1. Camera

Get Familiar with Cameras

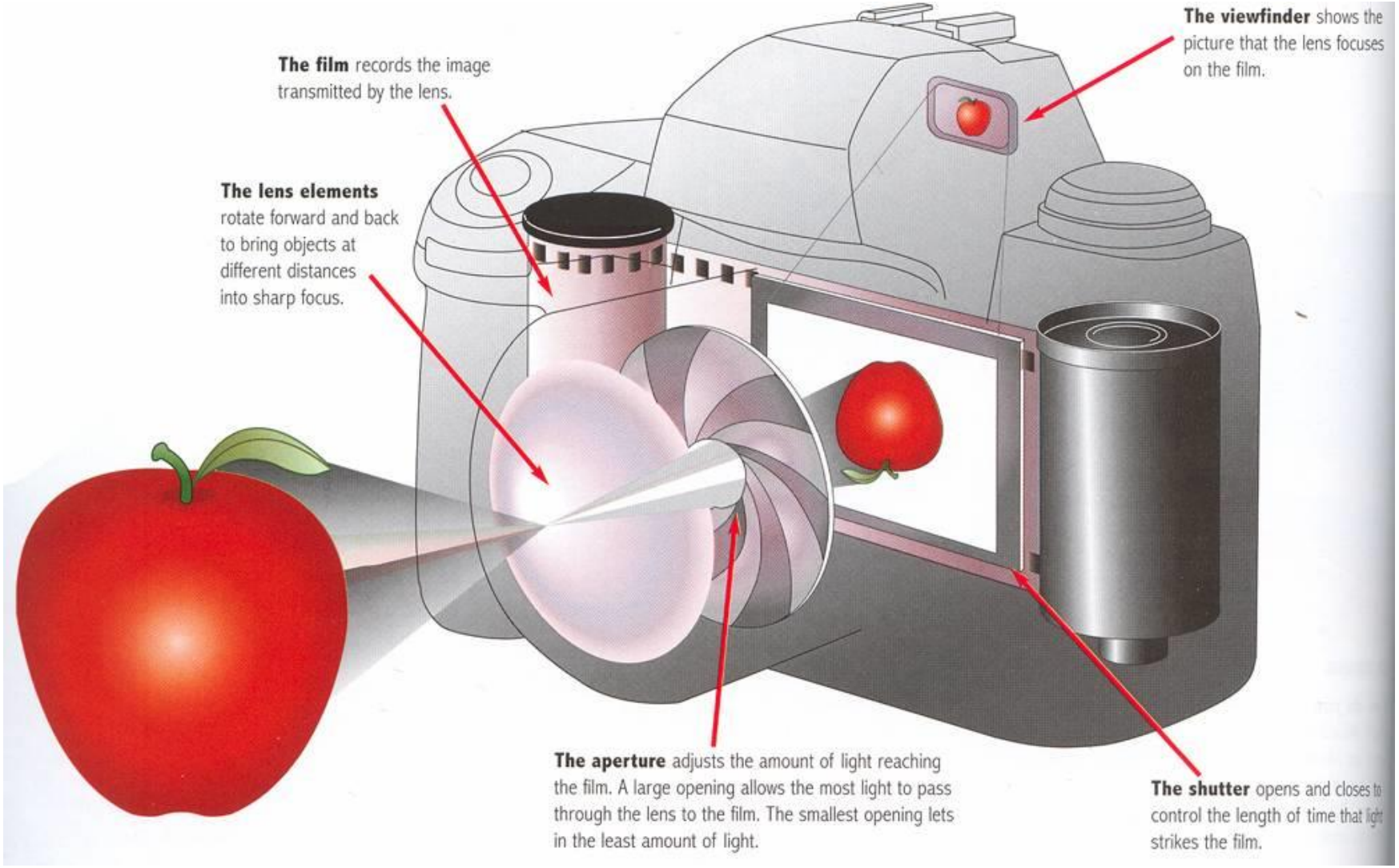
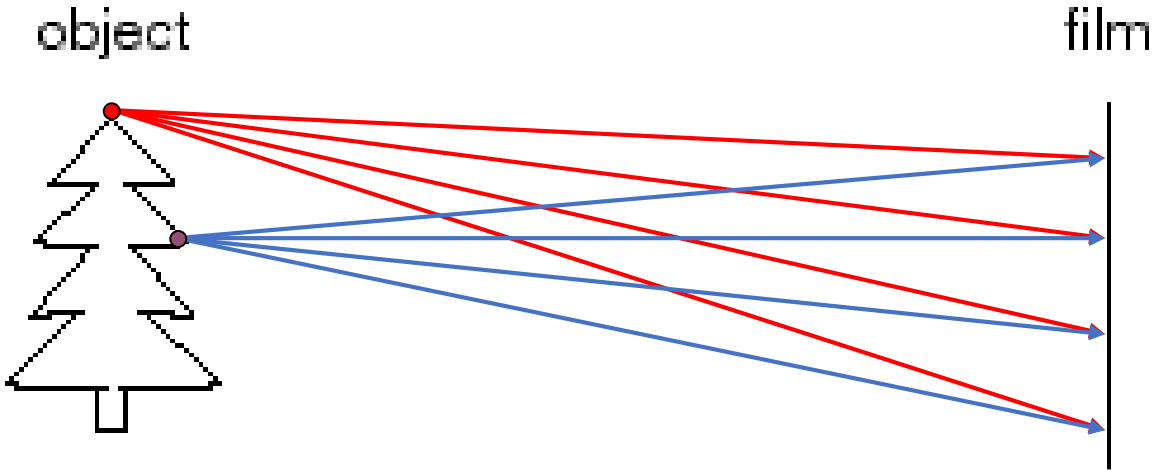
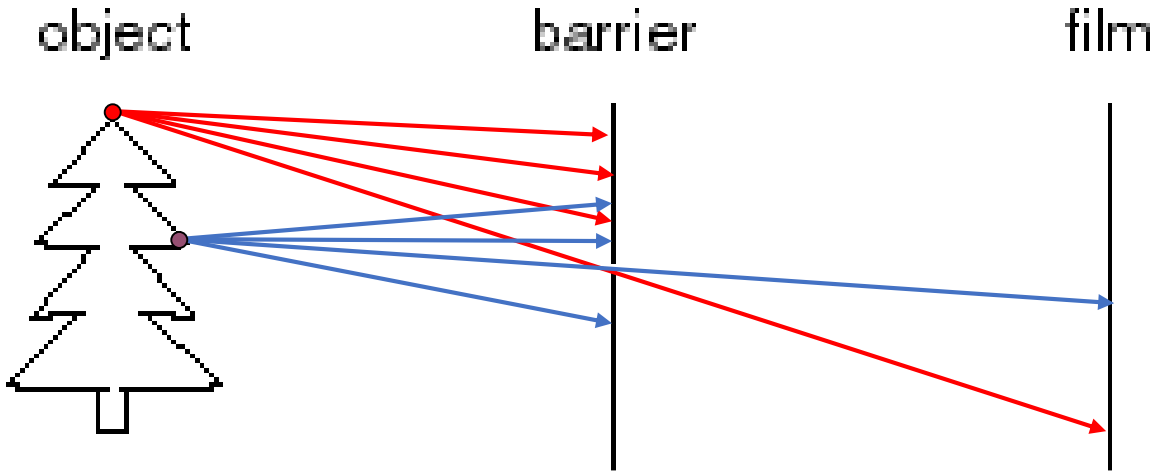


Image Formation



- Let's design a camera
  - Idea 1: put a piece of film in front of an object
  - Do we get a reasonable image?

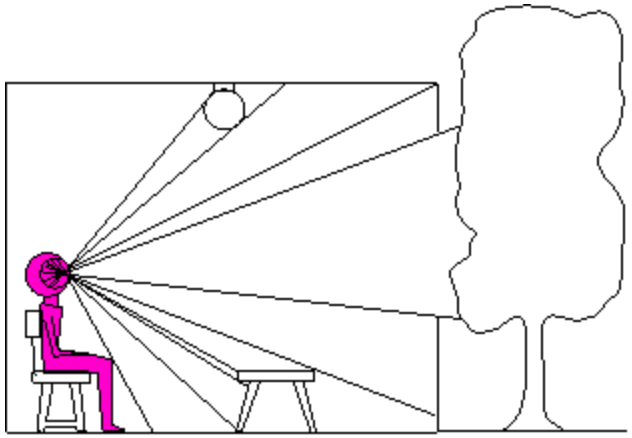
Pinhole Camera



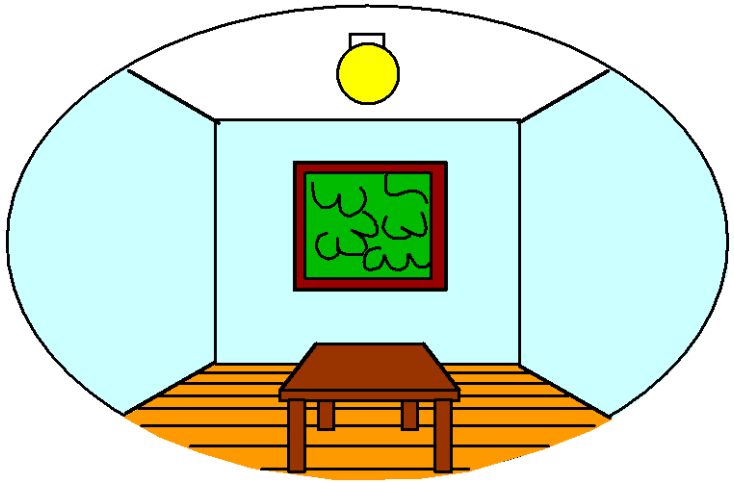
- Add a barrier to select rays
  - The opening known as the **aperture**
  - How does this transform the image?

Dimensionality Reduction Machine (3D to 2D)

3D world

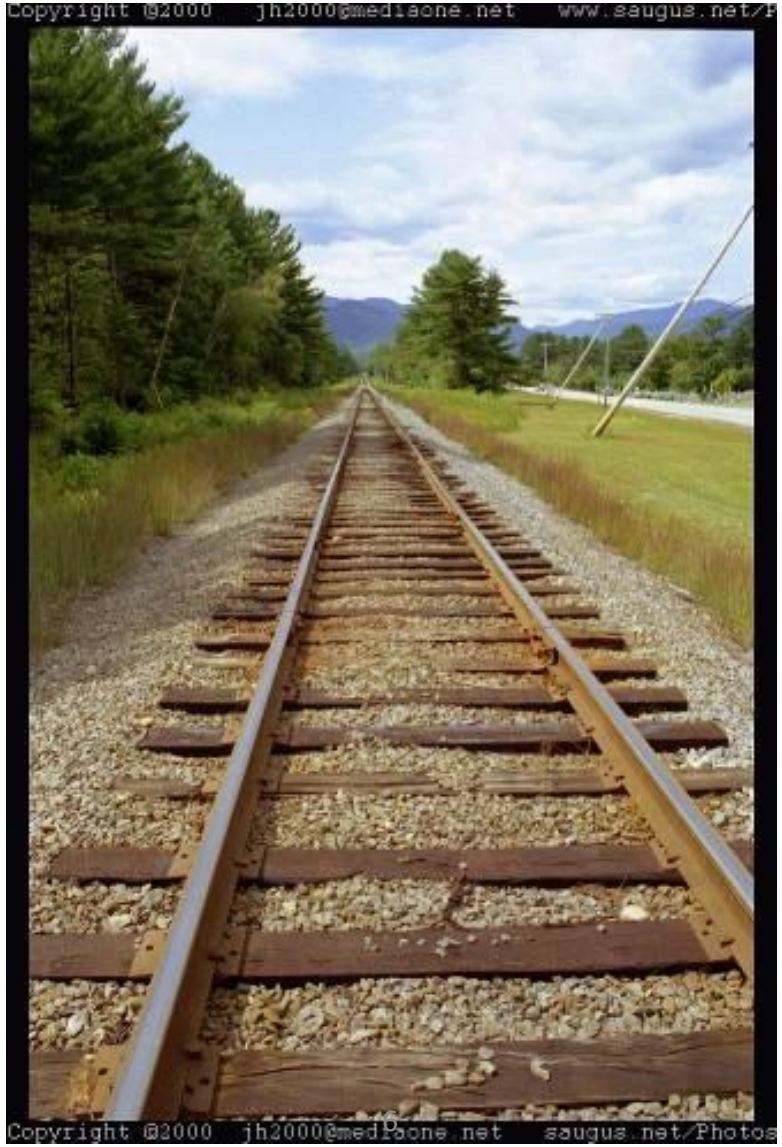


2D image

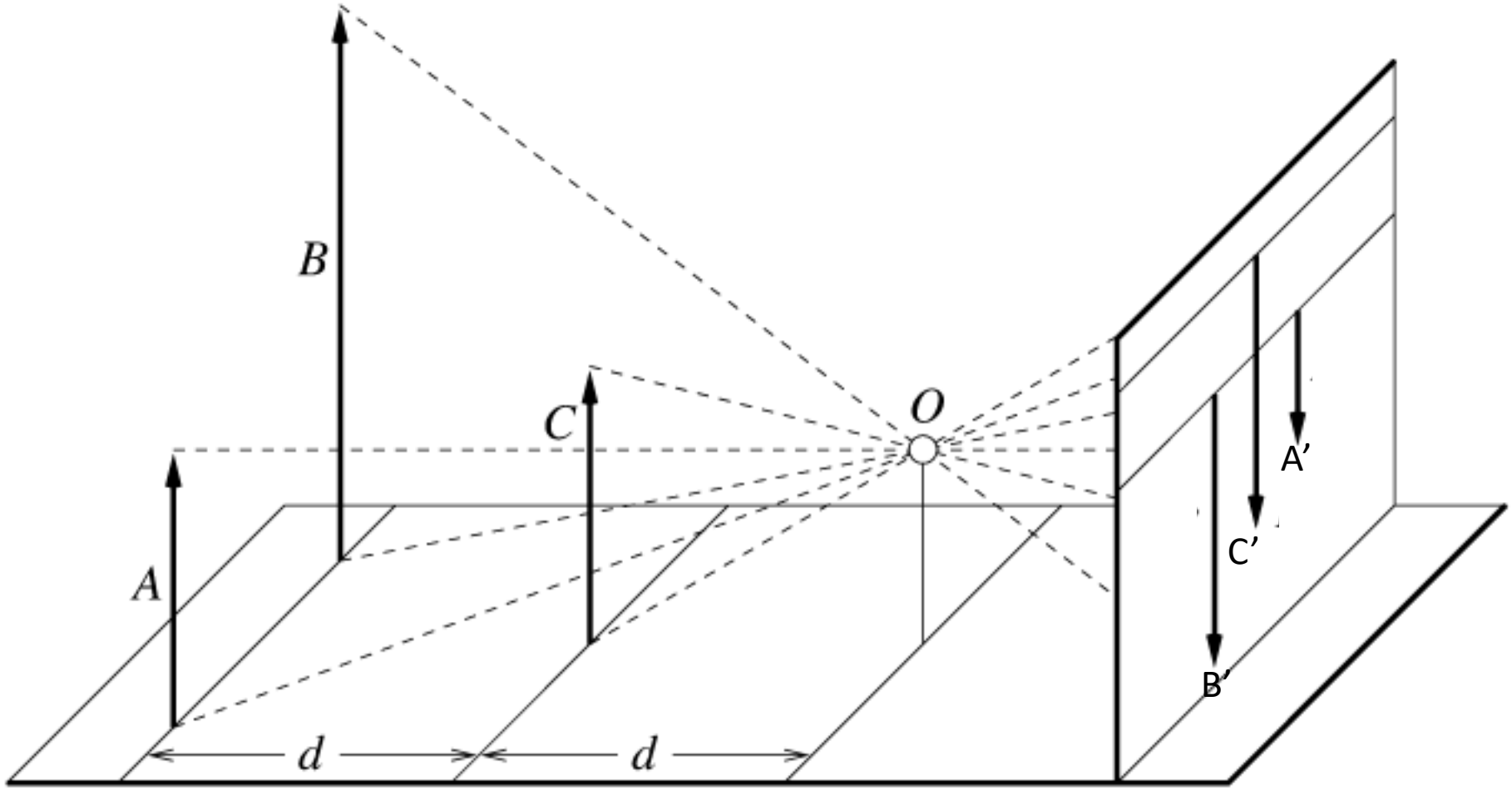


- We capture a 2D picture of the 3D world, what have we lost?
  - Distances (lengths)
  - Angles

Parallelism is lost

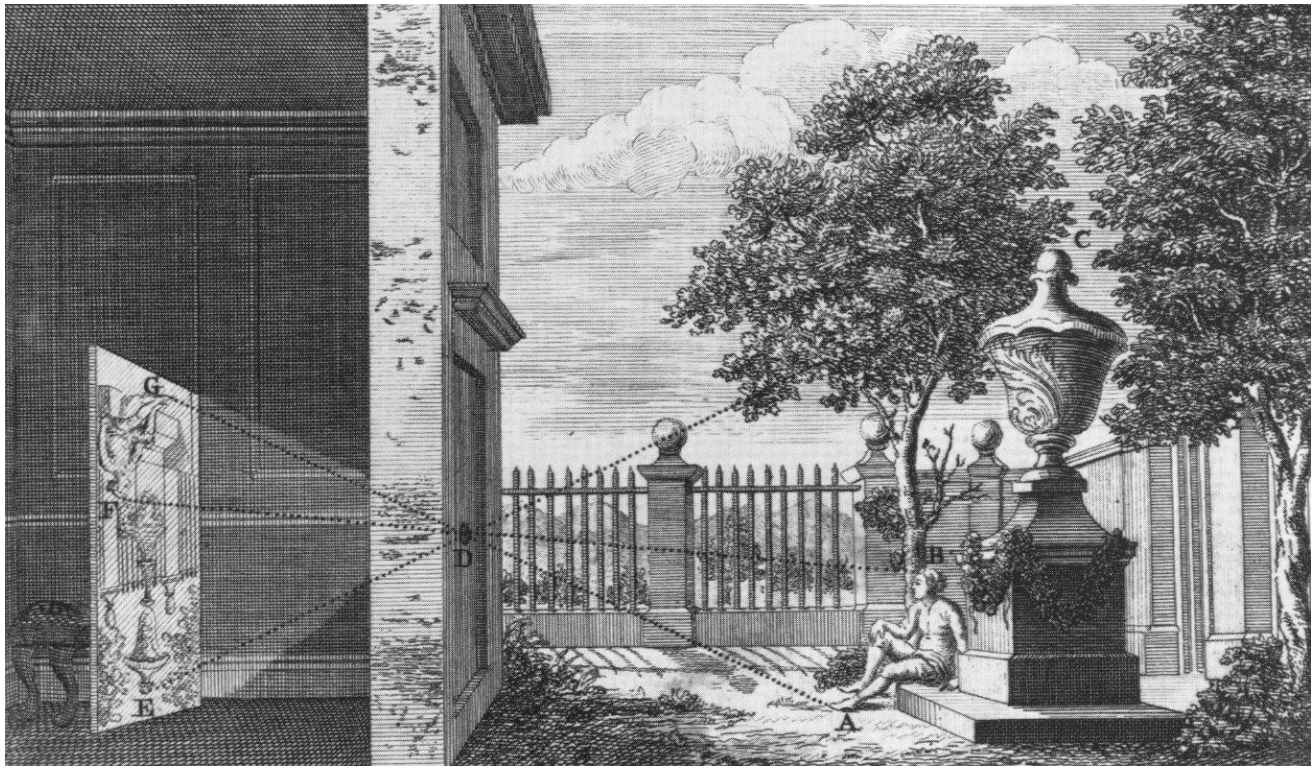


Lengths can’t be trusted…



Building a real camera

Pinhole Camera



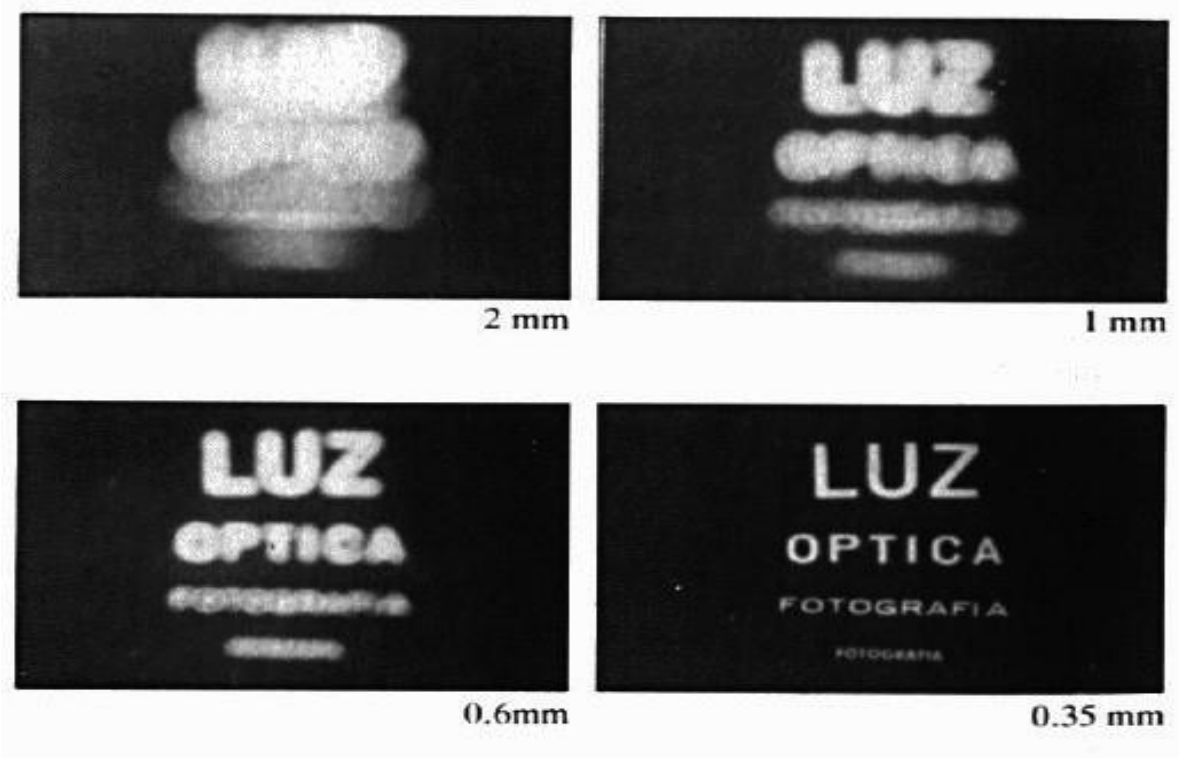
- First Idea: Mo-Ti, China (470-390 BC)
- First build: Al Hacen, Iraq/Egypt (965-1039 AD)
- Drawing aid for artists: described by Leonardo da Vinci (1452-1519)

Home-made Pinhole Camera

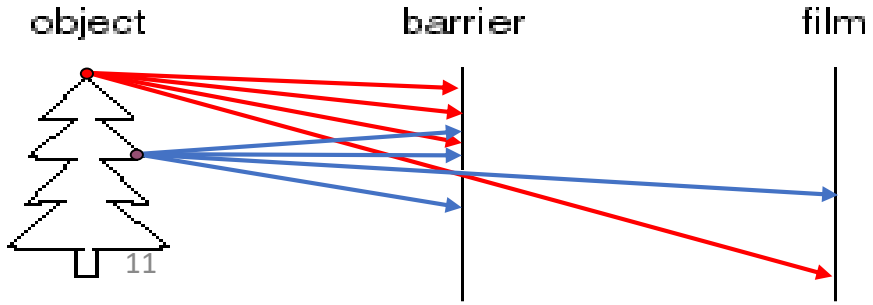
Why so blurry?

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

Shrinking the Aperture



- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects



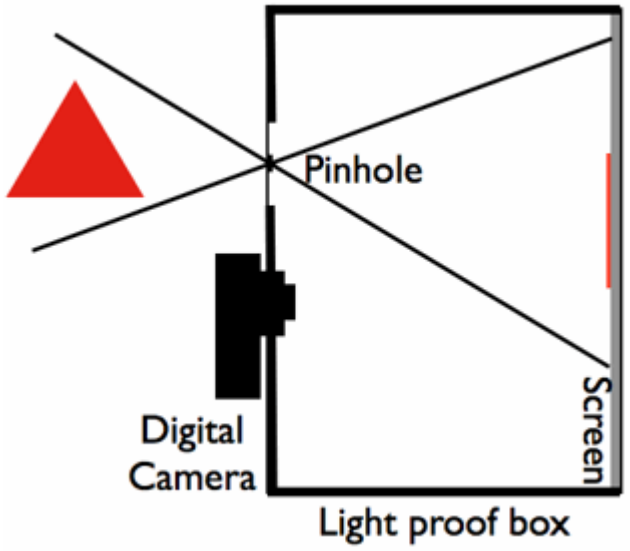
Shrinking the Aperture

Make Your Own Pinhole Camera at Home

- Build a pinhole camera using a shoebox and a digital camera

- Step by step instructions at
  http://graphics.cs.cmu.edu/courses/15-463/2012_fall/hw/proj5-camera/

- Stereo pinhole camera can be built too
  http://cs.brown.edu/courses/csci1290/2011/asgn/proj4/



8-hour exposure (Abelardo Morell)

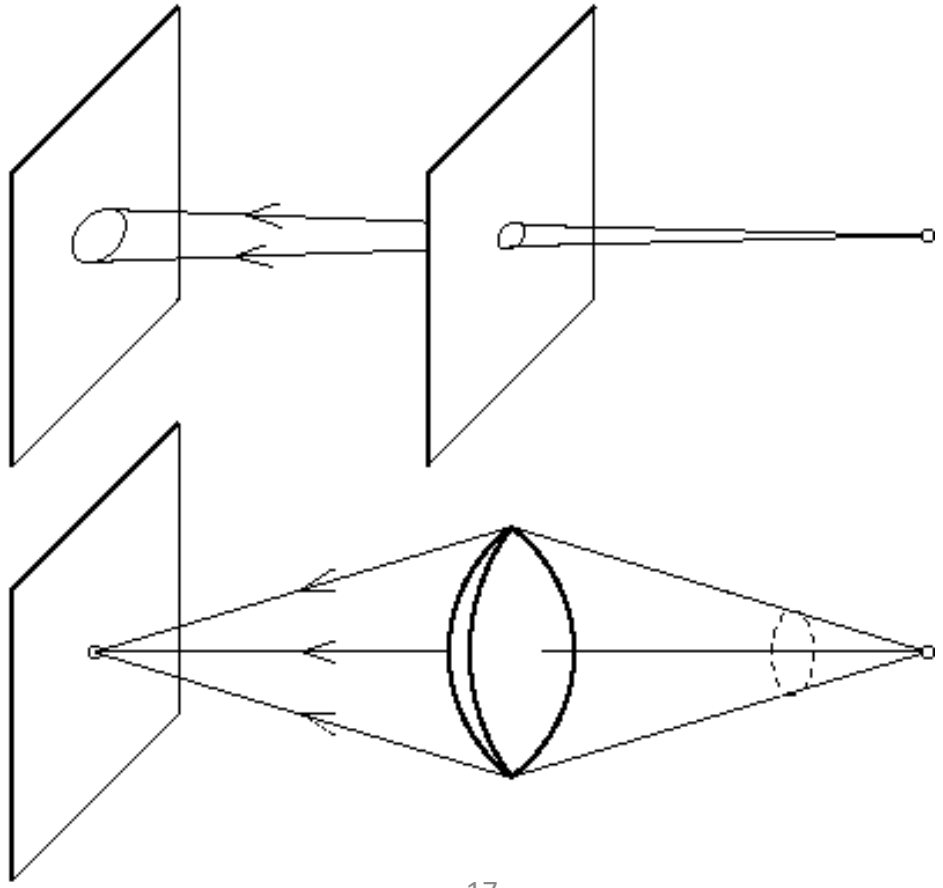
http://www.abelardomorell.net/books/books_m02.html

Questions?

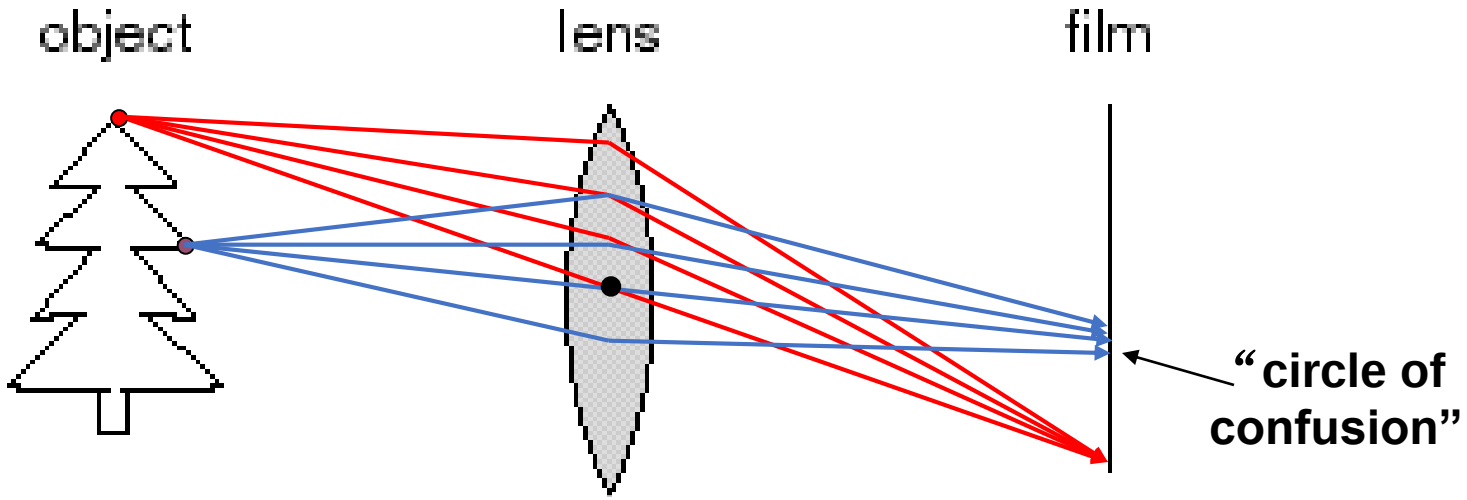
The reason for lenses

The reason for lenses

- Focus all lights shed on the lens to a single point
- Much more energy efficient than a pinhole

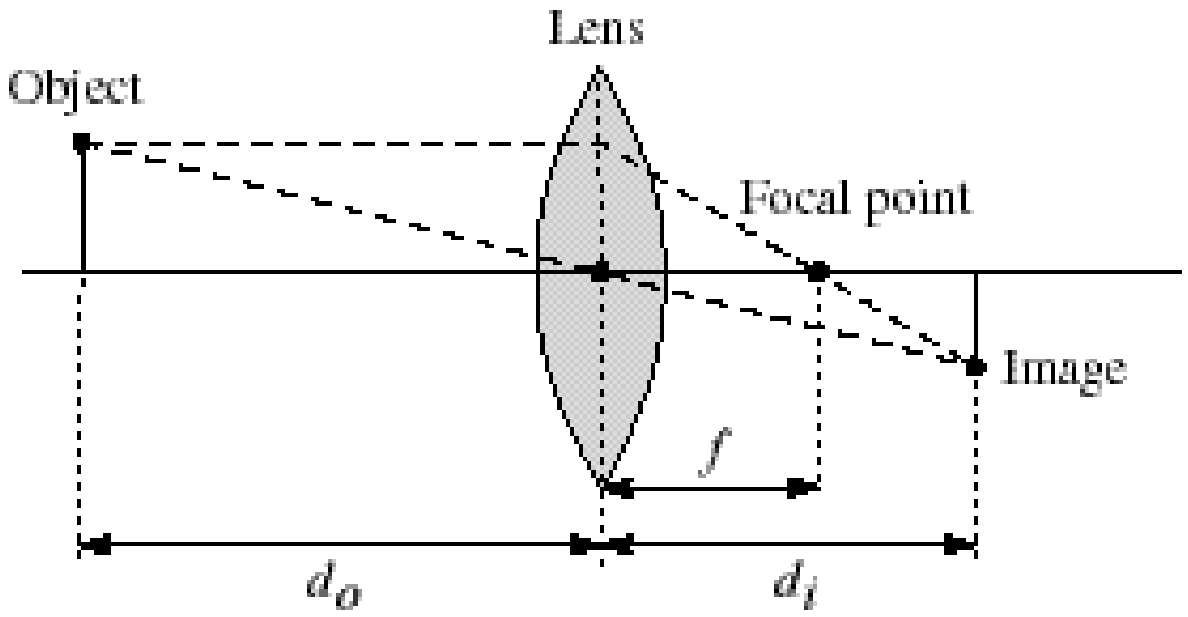


Problem with lenses



- There is a specific distance at which objects are “in focus”
  - other points project to a “circle of confusion” in the image
- Changing the shape of the lens changes this distance

Thin lenses



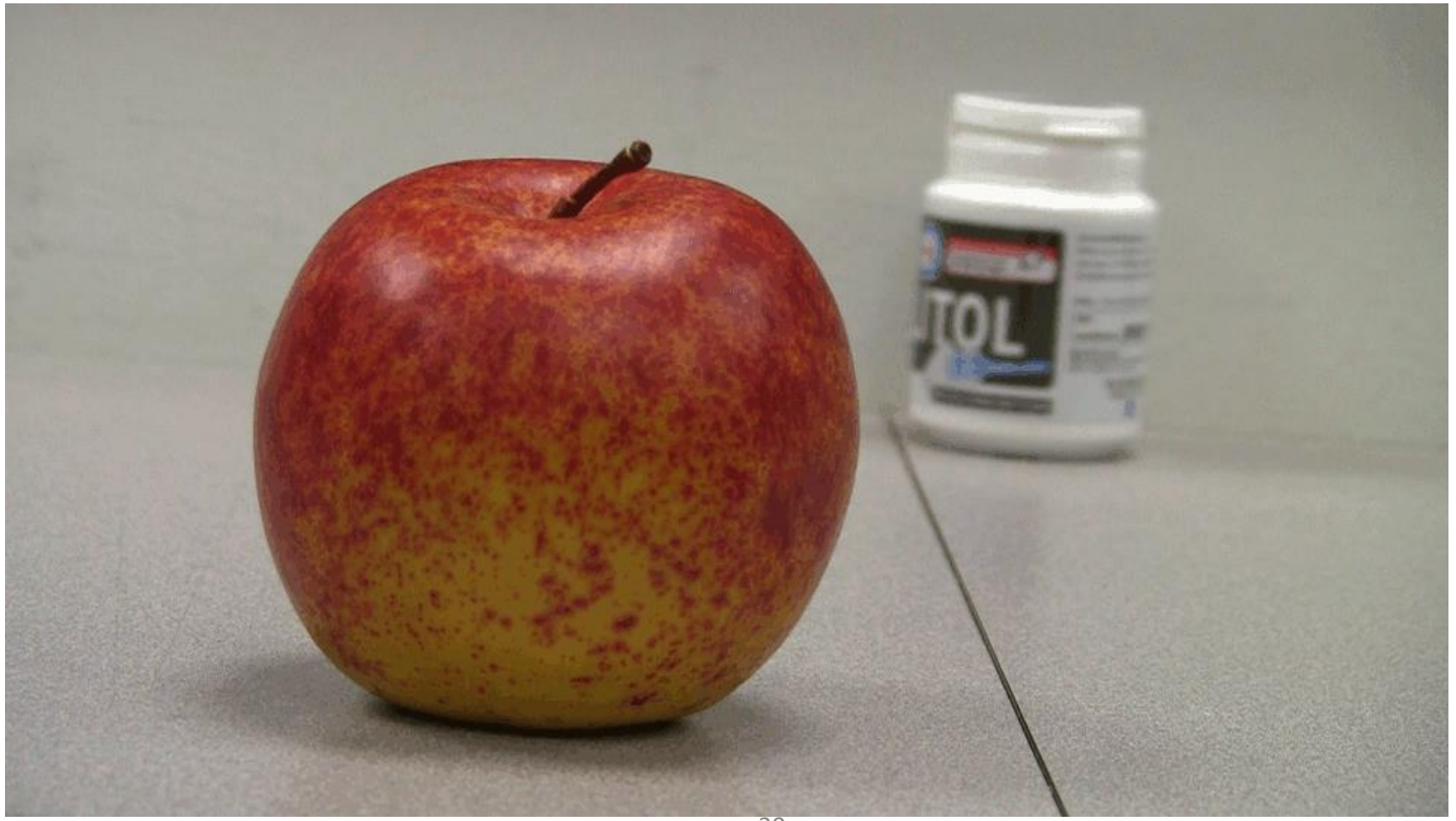
- Thin lens equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

  - Any object point satisfying this equation is in focus
  - Adjusting d_i to choose the object in focus

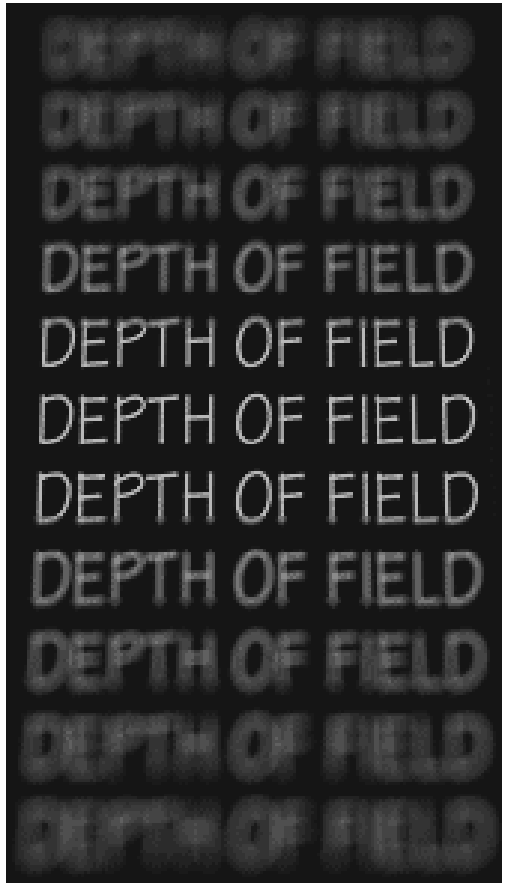
Varying Focus

- Changing the position of the sensor (image plane)

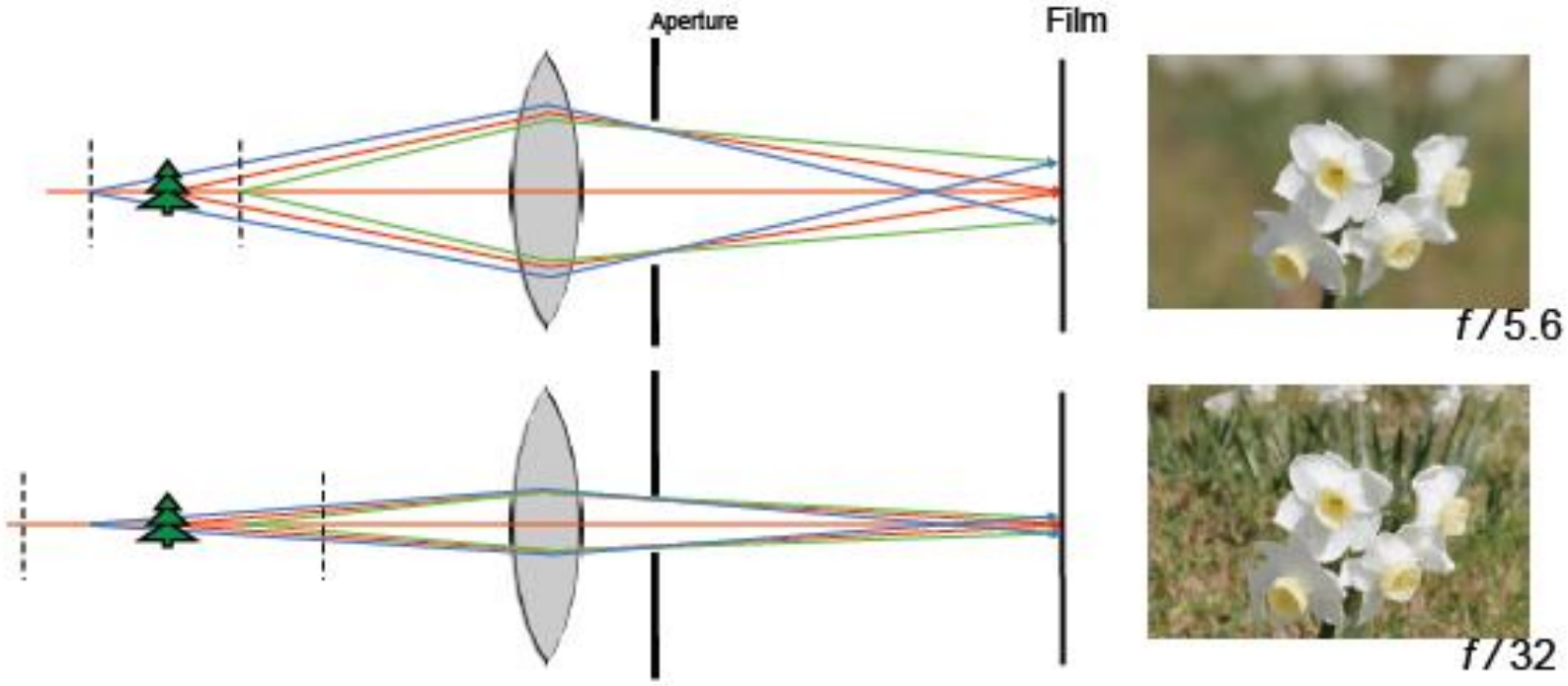


Depth of Field

- Only points at certain distance are in focus



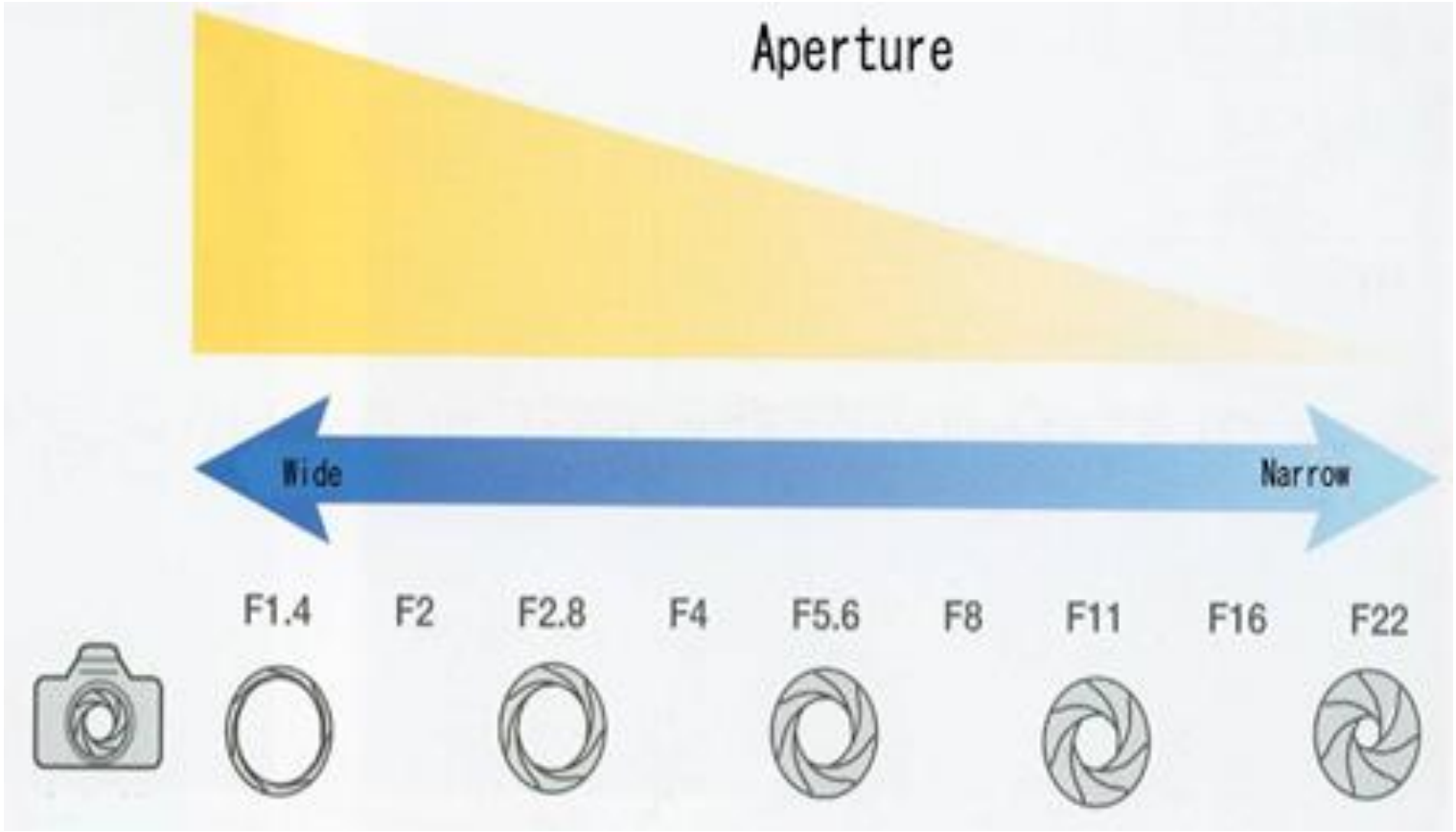
Aperture controls Depth of Field



- 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

F-number: focal length / aperture diameter

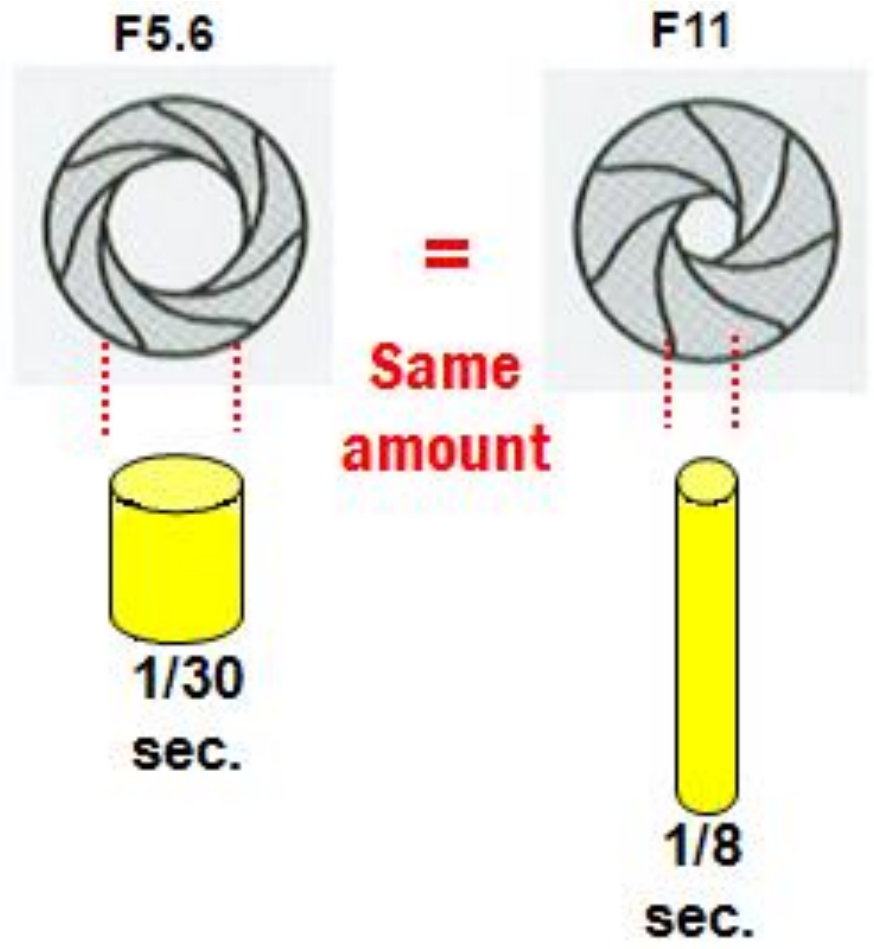
- Aperture size is controlled by the F-number



Varying the aperture

http://beginnersphotographyblog.com/842/how-changing-aperture-affects-depth-of-field/

Exposure: shutter speed vs. aperture

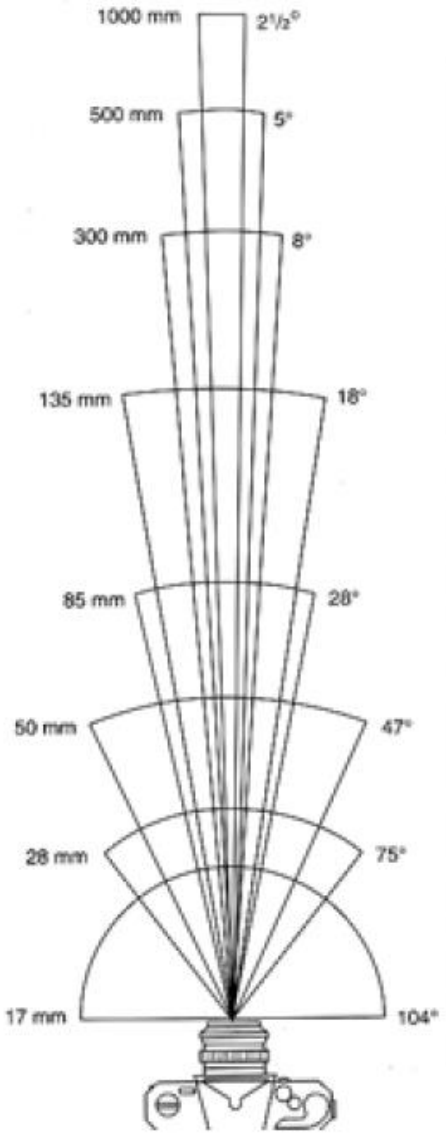


Shutter Speed

http://en.wikipedia.org/wiki/Shutter_speed

Questions?

Field of View (Zoom)



17mm

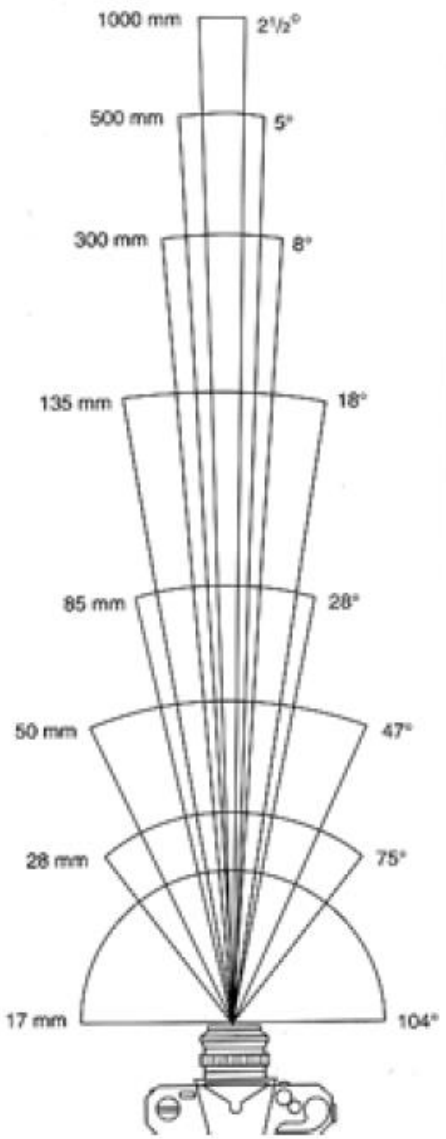
28mm

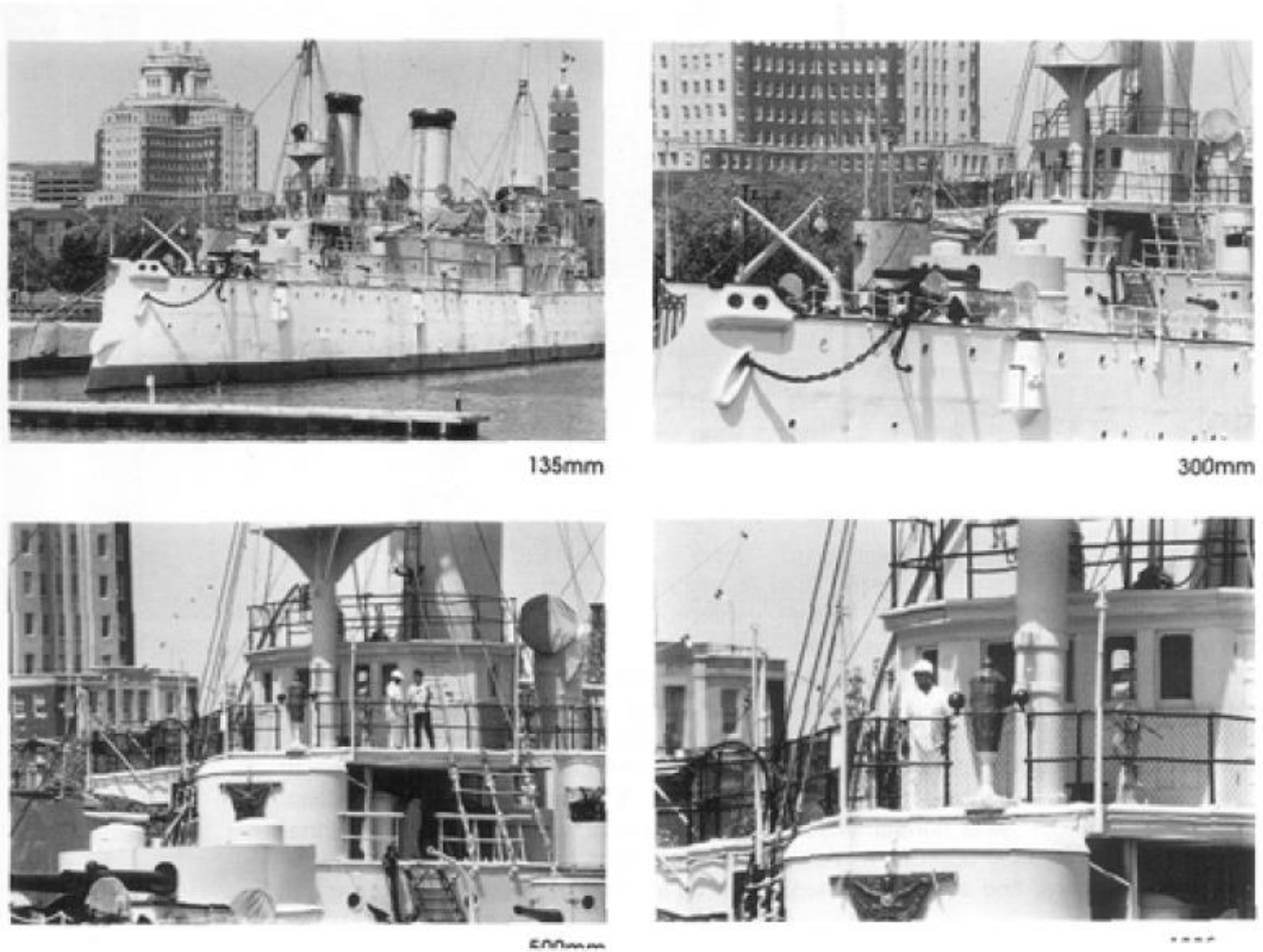
50mm

85mm

From London and Upton

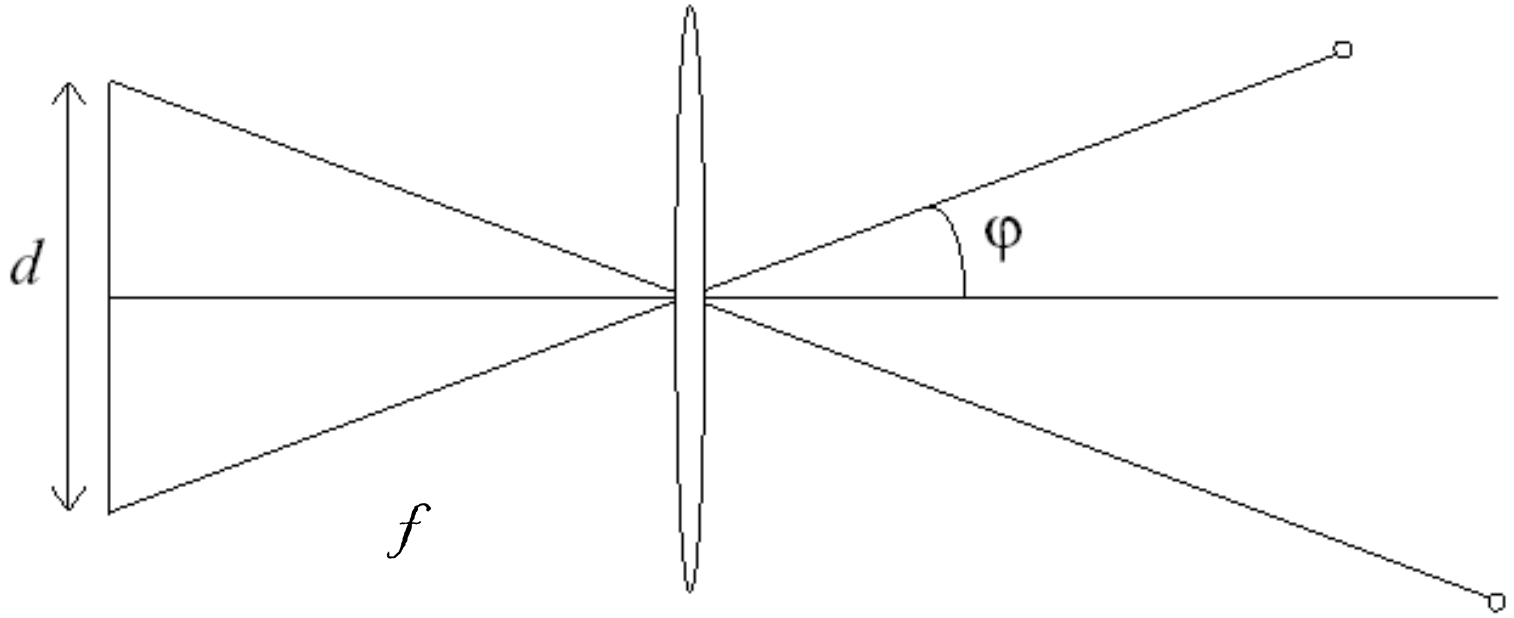
Field of View (Zoom)





From London and Upton

FOV depends on 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, when the film is fixed

Expensive toys…

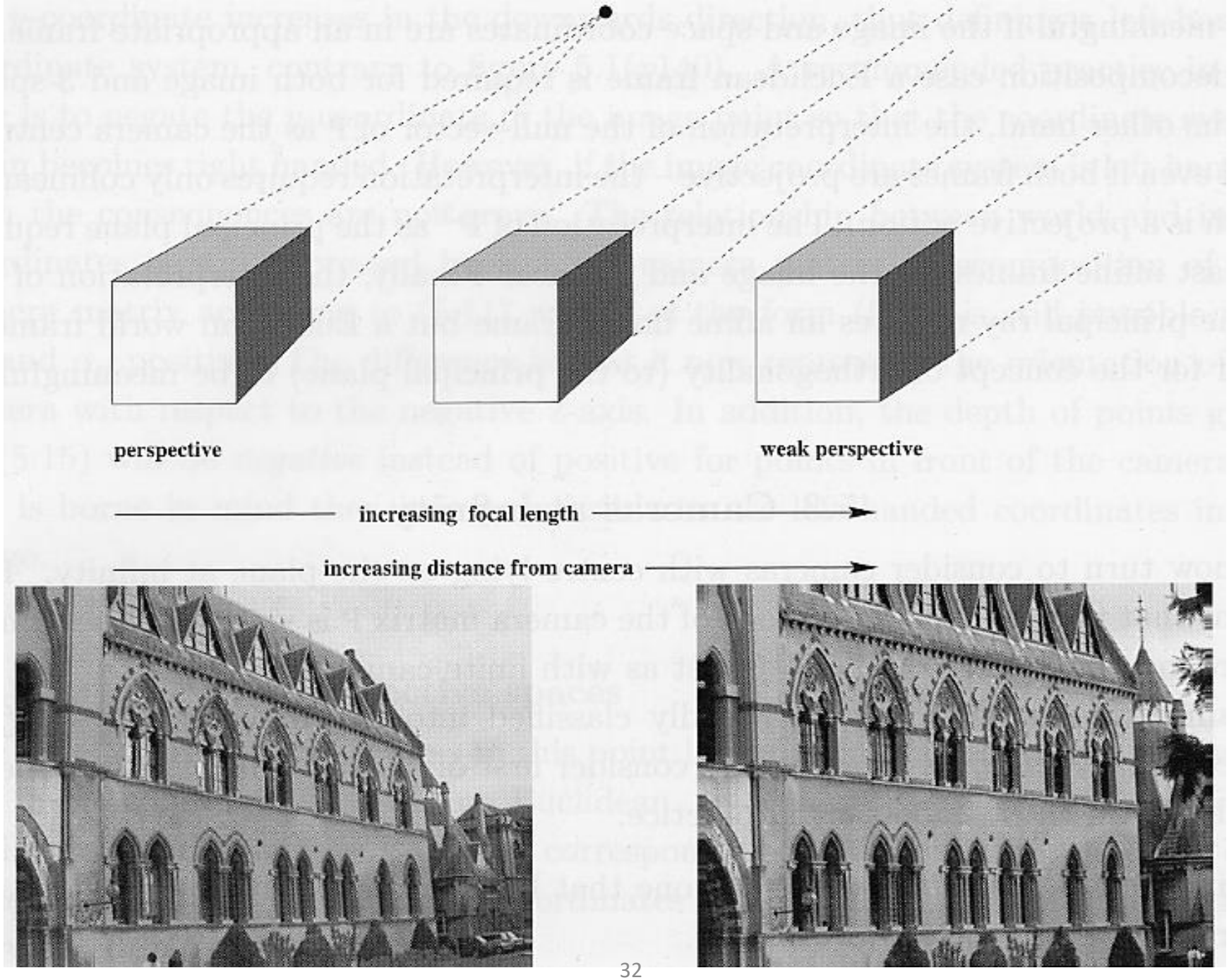
Sigma 200-500mm F2.8 EX DG lens

What does 1600mm lens look like?

http://www.digitalpixels.net/varia/the-web/sigma-200-500mm-f28-ex-dg-lens-on-the-field/

$14,600^{00}

http://dancarrphotography.com/blog/wp-content/uploads/2011/05/Canon_super_tele_comparison.jpg



From Zisserman & Hartley

Field of View / Focal Length

Large FOV
Camera close to car

Small FOV
Camera far from the car

Field of View / Focal Length

Large FOV
Camera close to face

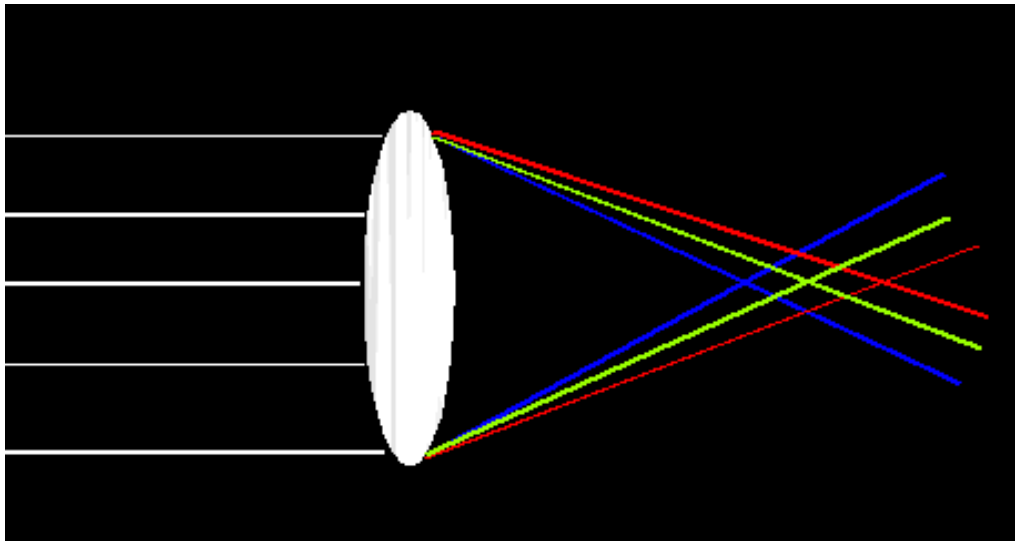
Standard

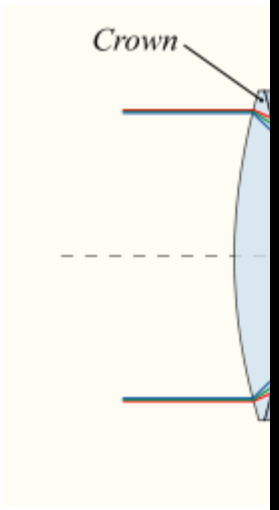
Small FOV
Camera far from the face

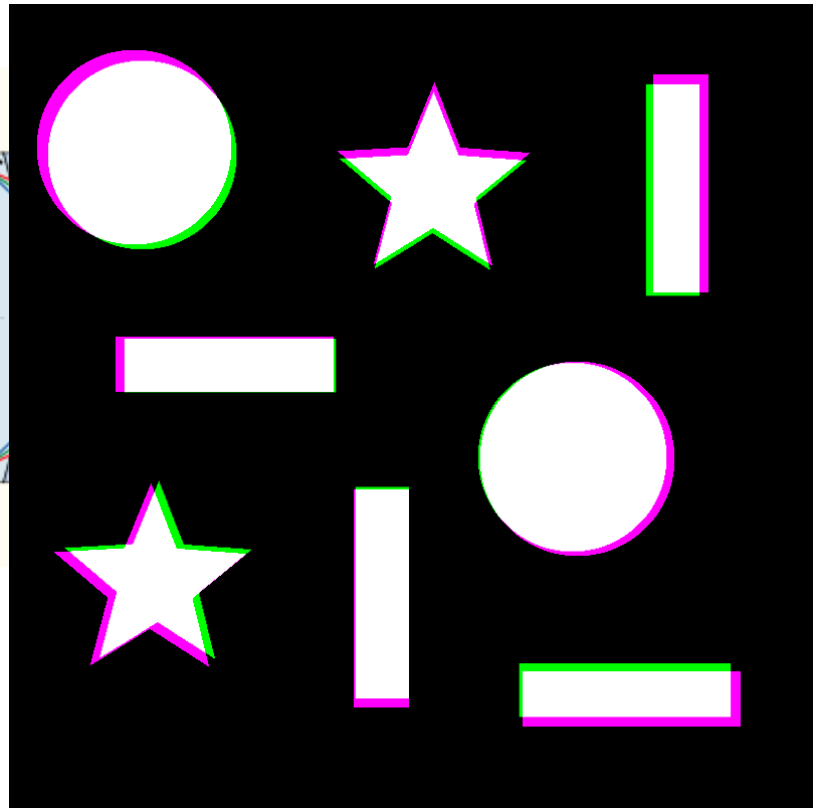
Questions?

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)







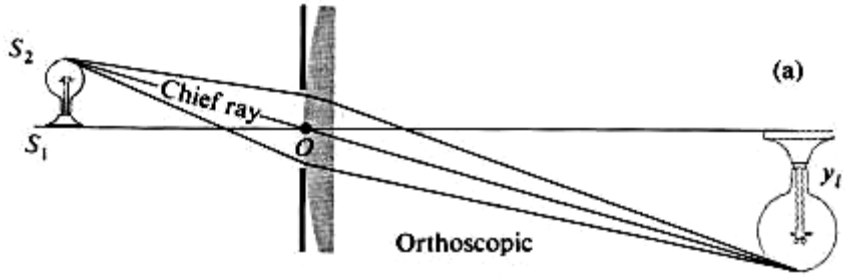
- Color fringes near edges of image
- Corrections: add ‘doublet’ lens of flint glass, etc.

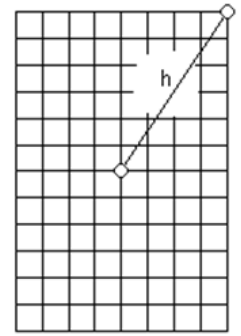
Chromatic Aberration

Near Lens Center

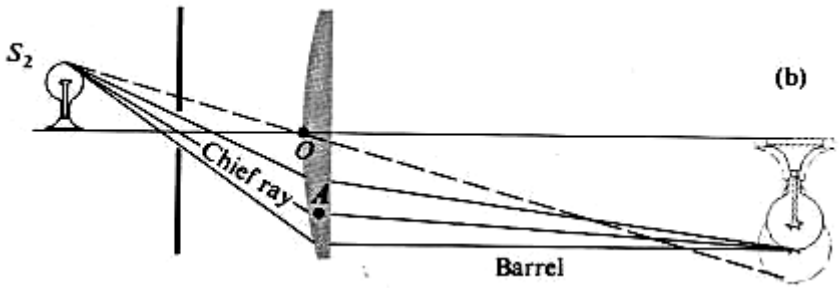
Near Lens Outer Edge

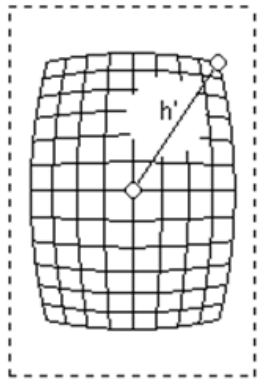
Radial Distortion



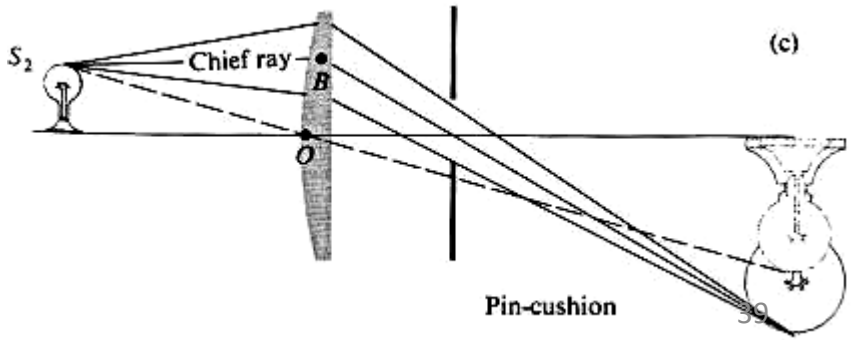


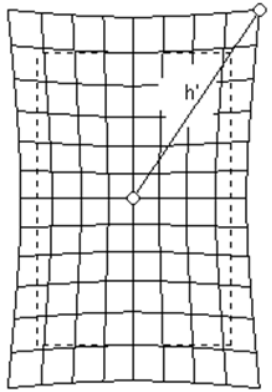
orthoscopic





barrel





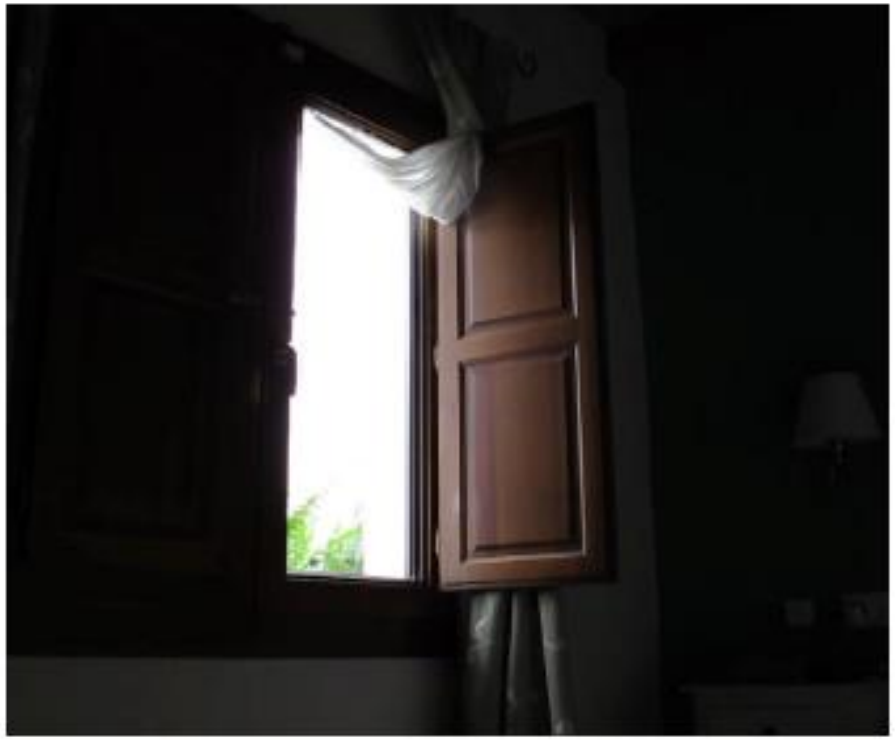
pincushion

Correcting radial distortion

from Helmut Dersch

Questions?

Accidental Pinhole Camera

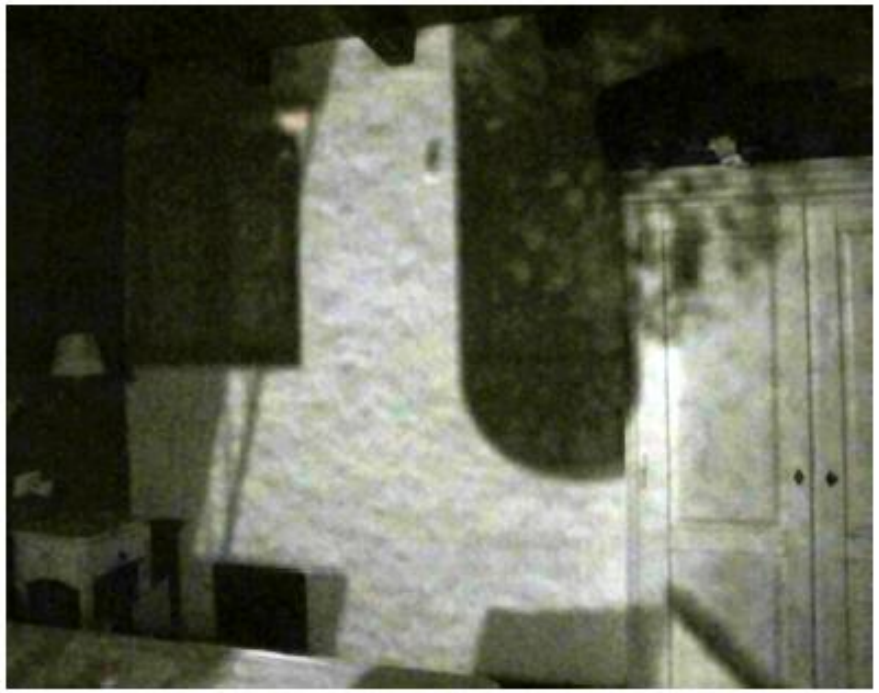


(a) an open window in a room

(b) a picture of the wall opposite the window

Accidental pinhole and pinspeck cameras: revealing the scene outside the picture; Antonio Torralba and William T. Freeman, CVPR 2012

Accidental Pinhole Camera



the same wall when the window is closed, leaving only a small hole

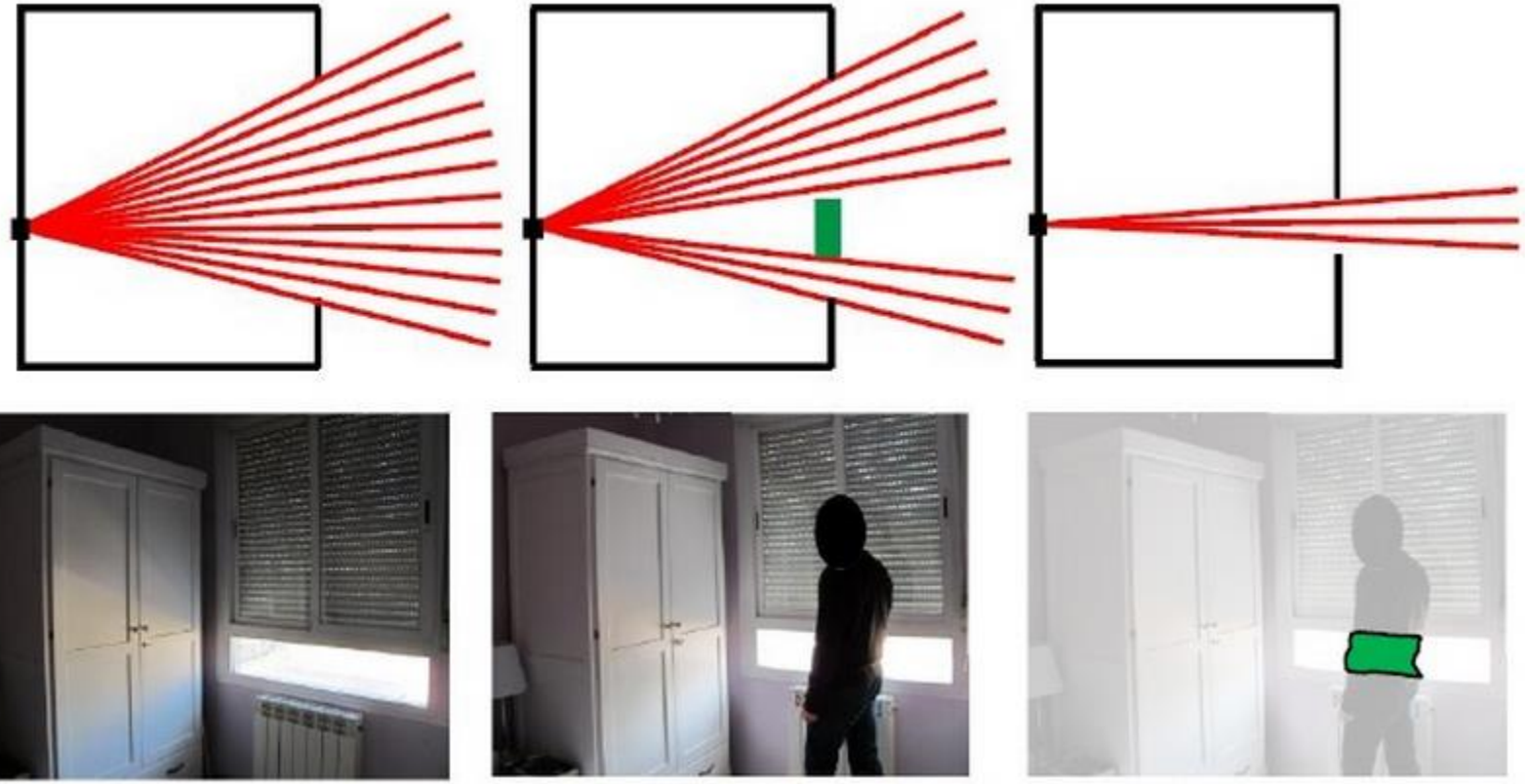
outside of the window

Accidental Pinhole Camera

How can we obtain a clearer picture??

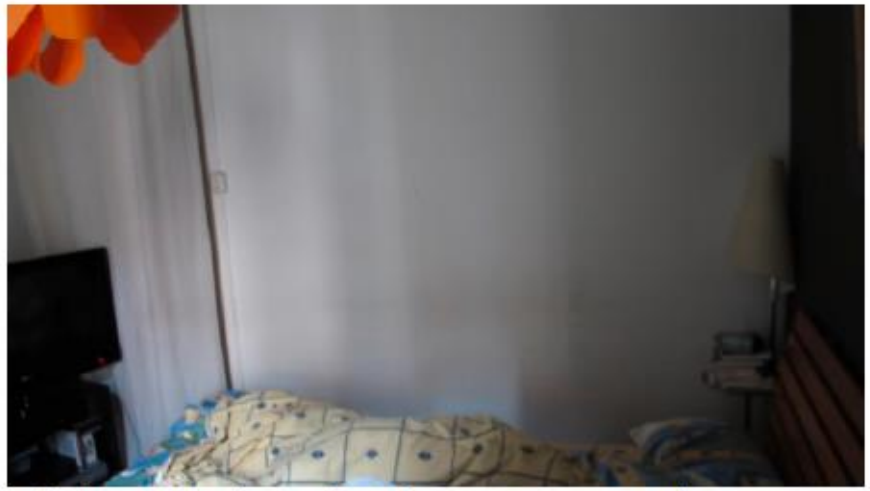
→ How to obtain an image with smaller pinhole??

Accidental Pinhole Camera

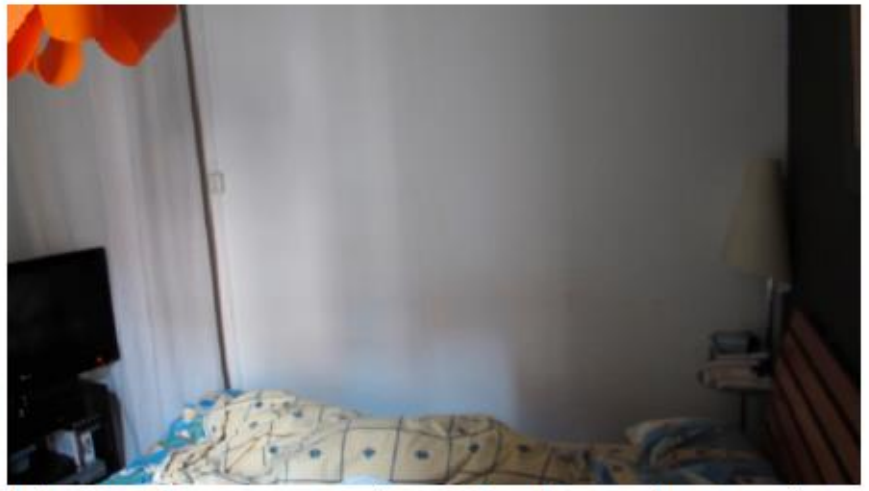


The difference image is the image captured by a camera with the occluder as a pinhole !

Accidental Pinhole Camera



a) Input (occluder present)



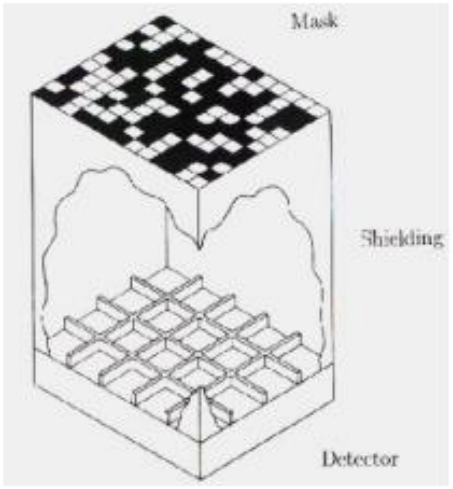
b) Reference (occluder absent)

c) Difference image (b-a)

d) Crop upside down

e) True view

Lensless Camera
(with programmable aperture)

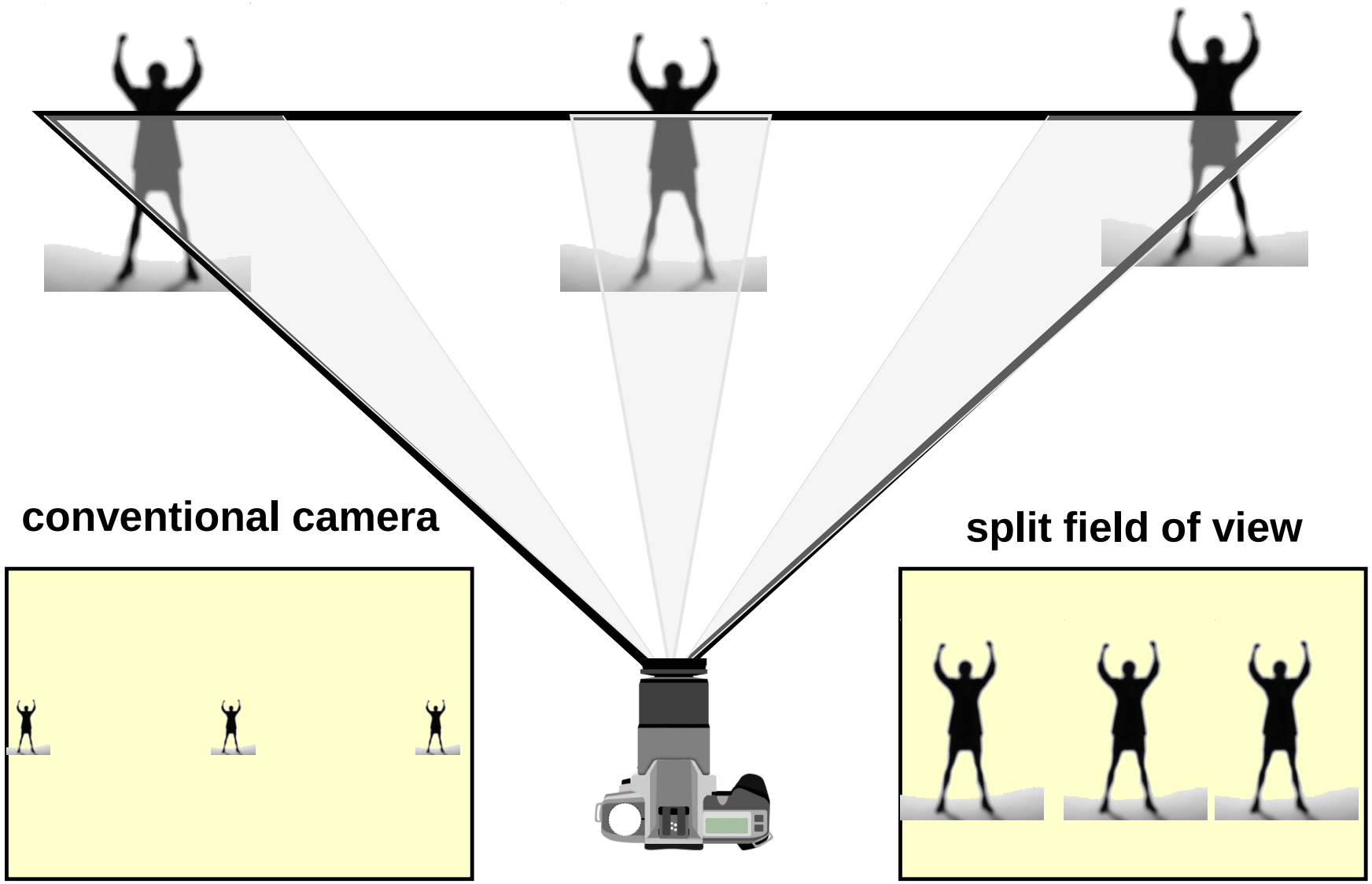


Replace the pinhole with a coded aperture.

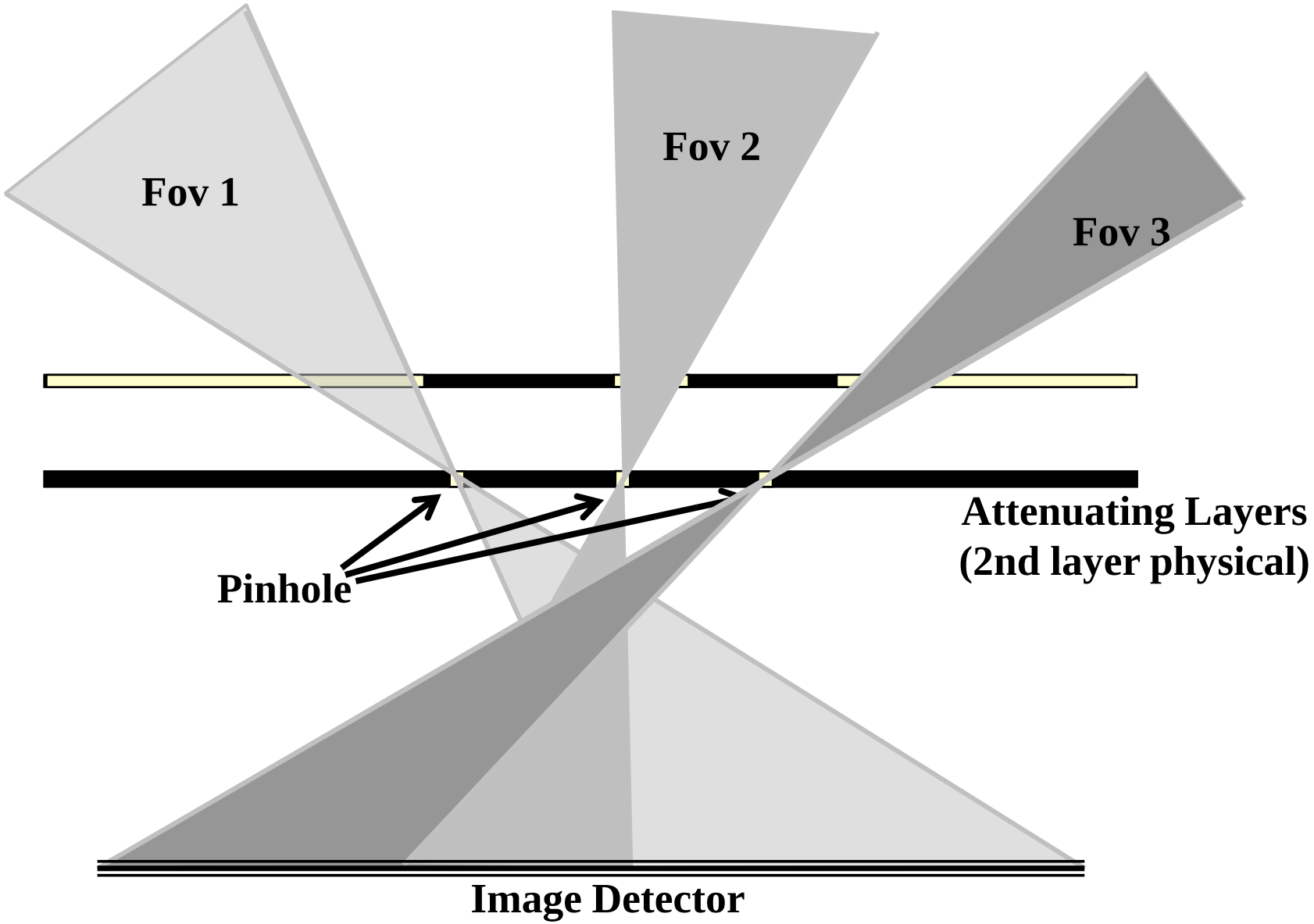
The aperture pattern (a LCD) is programmable.

Lensless Imaging with A Controllable Aperture, Assaf Zomet and Shree Nayar, CVPR 2006

Lensless Camera
(with programmable aperture)



Lensless Camera
(with programmable aperture)



Lensless Camera
(with programmable aperture)

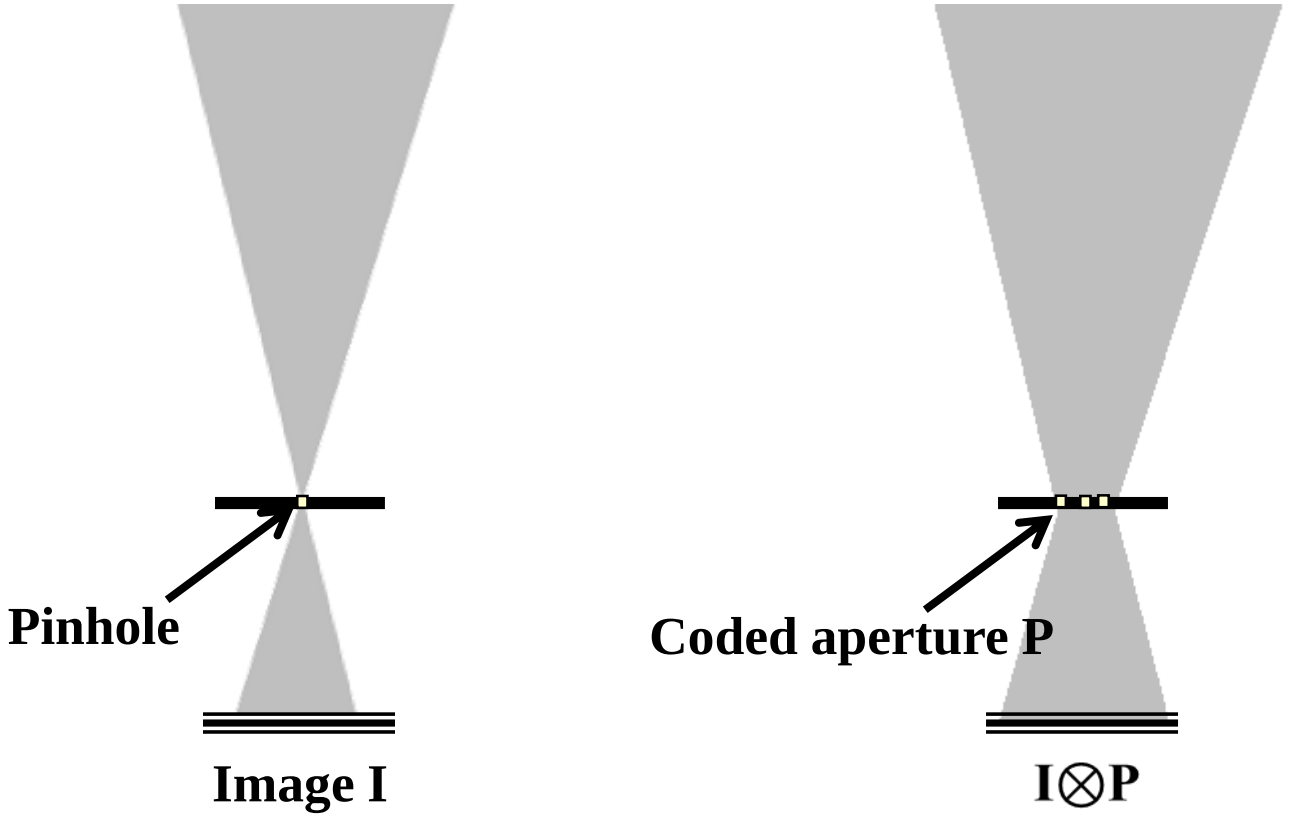
Conventional camera

This novel camera

Split field of view

Lensless Camera
(with programmable aperture)

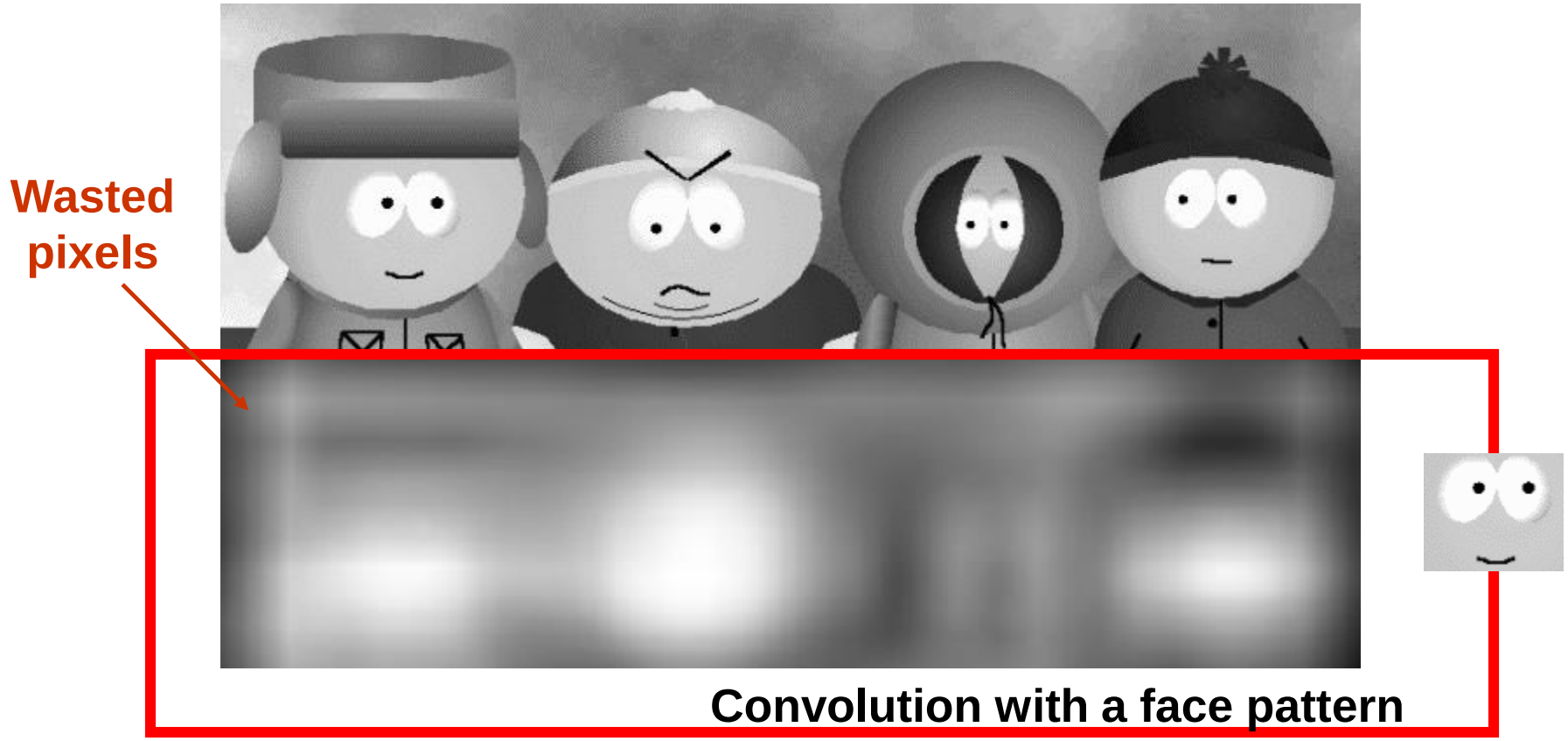
optical convolution



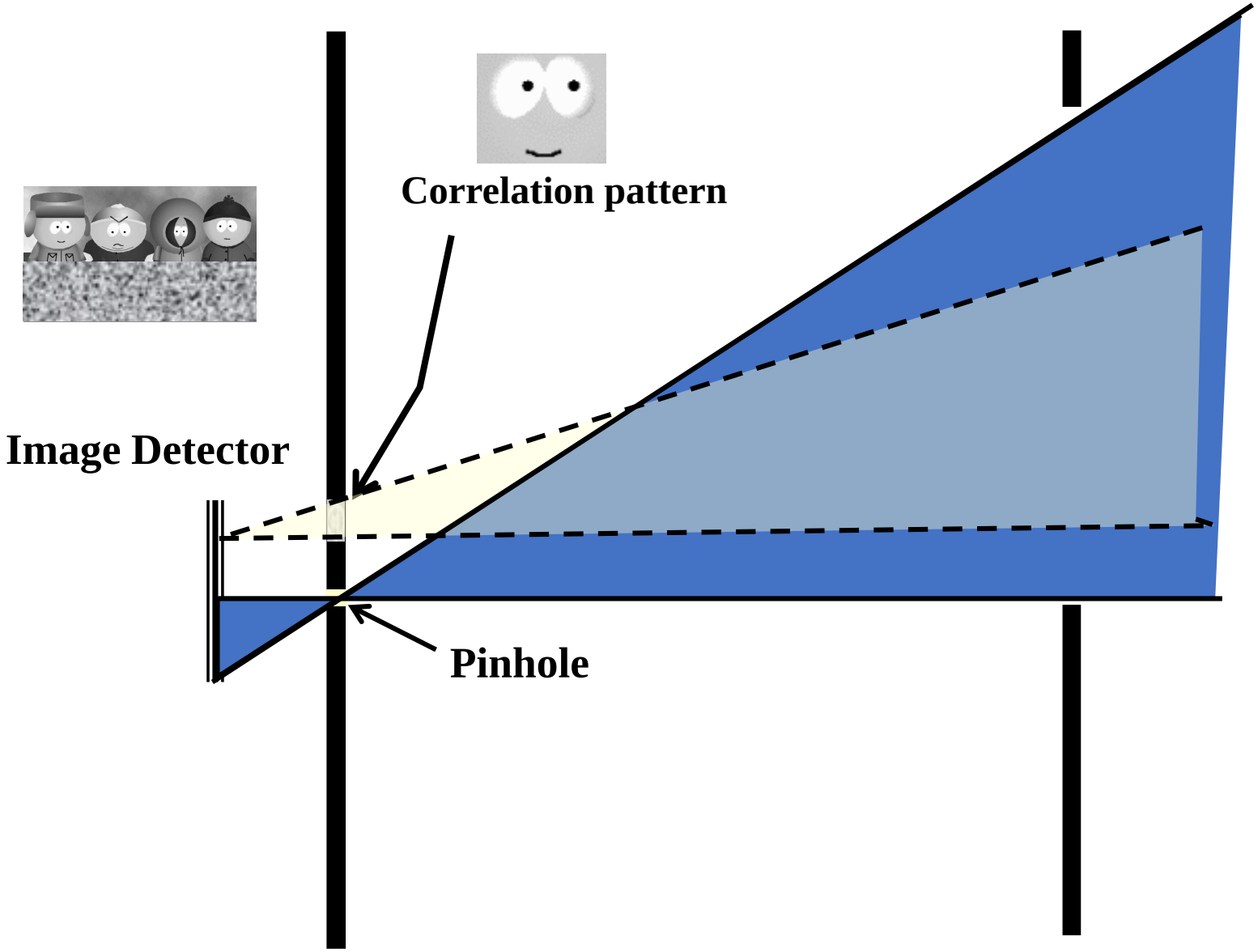
Put a coded pattern at the pinhole
The captured image is the convolution of the pattern with the original image (optical convolution!)

Lensless Camera
(with programmable aperture)

Face detection by convolution



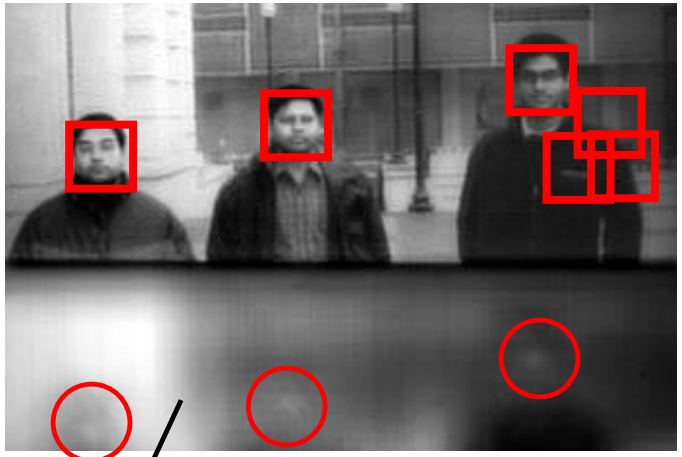
Lensless Camera
(with programmable aperture)



Lensless Camera
(with programmable aperture)

Conventional camera

This novel camera



Normalized correlation:

$$d(I,P,x,y) \propto \frac{\sum_{u,v} I(x+u,y+v)P(u,v)}{\sqrt{\sum_{u,v} I^2(x+u,y+v)}}$$

Image **Pattern**

Correlation Pattern

See original paper for more details

Questions?