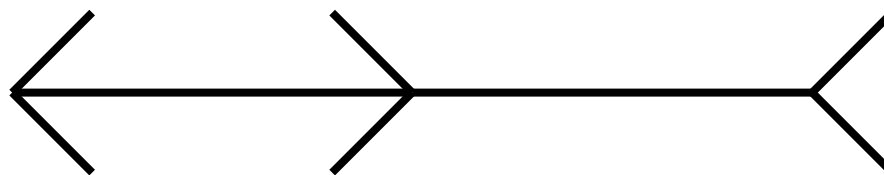
IAS-LAB



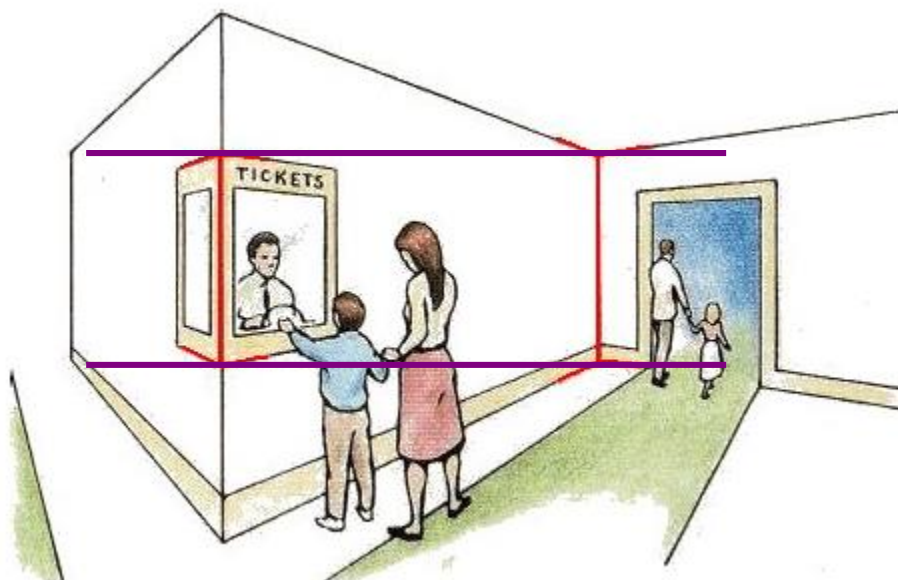
Credit: D. Forsyth

Length can't be trusted



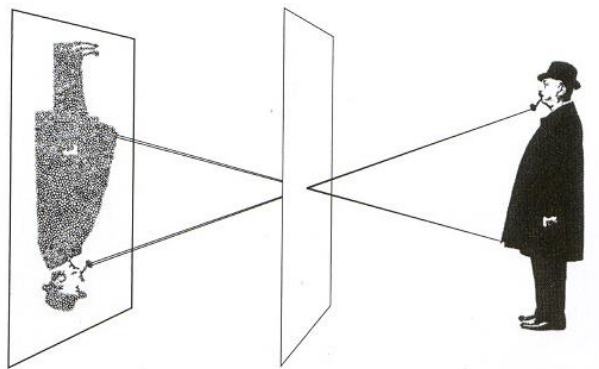


Müller-Lyer Illusion

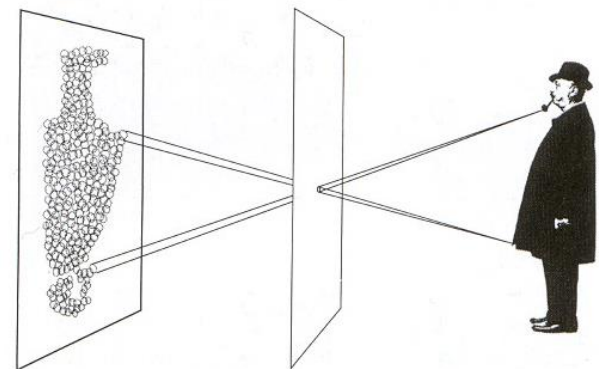
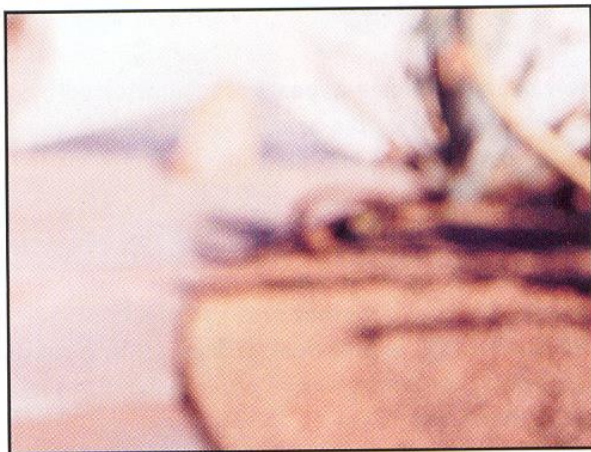


Effect of "pinhole size"

Photograph made with small pinhole



Photograph made with larger pinhole



- Gather more light
- Need to be focused

Photograph made with small pinhole

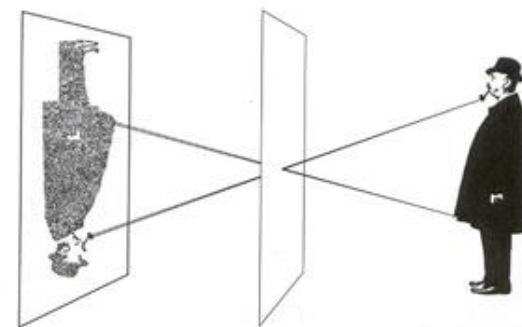


To make this picture, the lens of a camera was replaced with a thin metal disk pierced by a tiny pinhole, equivalent in size to an aperture of $f/182$. Only a few rays of light from each point on the

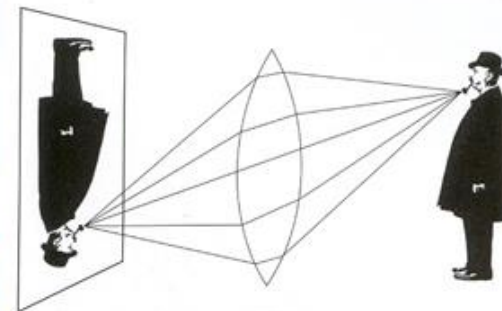
Photograph made with lens



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.

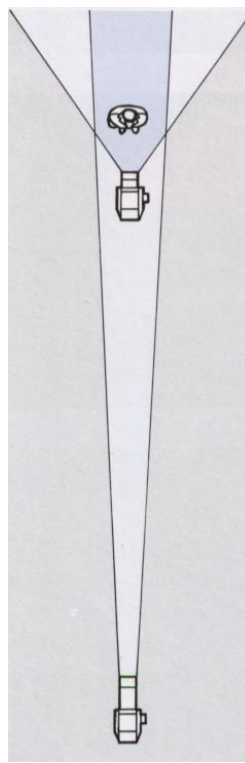
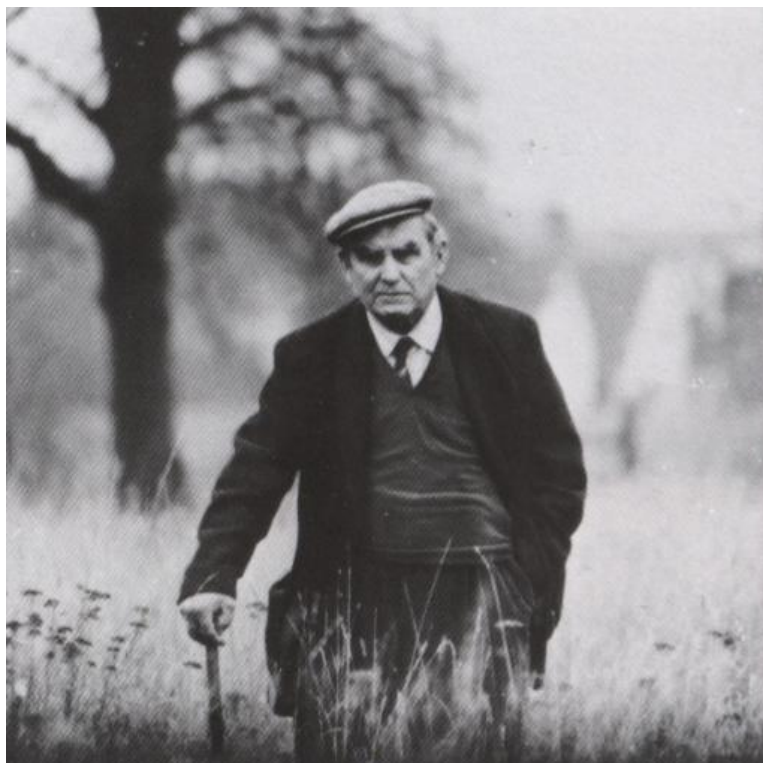


subject got through the tiny opening, producing a soft but acceptably clear photograph. Because of the small size of the pinhole, the exposure had to be 6 sec long.



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.

- Focal length is not the only element to change subject size
- We can compensate a change in focal length by moving the viewpoint
 - A change in the background occurs

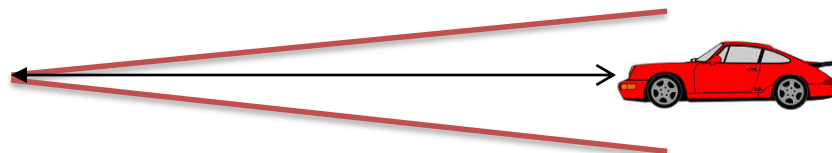
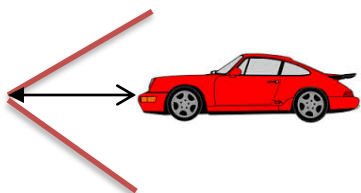




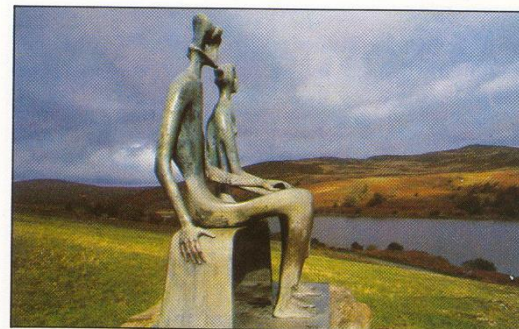
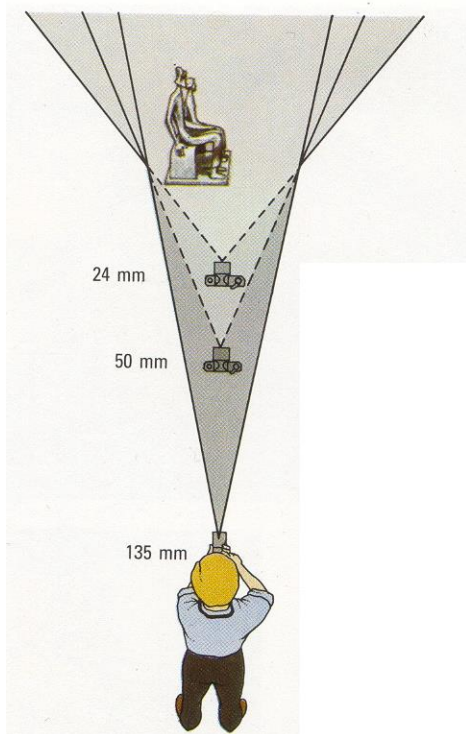
Large FOV, small f
Camera close to car



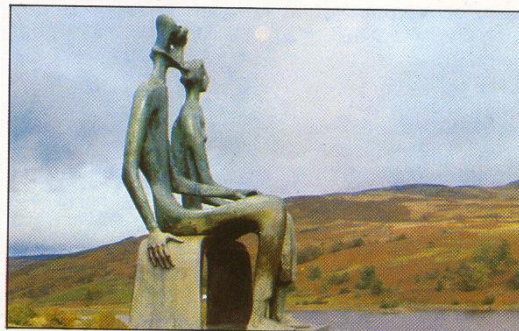
Small FOV, large f
Camera far from the car



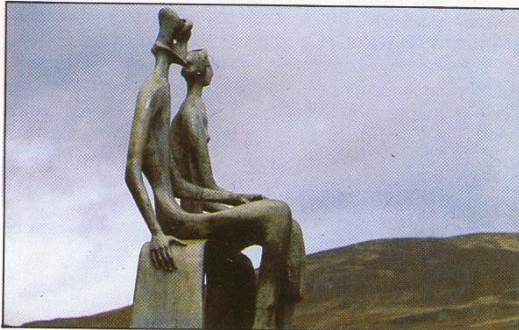
- Telephoto makes it easier to select background (a small change in viewpoint is a big change in background)



Grand-angulaire 24 mm



Normal 50 mm



Longue focale 135 mm



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Vertigo effect

IAS-LAB



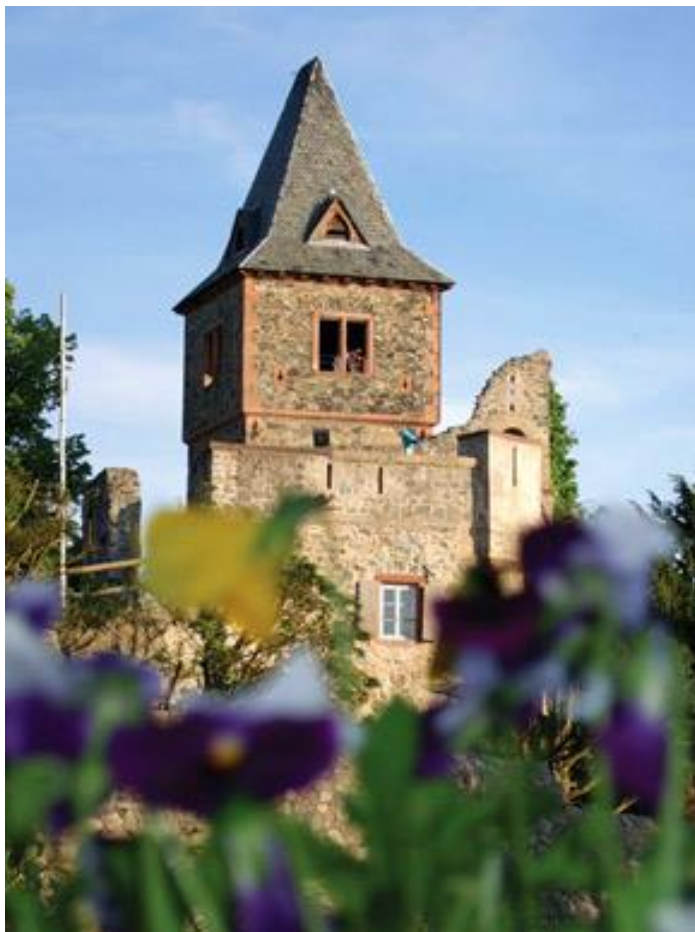
Animations by Frank Palermo



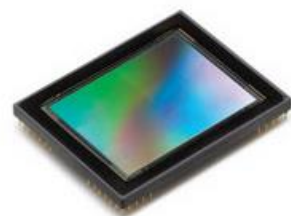
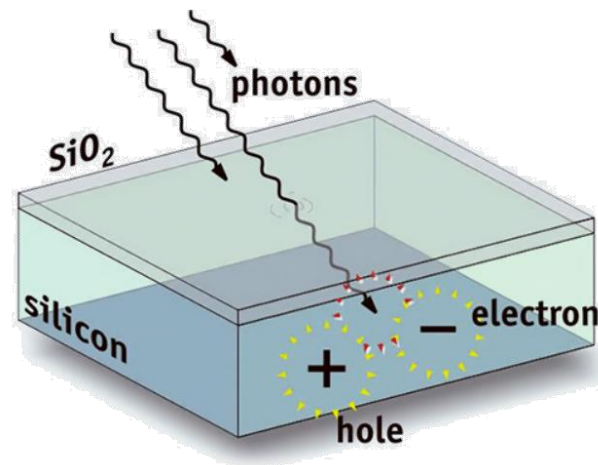
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Change in focus

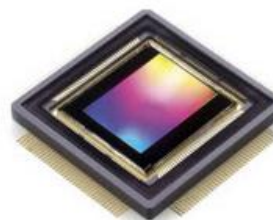
IAS-LAB



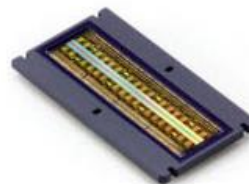
- Digital camera
 - Film \rightarrow sensor
 - Photons converted to electrons
 - Two main types
 - CCD
 - CMOS



CCD



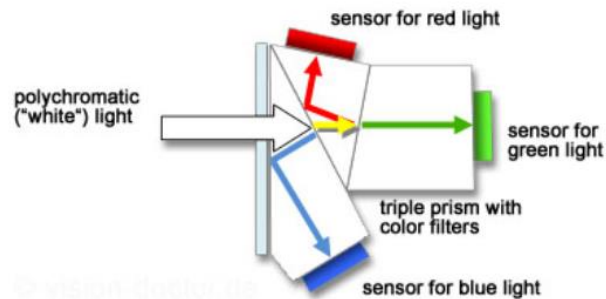
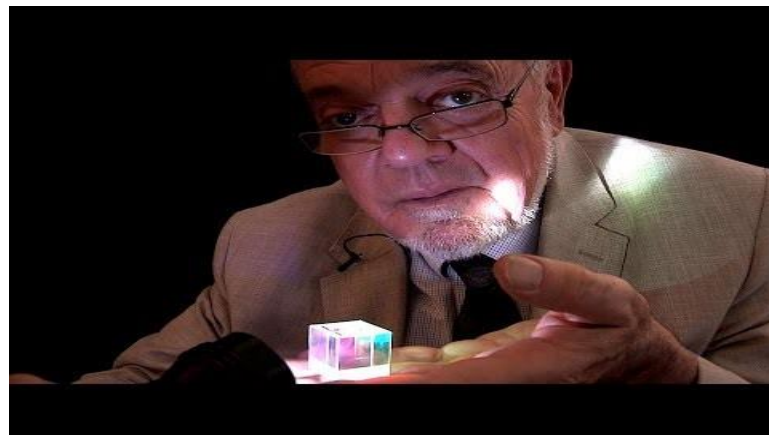
CMOS



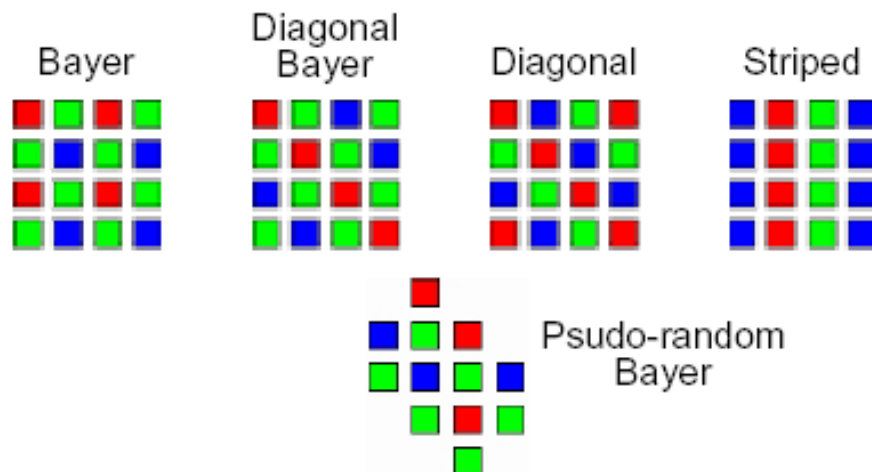
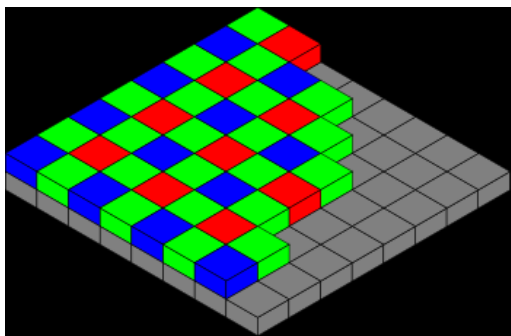
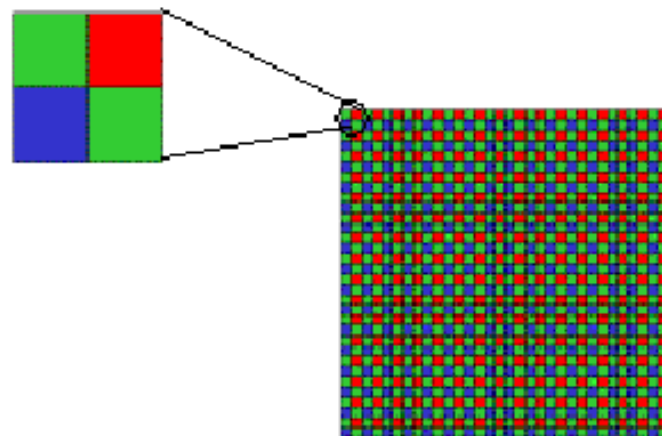


- CCD and CMOS do not differentiate on wavelength/photon energy
 - The total energy is measured
- Essentially, greyscale sensors
- Color sensed by:
 - 3-chip color: split incident light + filters and separate R, G and B color imagers
 - Single-chip color: a single imager with filters
 - Chip penetration depending on wavelength

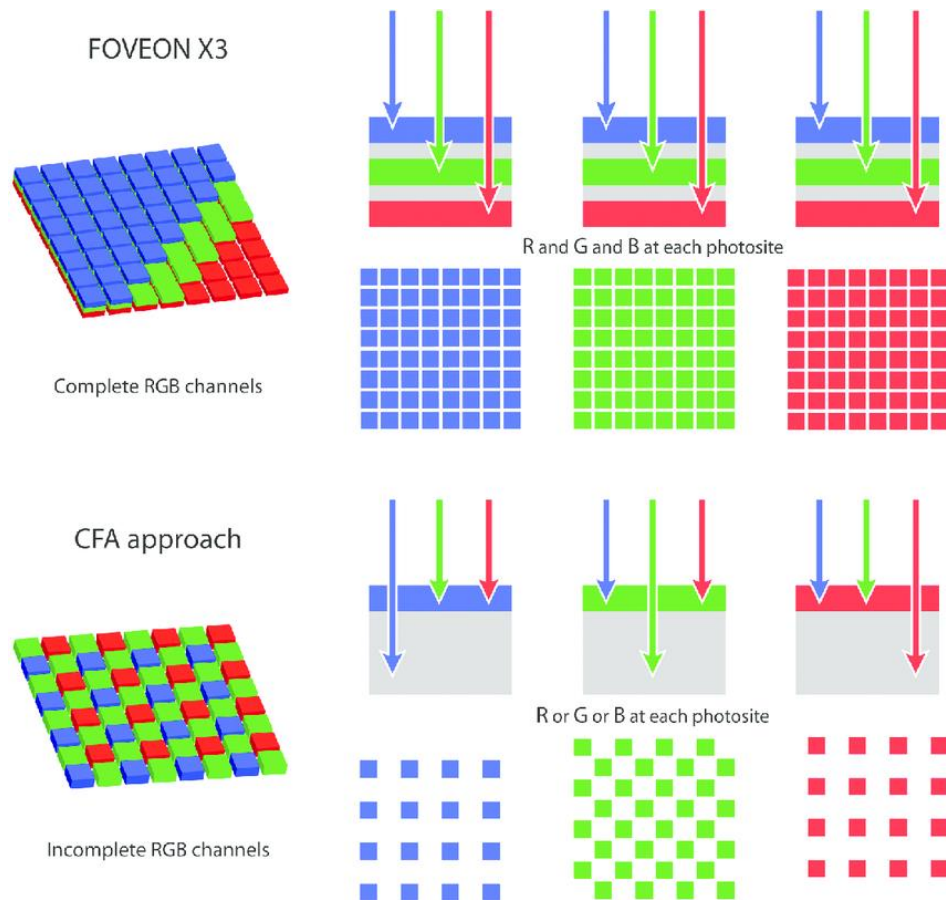
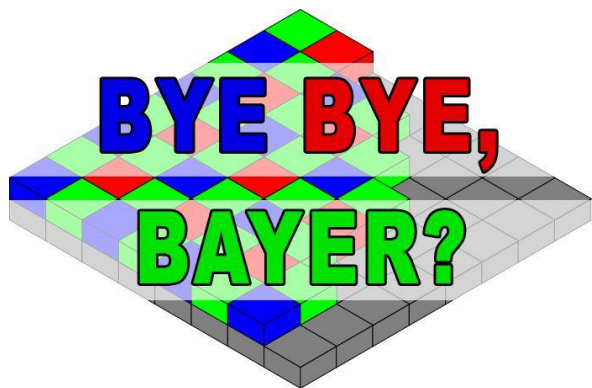
- Trichroic prism
- Dedicated sensors



- Bayer Color Filter Array (CFA) or Mosaic
- Needs interpolation to provide complete color info at each pixel
 - (Lab 4)



- No need to interpolate
- No information loss



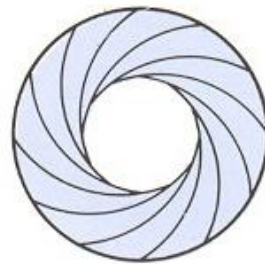
Incoming light

- Two parameters

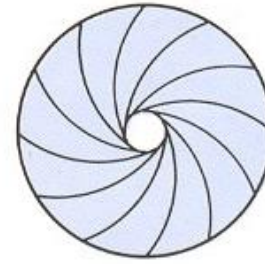
- Aperture



Full aperture

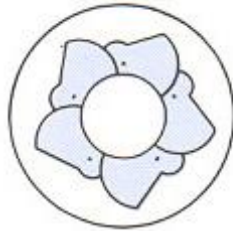
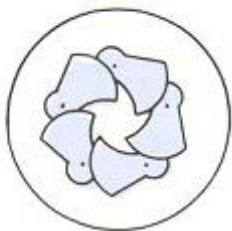


Medium aperture

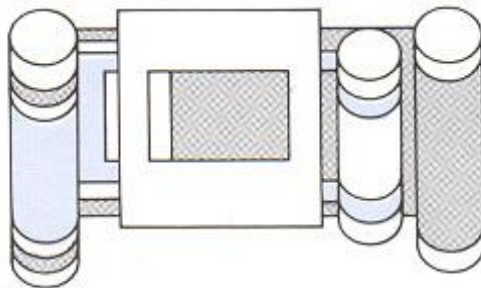


Stopped down

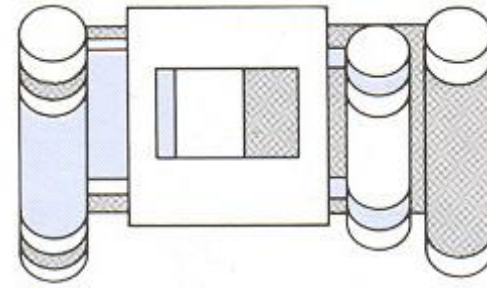
- Shutter speed



Blade (closing) Blade (open)



Focal plane (closed)

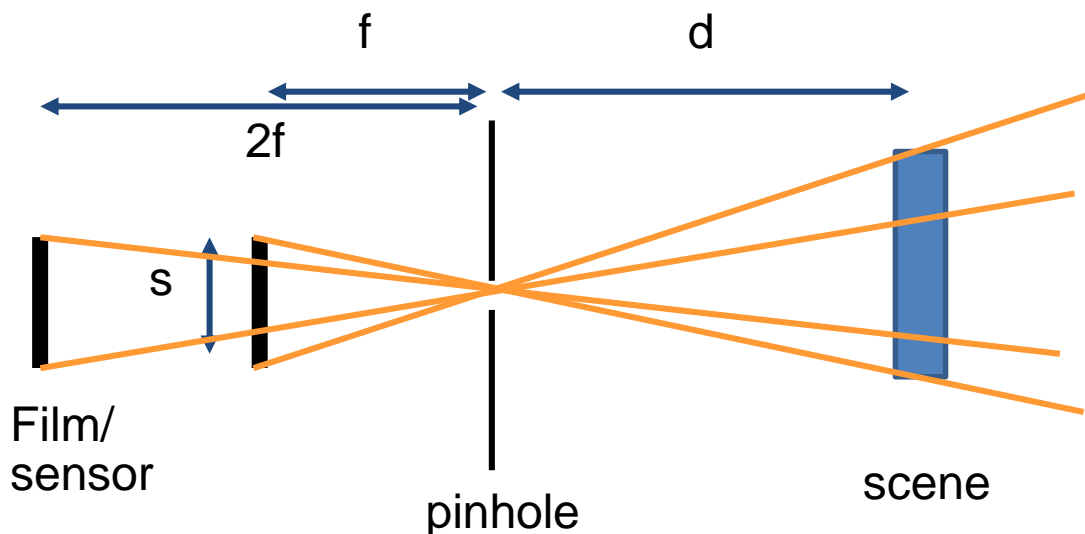


Focal plane (open)



- Diameter of lens opening
- Expressed as a fraction of focal length, f-number
 - $f/2.0$ on a 50mm: aperture = 25mm
 - $f/2.0$ on a 100mm: aperture = 50mm

- Go back to the pinhole model
- When the focal length is doubled
 - Projected object size is doubled
 - Amount of light gathered is $/4$
- This is why f-stops are used instead of metric aperture





- Diameter of lens opening
- Expressed as a fraction of focal length, f-number
 - $f/2.0$ on a 50mm: aperture = 25mm
 - $f/2.0$ on a 100mm: aperture = 50mm
- Small f means a large aperture
- Typical numbers:
 - $f/4$, $f/5.6$, $f/8$
 - Progression?

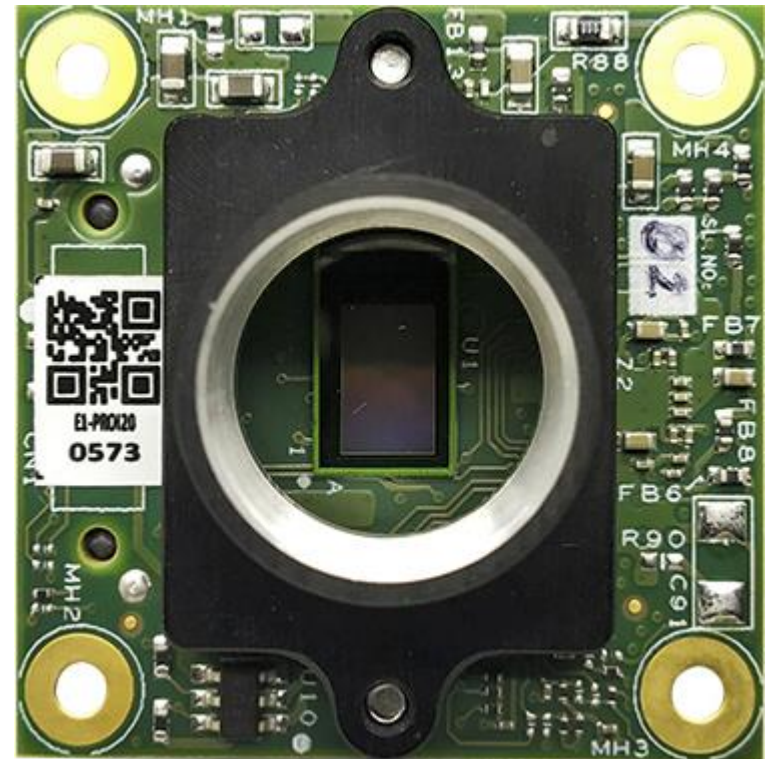


- Diameter of lens opening
- Expressed as a fraction of focal length, f-number
 - $f/2.0$ on a 50mm: aperture = 25mm
 - $f/2.0$ on a 100mm: aperture = 50mm
- Small f means a large aperture
- Typical numbers:
 $f/2.0, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32$
 - Progression?

- The sensor/film is usually shielded from light
- A picture is acquired when the shutter opens and closes, exposing the sensor/film
- Exposure time: the time the sensor is exposed to light
 - Typical: $1/60s$, $1/125s$, ..., $1/4000s$



- Video cameras use electronic shutters
- The effect of shielding and unshielding is obtained by electronic control
- Two key parameters:
 - **Exposure time**
 - Time needed for acquiring an image, AKA integration time
 - **Framerate**
 - Time distance between consecutive frames



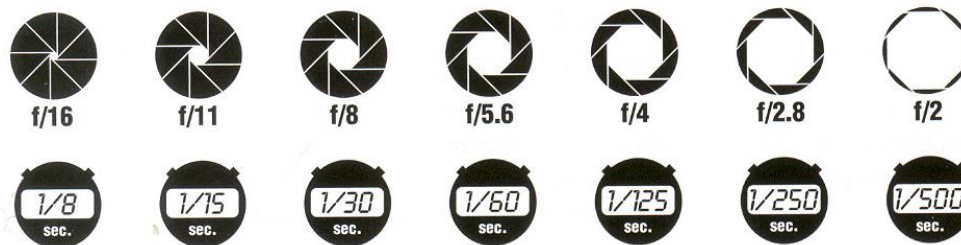
- Video cameras use electronic shutters
- The effect of shielding and unshielding is obtained by electronic control
- Two technologies:
 - **Global shutter**
 - All the pixels acquired at the same time
 - **Rolling shutter**
 - The image is acquired row by row





- <https://www.youtube.com/watch?v=YmEH8z1JWgc>
- <https://www.youtube.com/watch?v=dNVtMmLlnoE>

- Given a needed amount of light, the same exposure is obtained with an exposure x2 and an aperture area /2
 - f-stops progression: $\sqrt{2}$, shutter speed progression: 2
- Several pairs of shutter speed/aperture provide the same amount of light



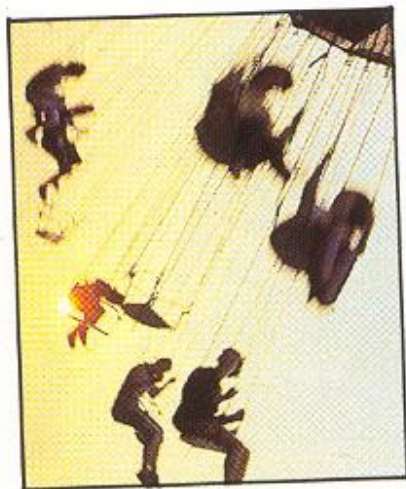
- Choice on shutter speed: freeze motion vs motion blur, camera shake
- Choice on aperture: depth of field, diffraction

- Longer exposure time: more light, more motion blur
- Shorter exposure time: less light, freeze motion

1/15 s



1/60 s



1/250 s



1/1000 s



- Longer exposure time: more light, more motion blur
- Shorter exposure time: less light, freeze motion



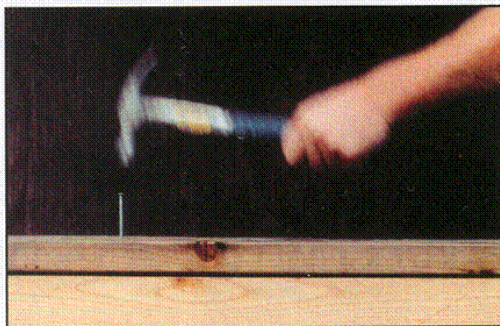


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Freezing motion

IAS-LAB

Slow shutter speed



Fast shutter speed



Walking people



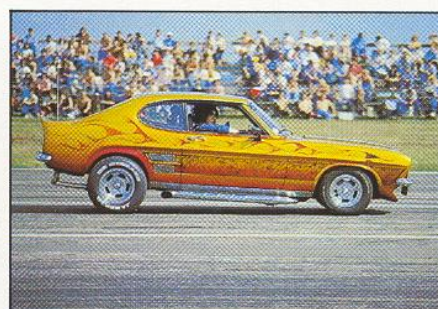
1/125

Running people



1/250

Car

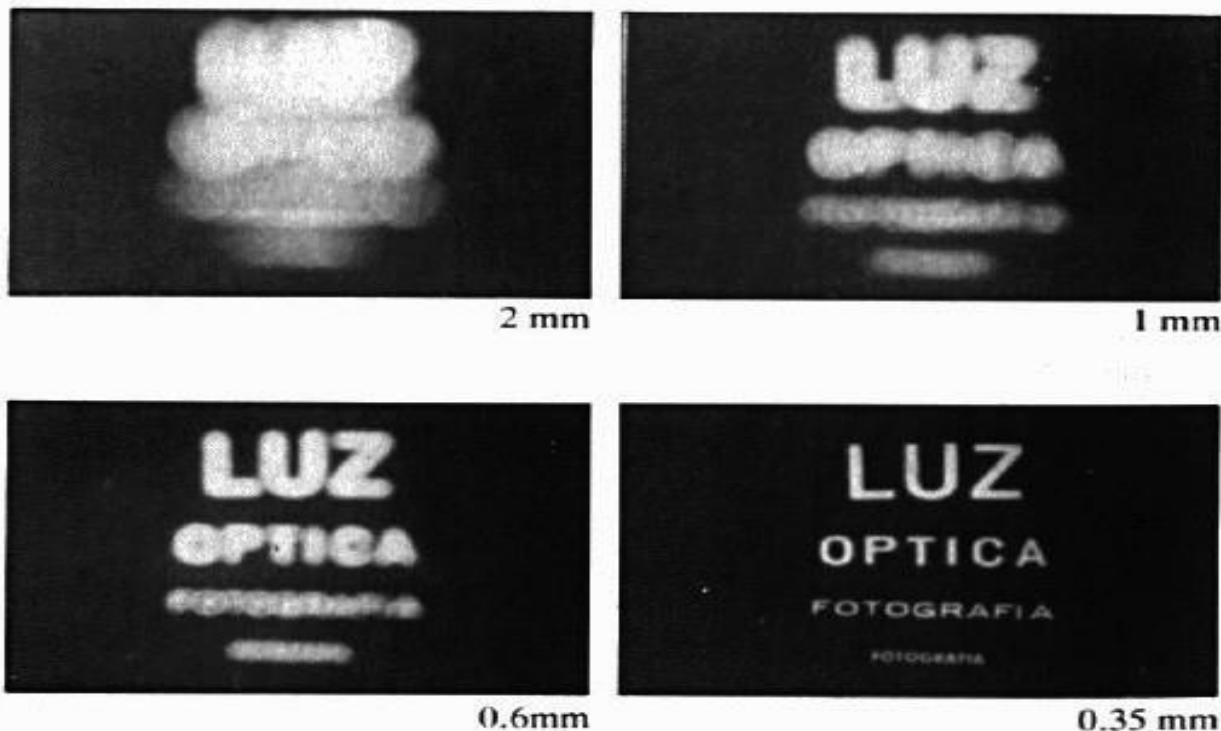


1/500

Fast train



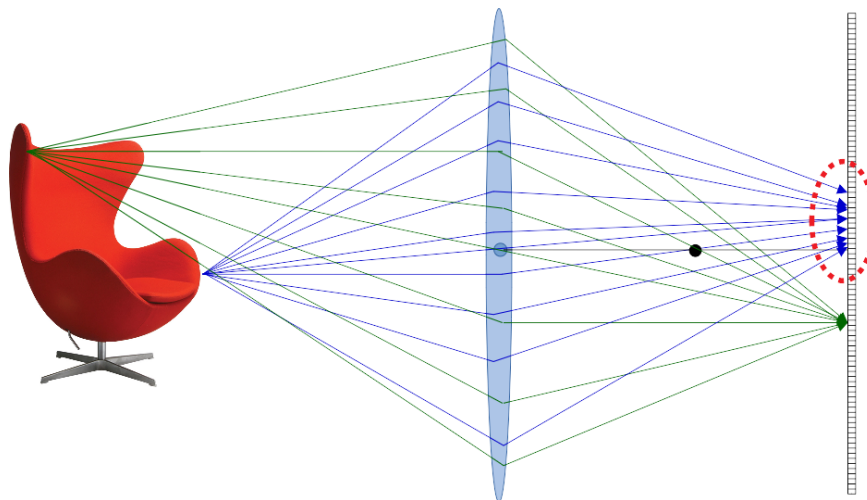
1/1000



- Why not using the smallest aperture?
 - Less light
 - Diffraction effects!

Depth of field

- Aperture controls the depth of field
 - A smaller aperture increases the range in which the object is approximately in focus
 - Depth of field: the depth in which we can neglect the presence of the circle of confusion





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Depth of field

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Varying the aperture

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Large aperture = small DOF



Small aperture = large DOF

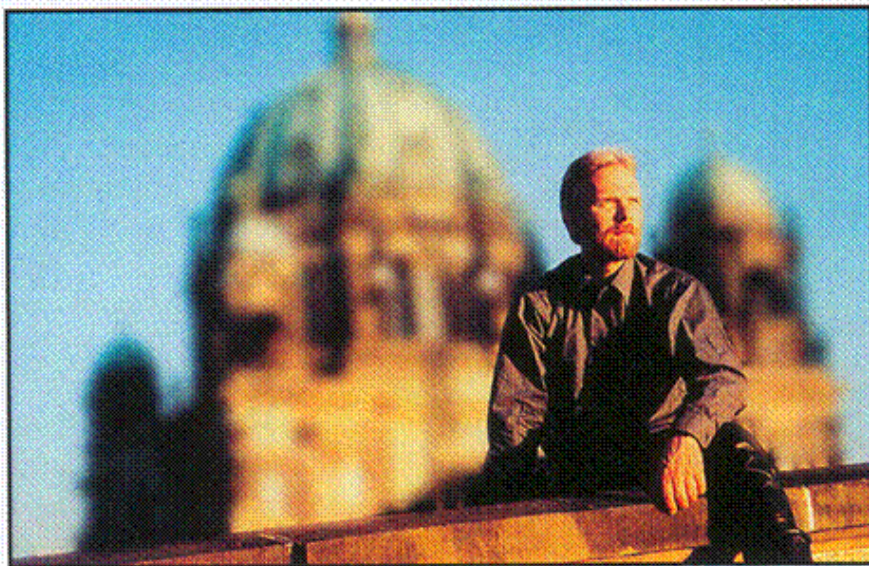


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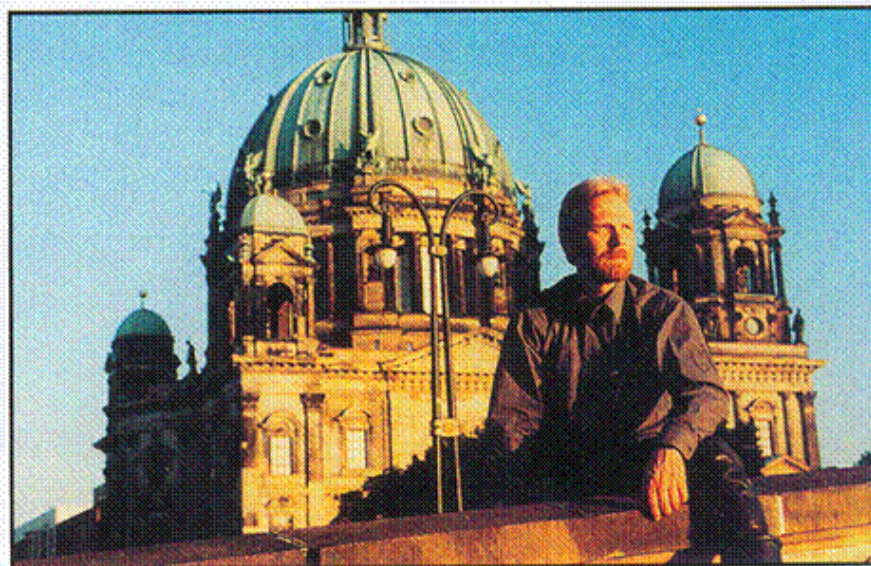
Aperture and depth of field

IAS-LAB

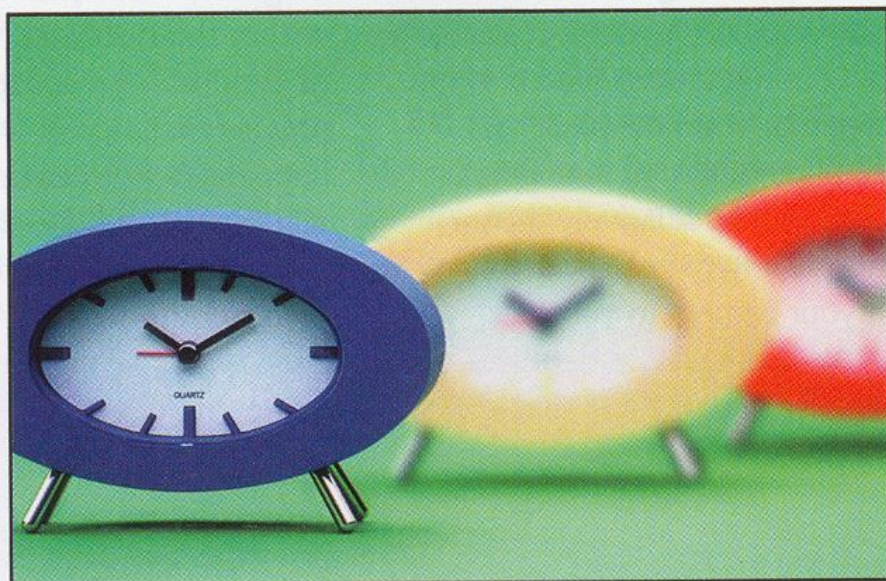
Large aperture opening



Small aperture opening



LESS DEPTH OF FIELD



Wider aperture



$f/2$

MORE DEPTH OF FIELD



Smaller aperture



$f/16$



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Real cameras

Stefano Ghidoni

