# Machine Vision: Image Acquisition

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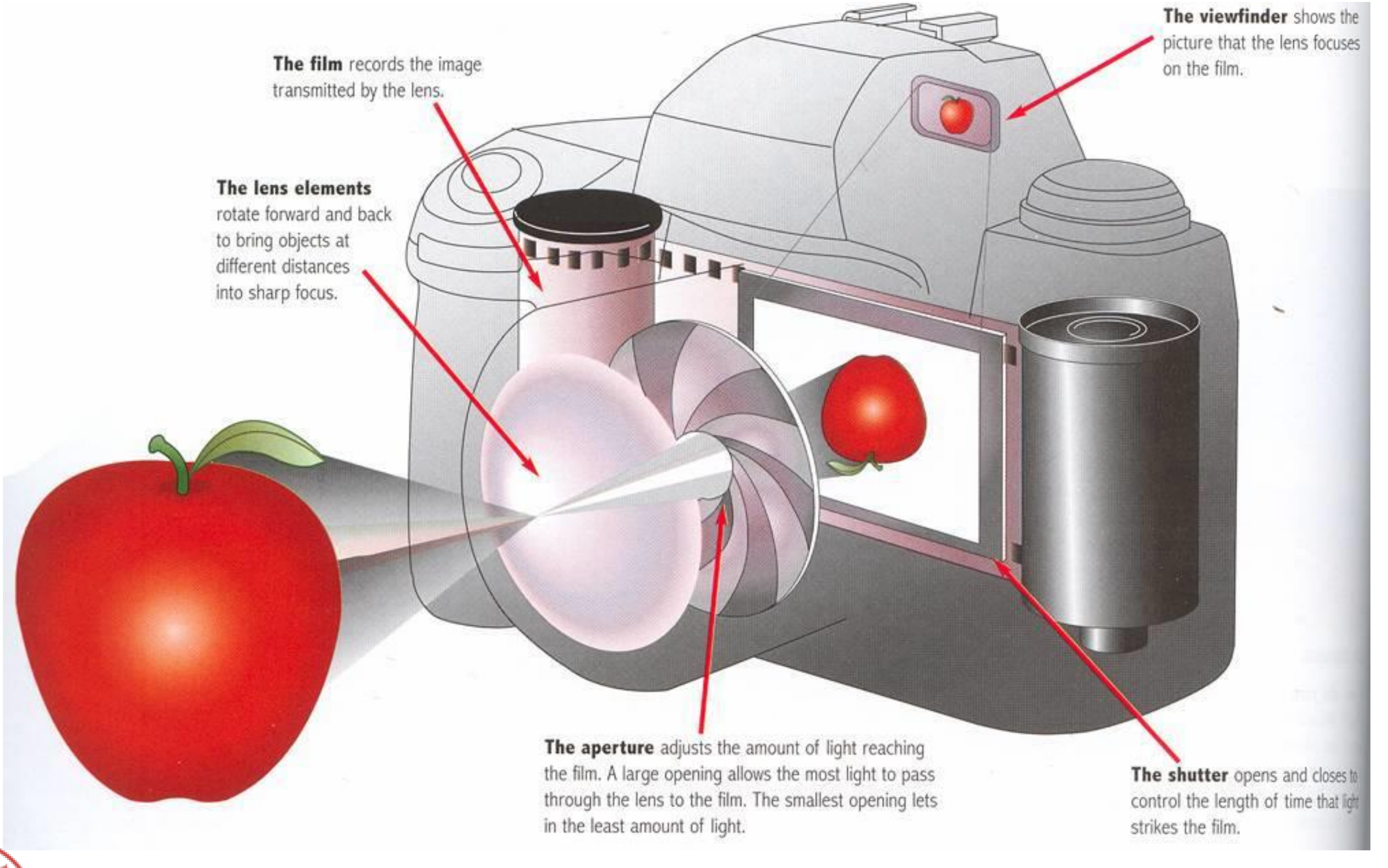
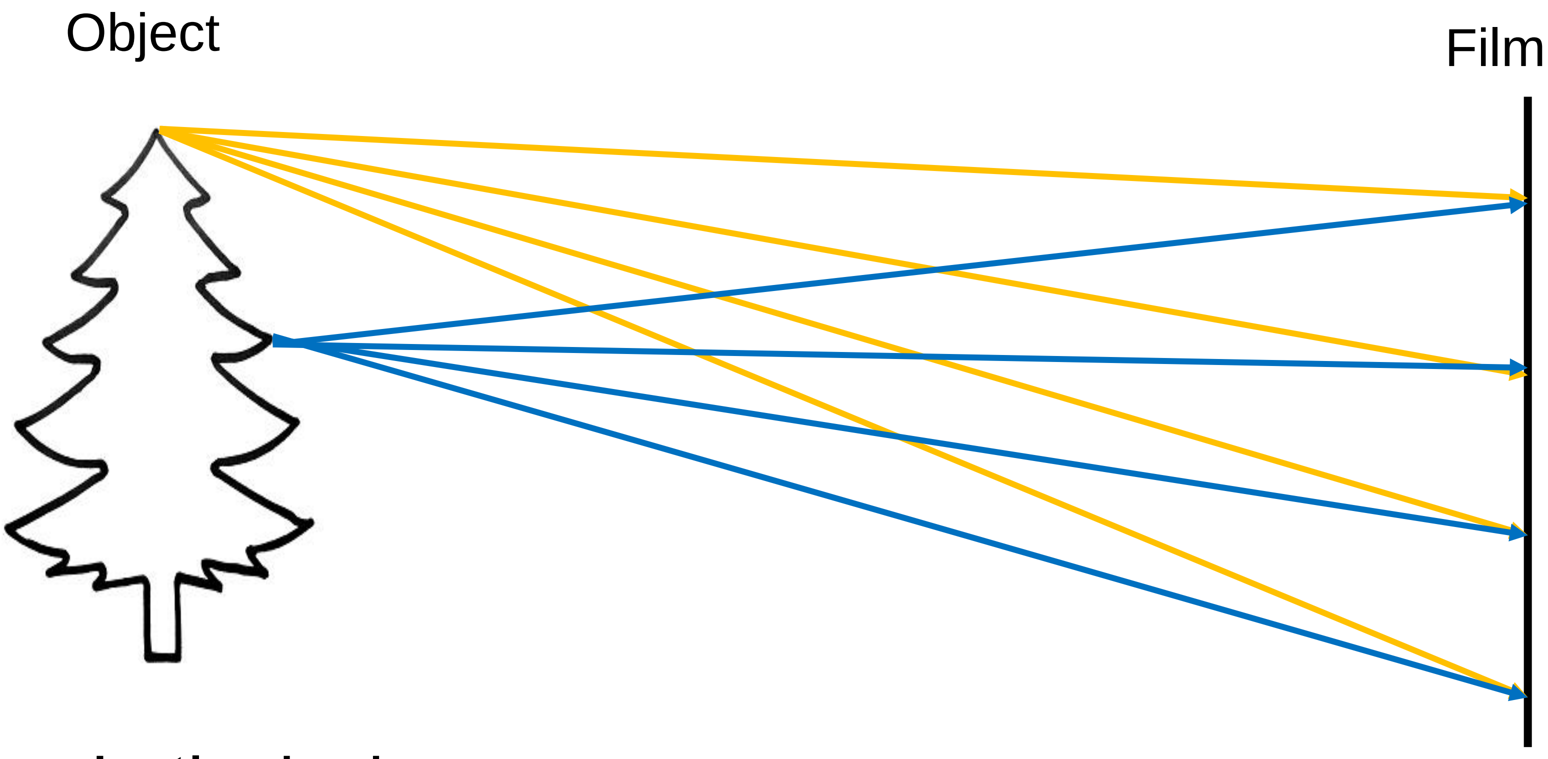
# Cameras

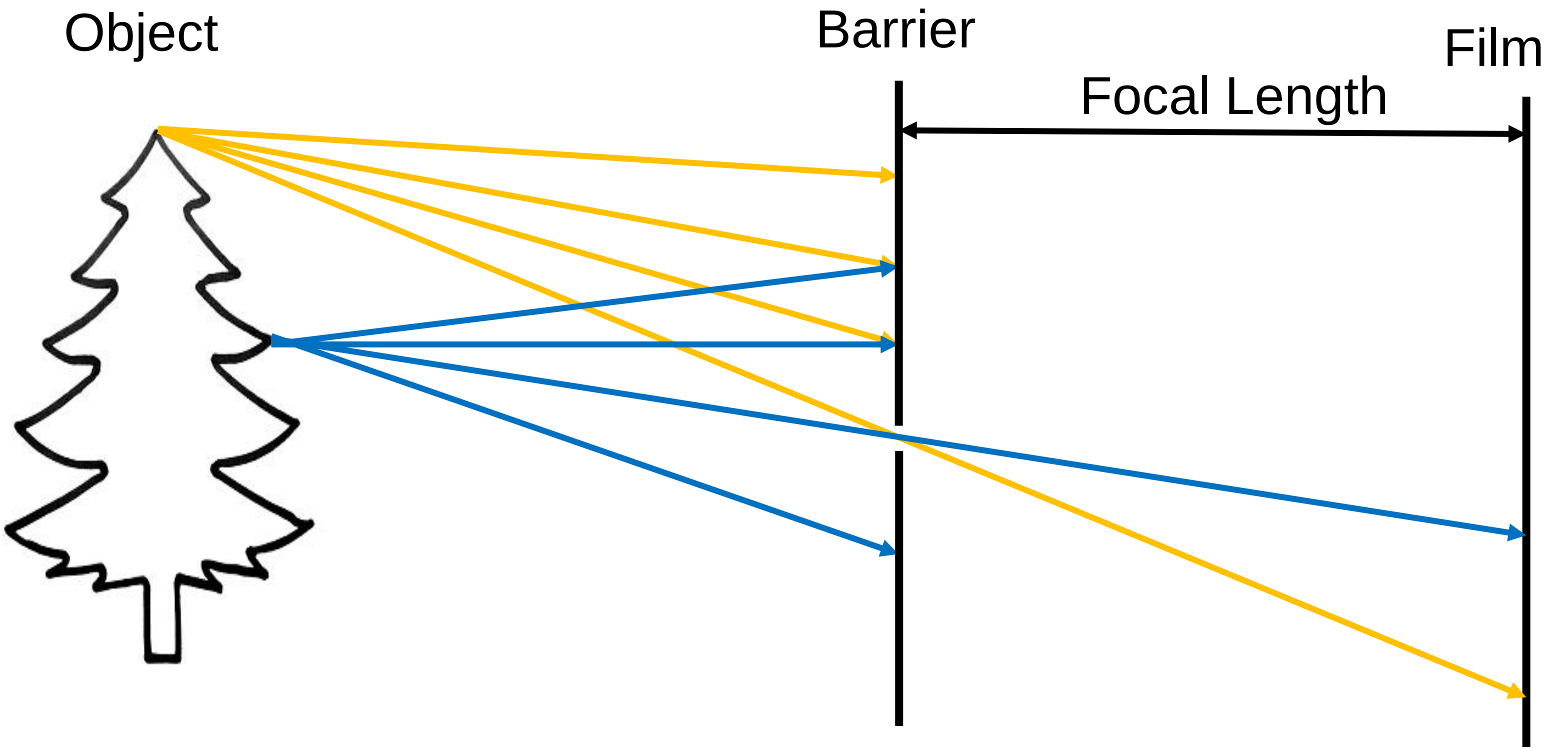

The viewfinder shows the picture that the lens focuses on the film.
The film records the image transmitted by the lens.
The lens elements rotate forward and back to bring objects at different distances into sharp focus.
The aperture adjusts the amount of light reaching the film. A large opening allows the most light to pass through the lens to the film. The smallest opening lets in the least amount of light.
The shutter opens and closes to control the length of time that light strikes the film.

# 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?

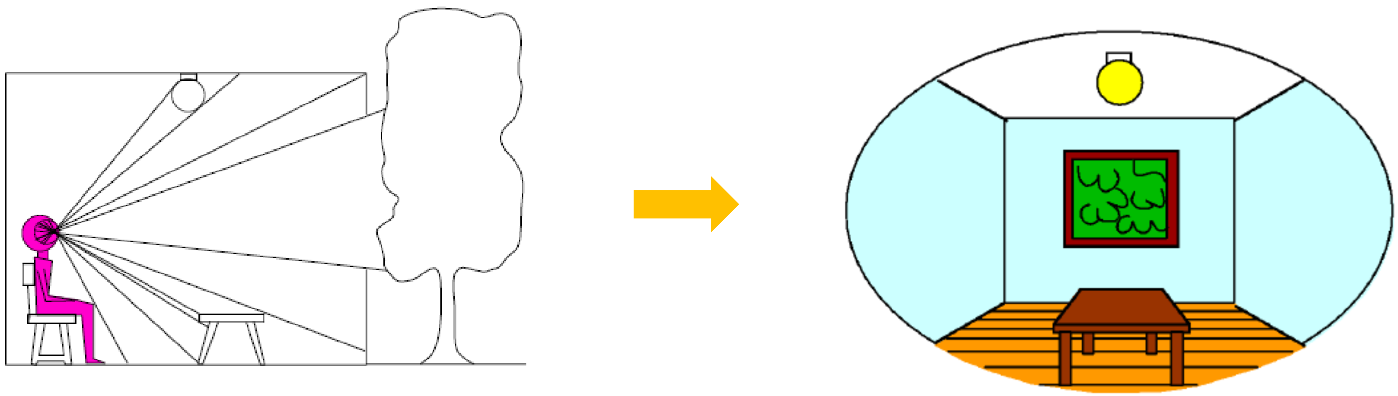
# Image formation




- 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?

# Dimensionality Reduction Machine (3D to 2D)

3D world 2D image



Point of observation

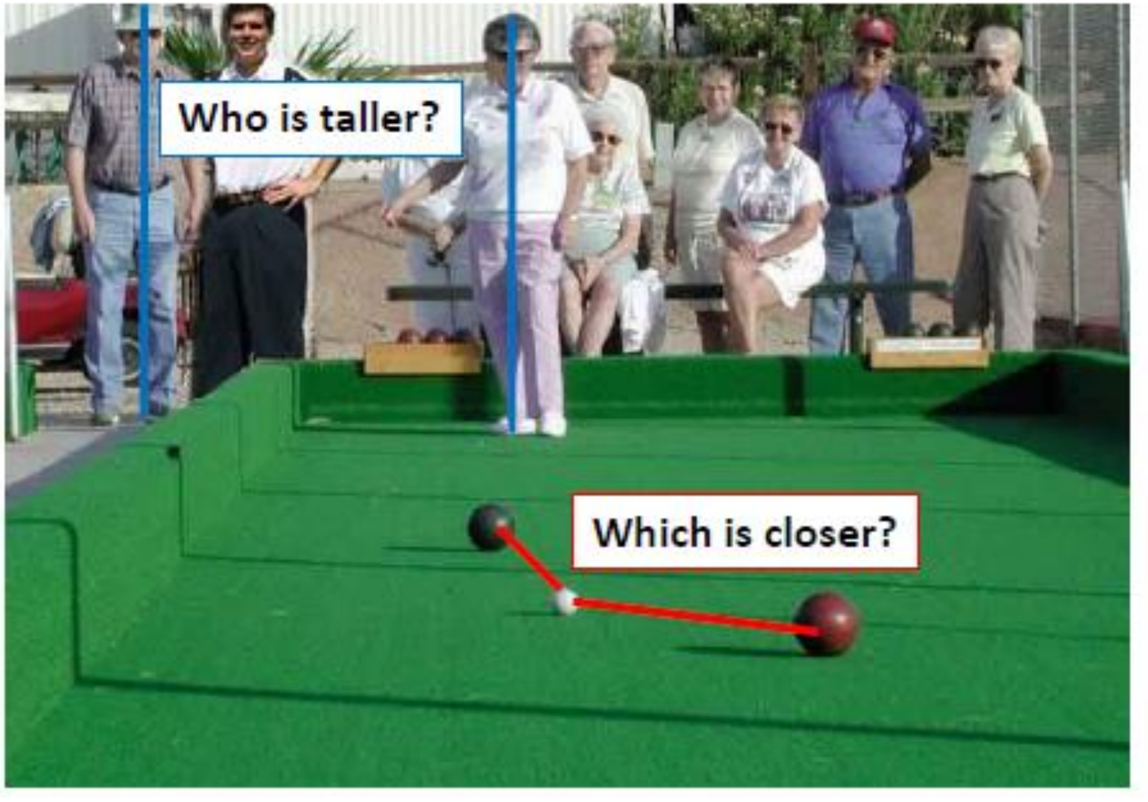
- We capture a 2D picture of the 3D world, what have we lost?
  - Distances(lengths)
  - Angles

# Dimensionality Reduction Machine (3D to 2D)

- Projection can be tricky…

# Dimensionality Reduction Machine (3D to 2D)

- What is lost?
  ----Length



# Dimensionality Reduction Machine (3D to 2D)

- Length is not preserved

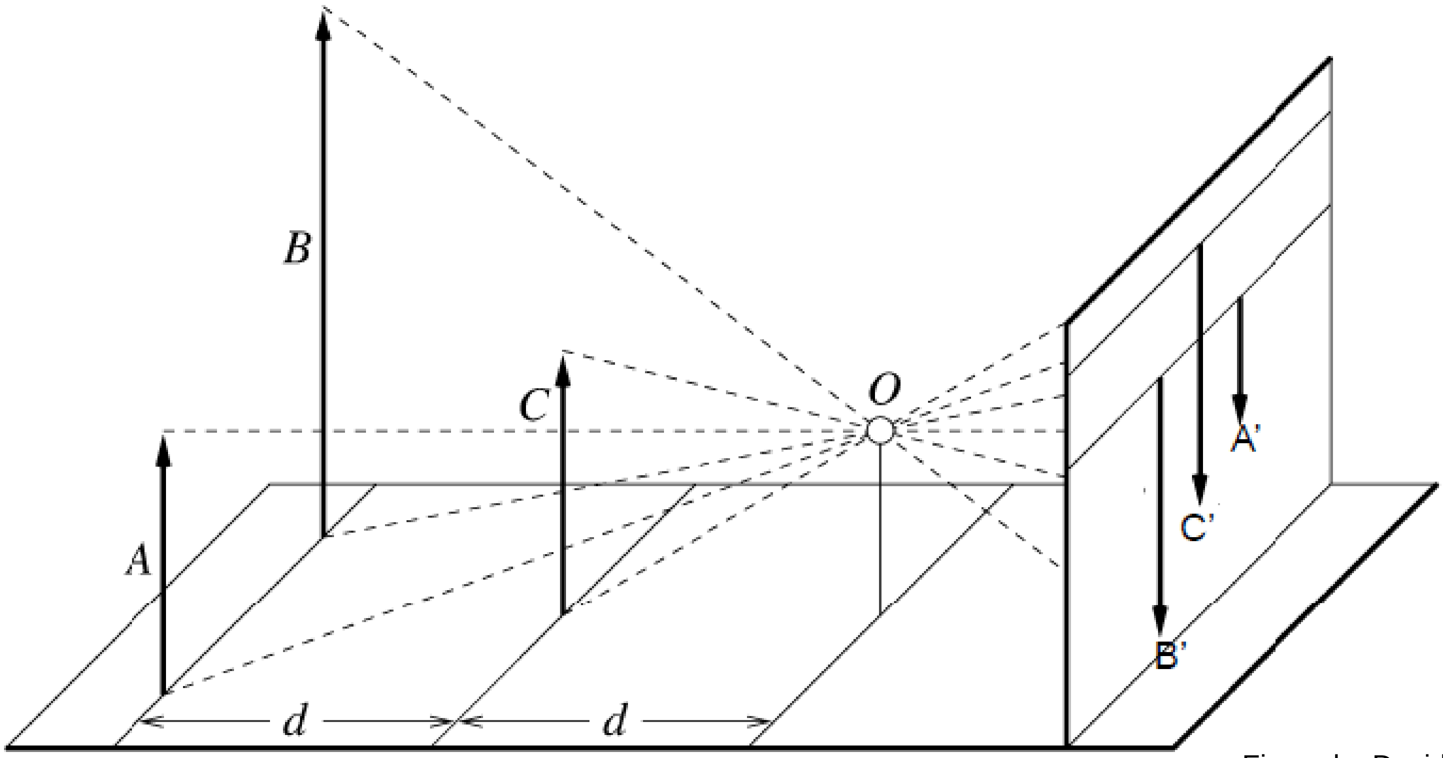
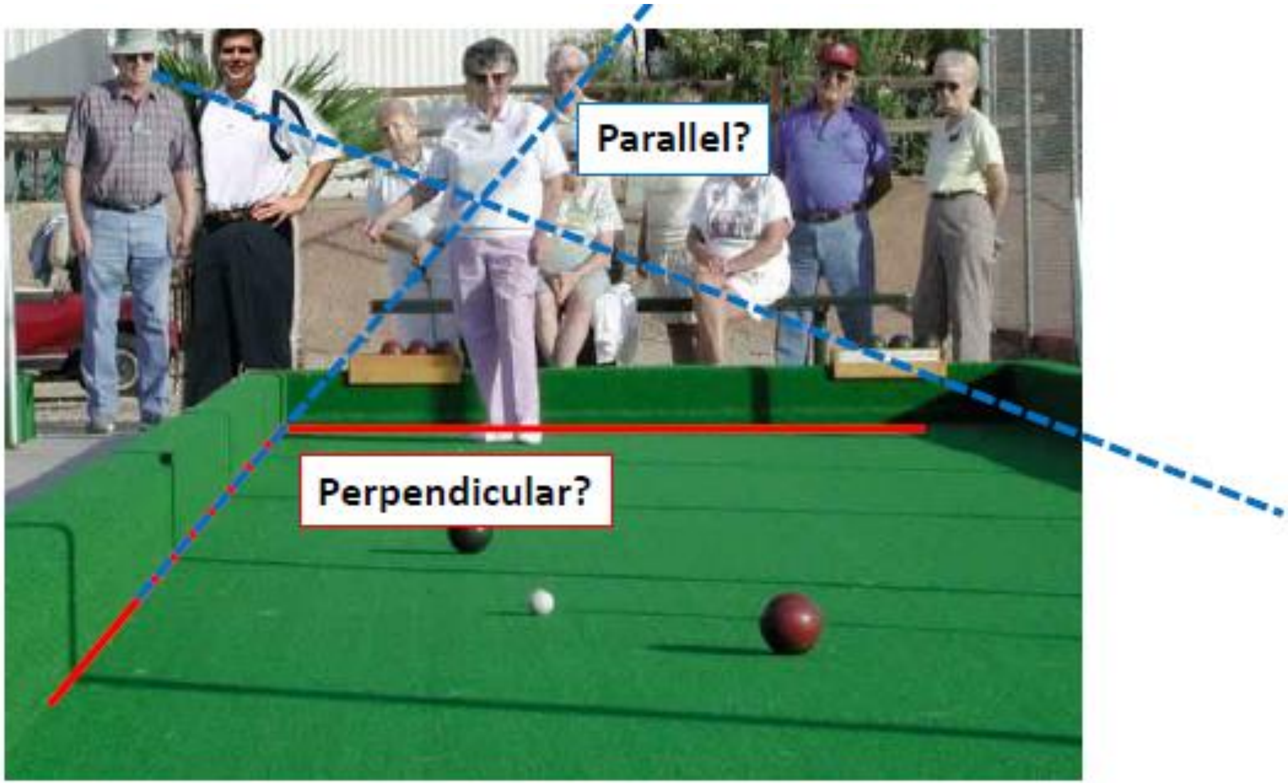



Figure by David Forsyth

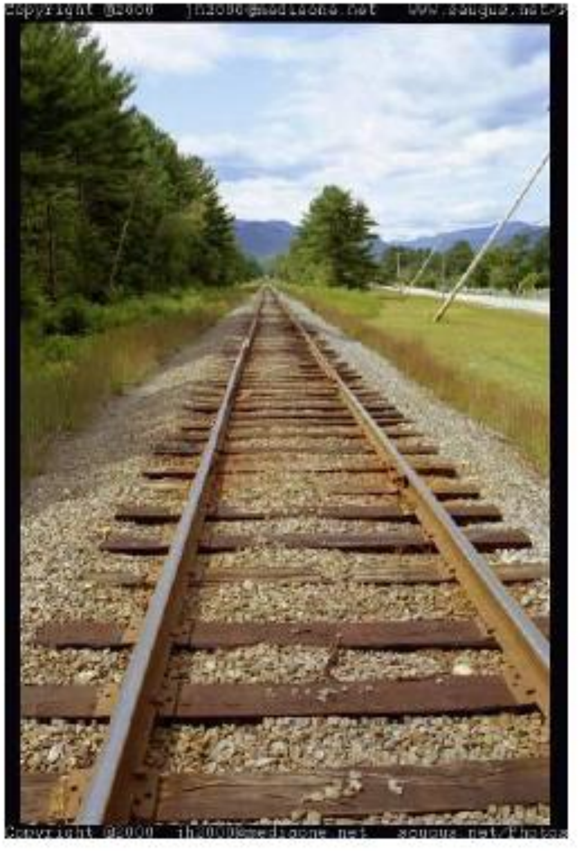
# Dimensionality Reduction Machine (3D to 2D)

- What is lost?
  ----Length
  ----Angles



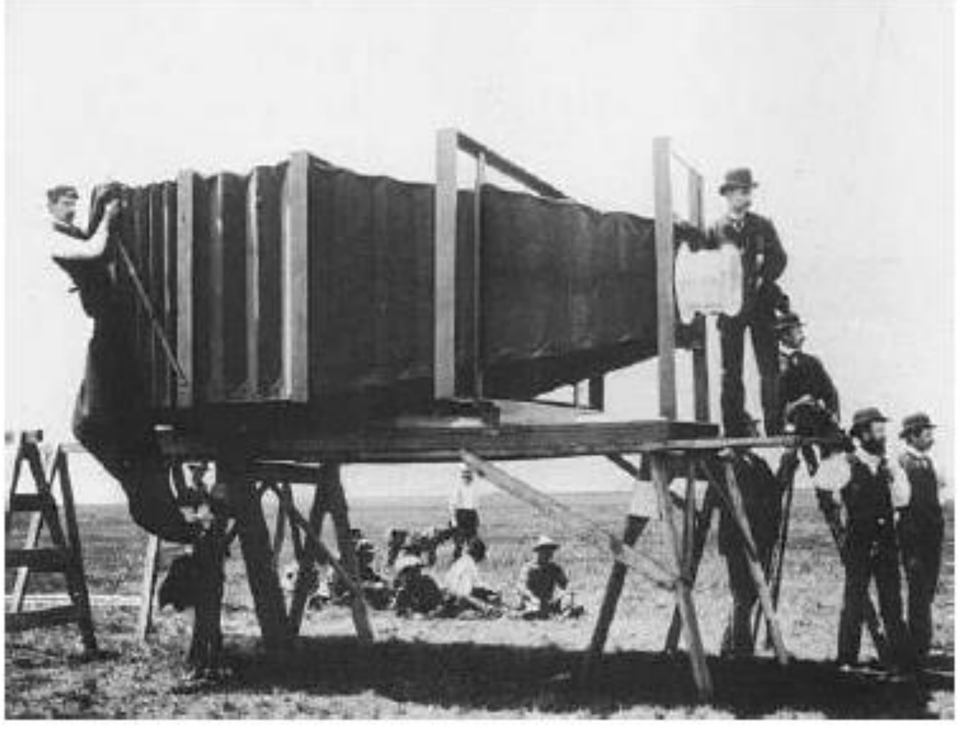
# Dimensionality Reduction Machine (3D to 2D)

- Parallel lines in images



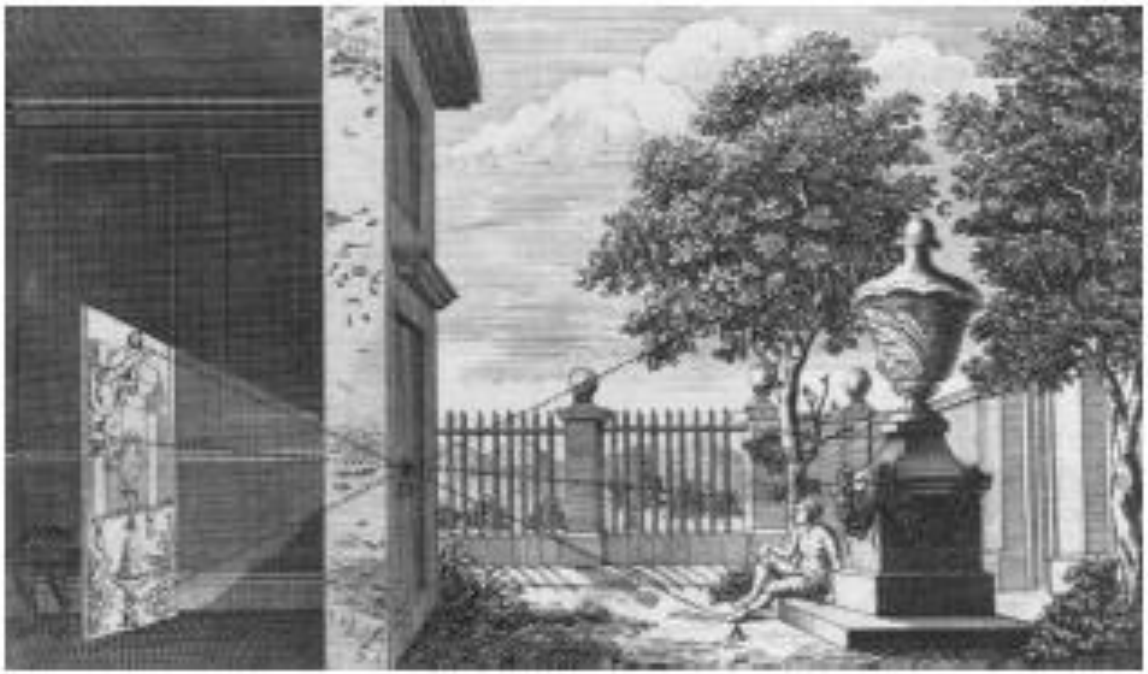
# Building a real camera

# The largest camera (1900)



- In 1900 the Chicago & Alton Railroad Train co. , commissioned Lawrence with the manufacture of the largest camera ever made and the largest photo ever shot in order to promote a new train.

# Building a real 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)

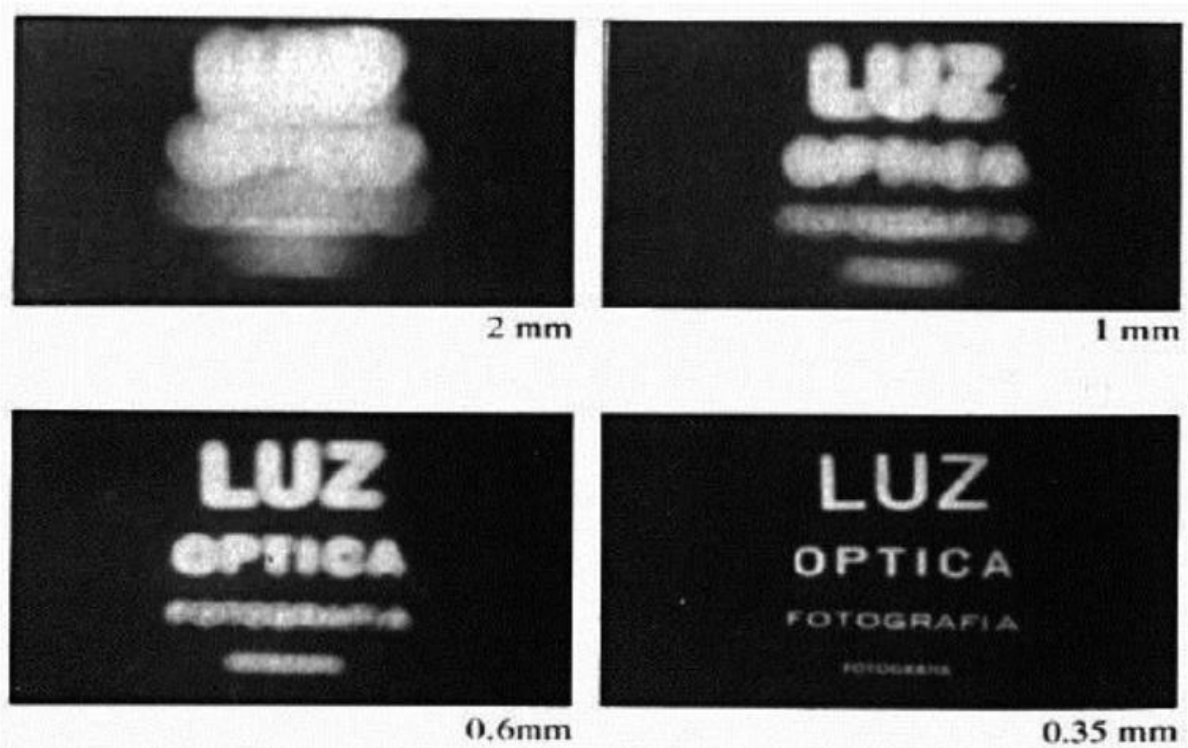
# Home-made pinhole camera

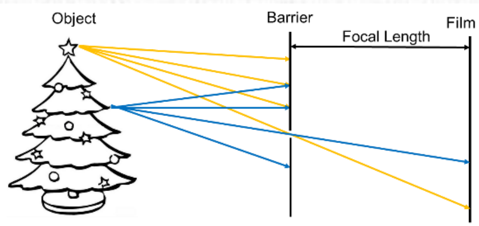

35mm-pinhole-camera

Why so blurry?

http://www.pauldebevec.com/Pinhole/

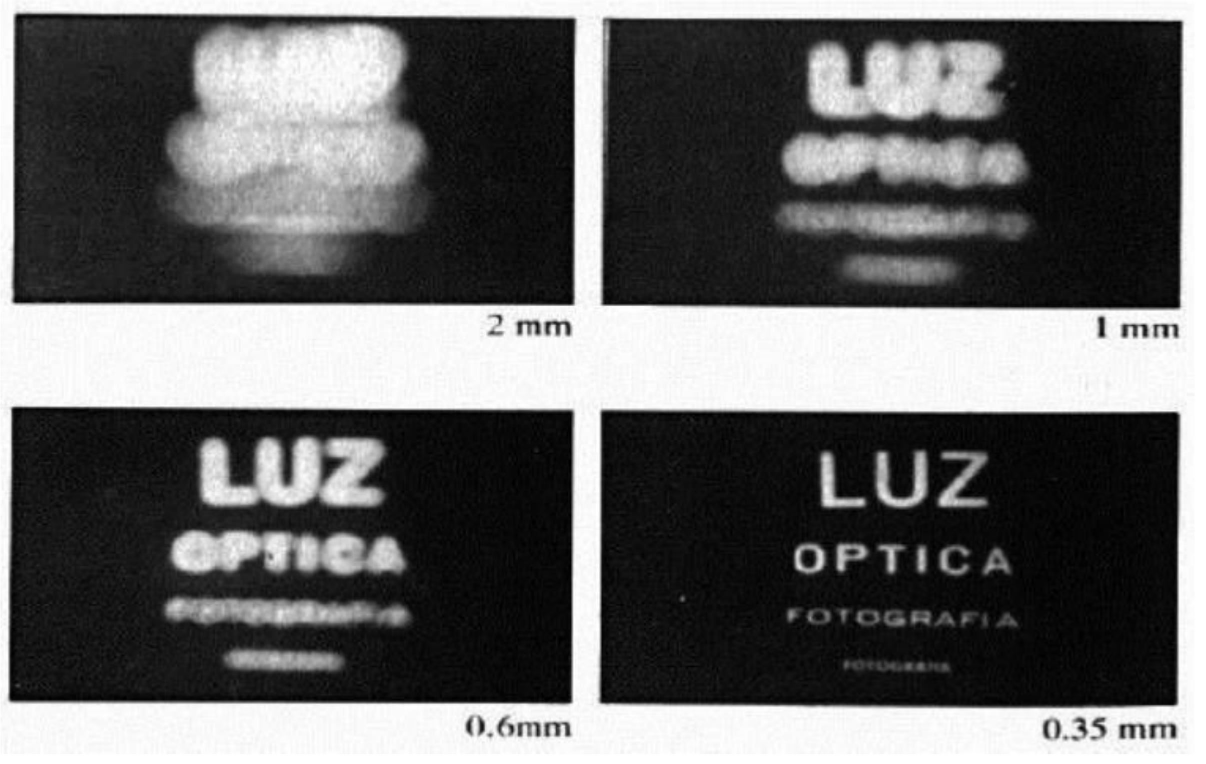
# Shrinking the aperture



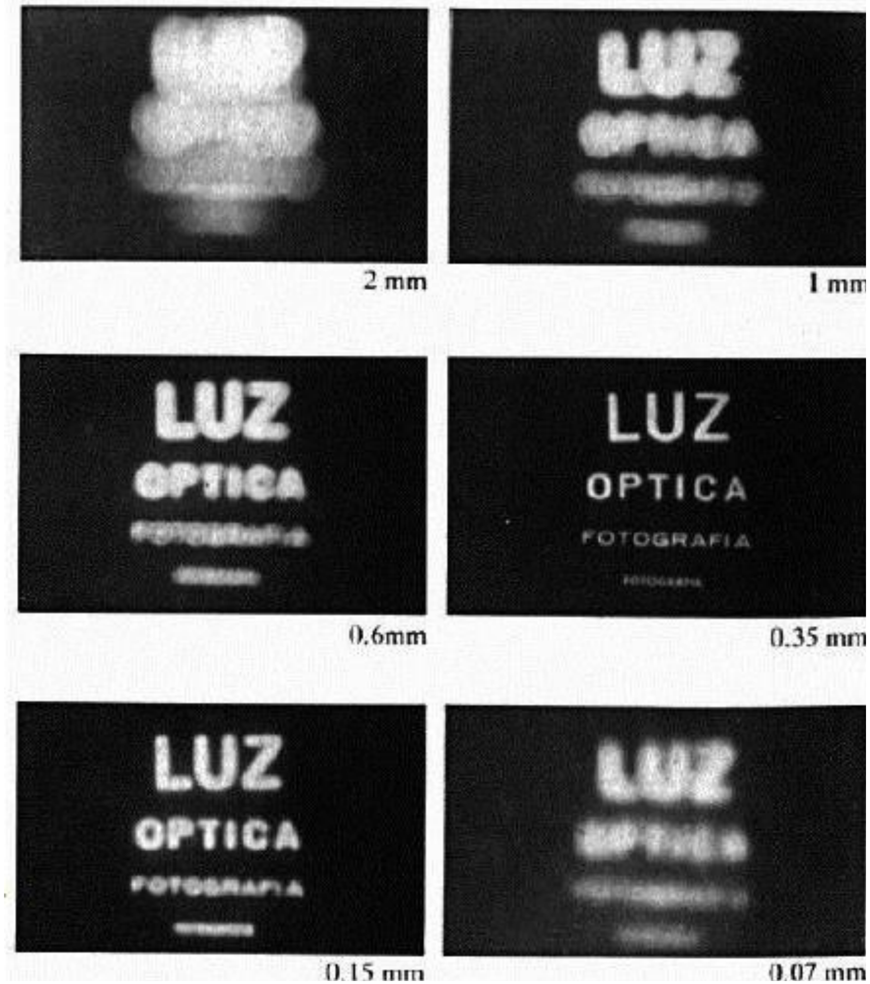

point of spread function

# Shrinking the aperture

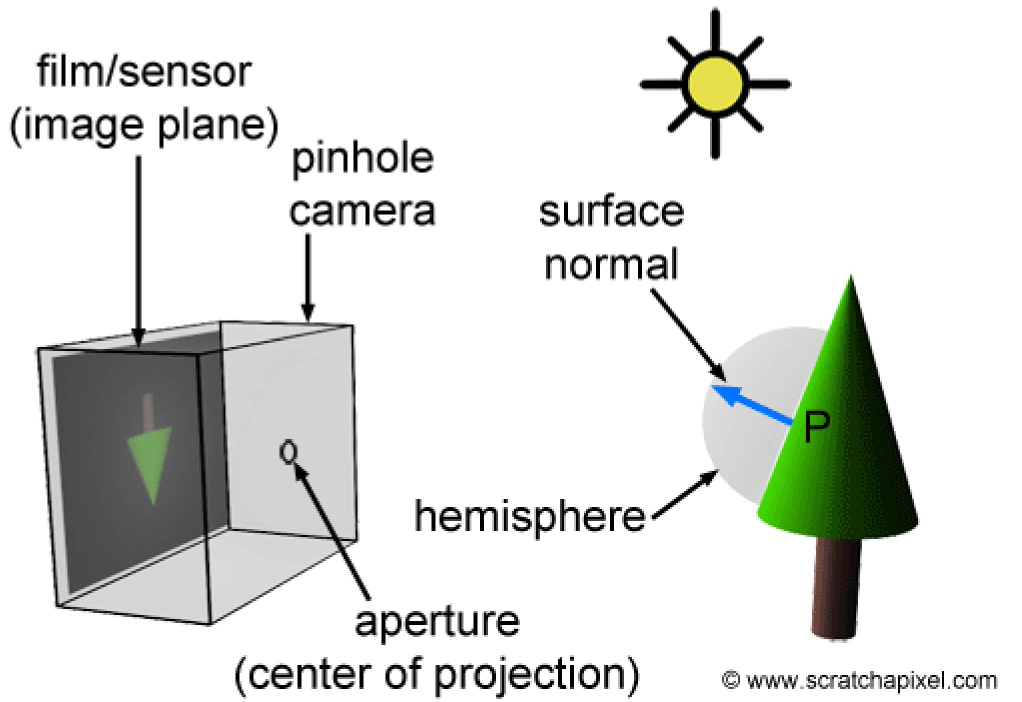



- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects

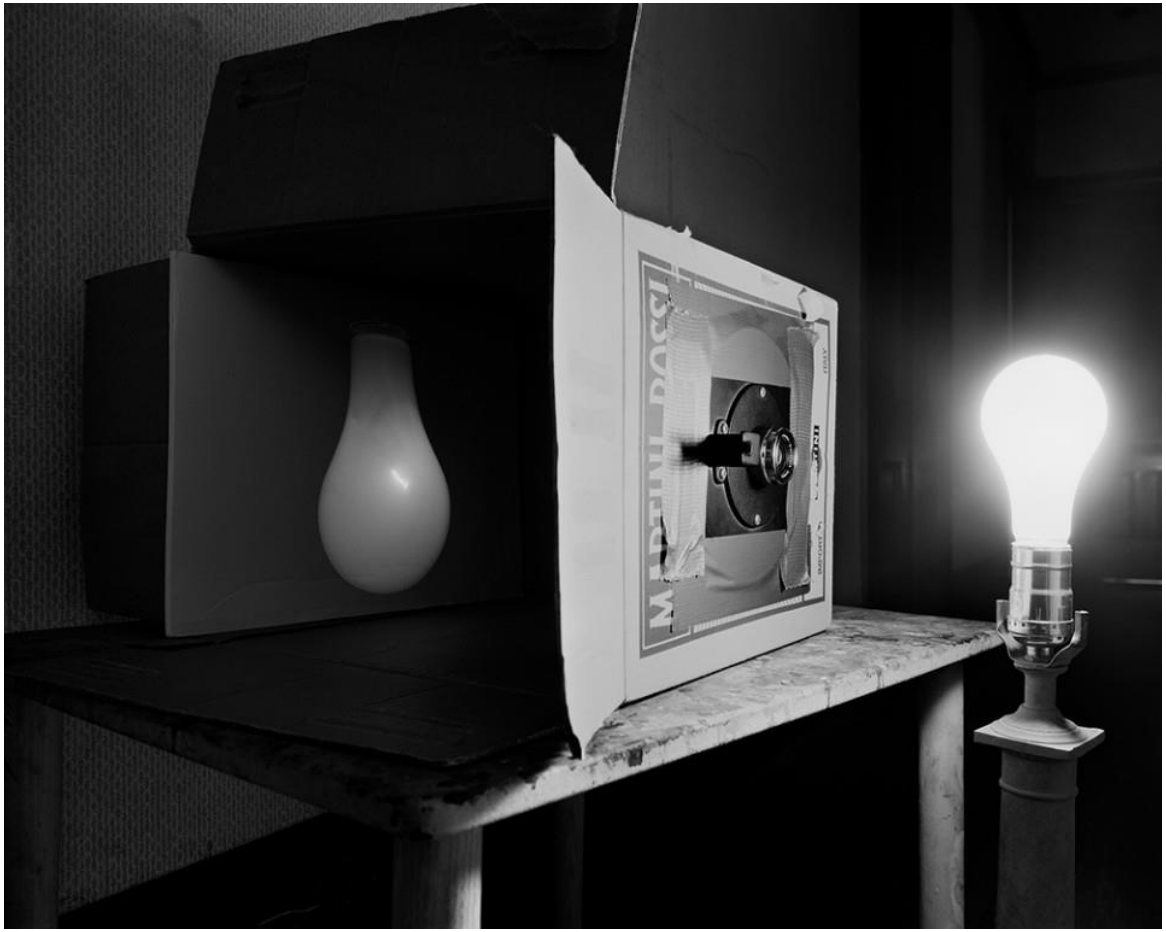
# Shrinking the aperture



# How to make a pinhole camera

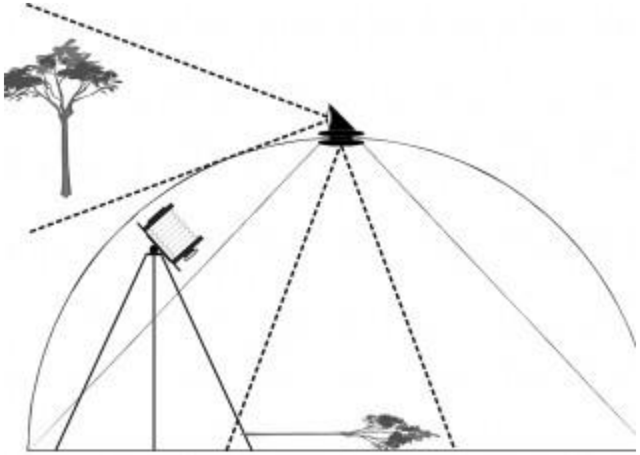


# How to make a pinhole camera

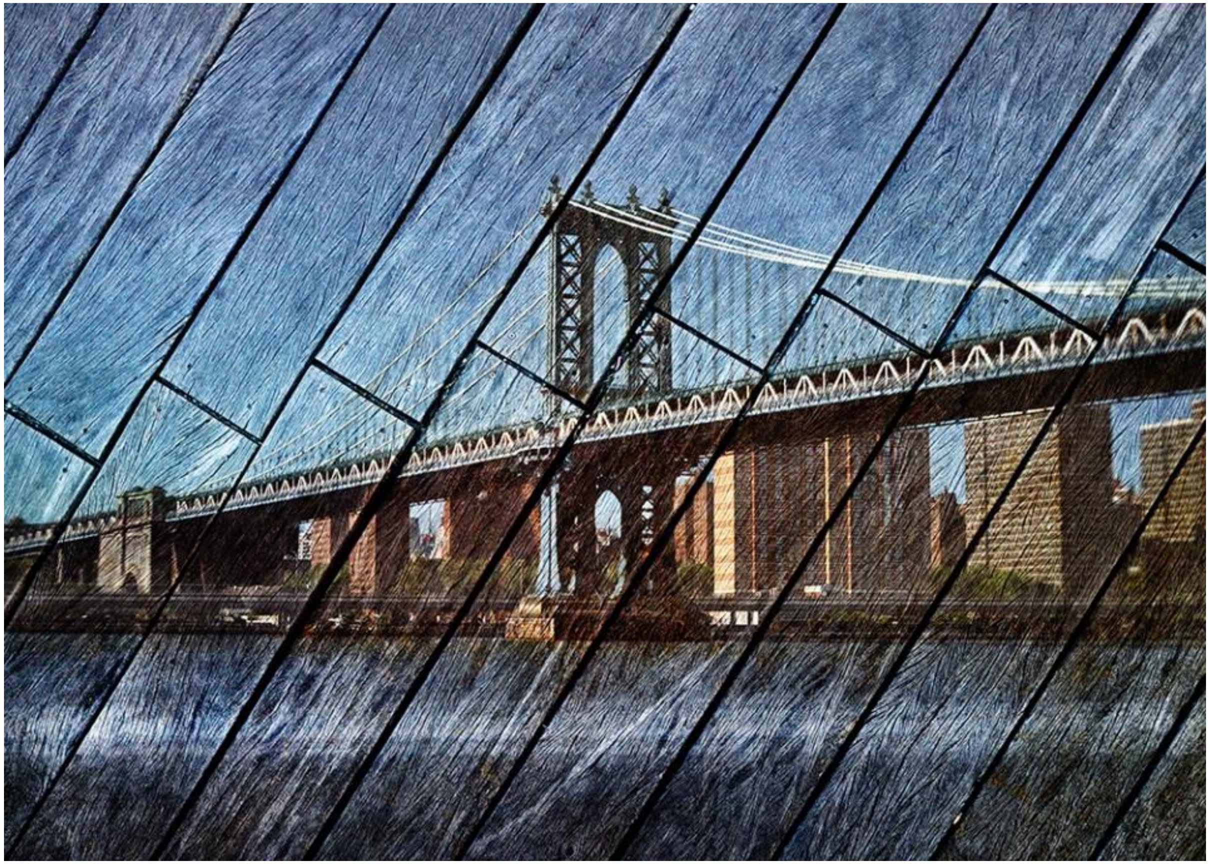


# How to make a pinhole camera

Camera Obscura: View of Toledo in Hotel Room, Toledo, Spain, 2013



Tent-Camera Diagram, Tent-Camera Production Shot, Tent-Camera Image: Pond in Hampstead Heath. London, England, 2017

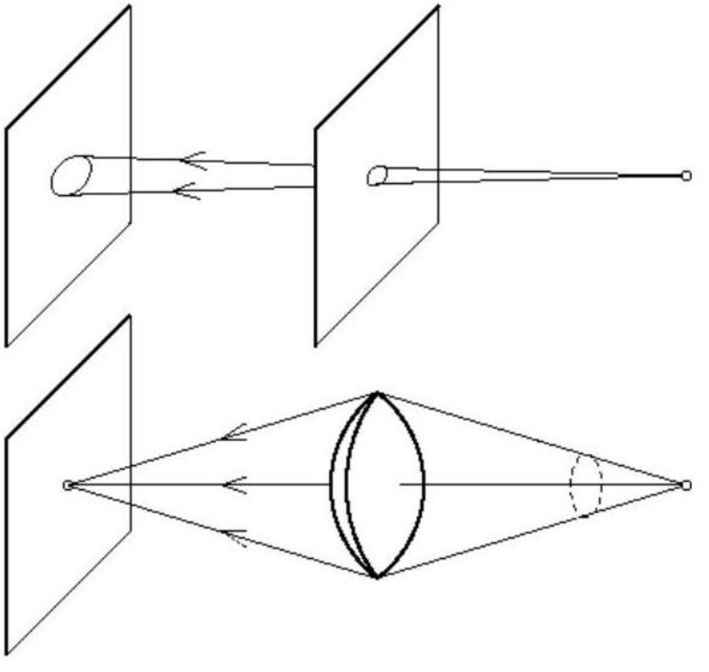


Tent-Camera Image on the Ground: View of the Manhattan Bridge on Wood Boards, New York, 2015

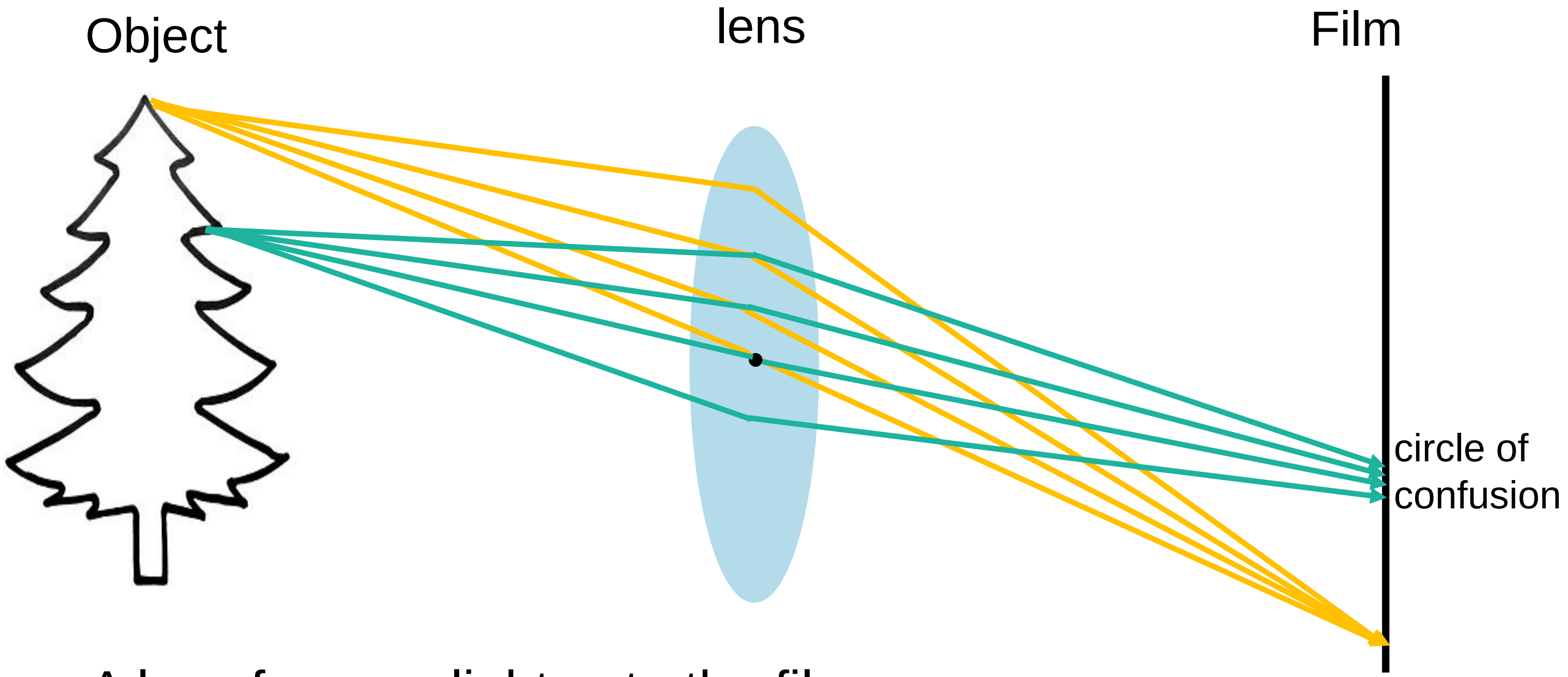
# Reason for lens

# Reason for lenses

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

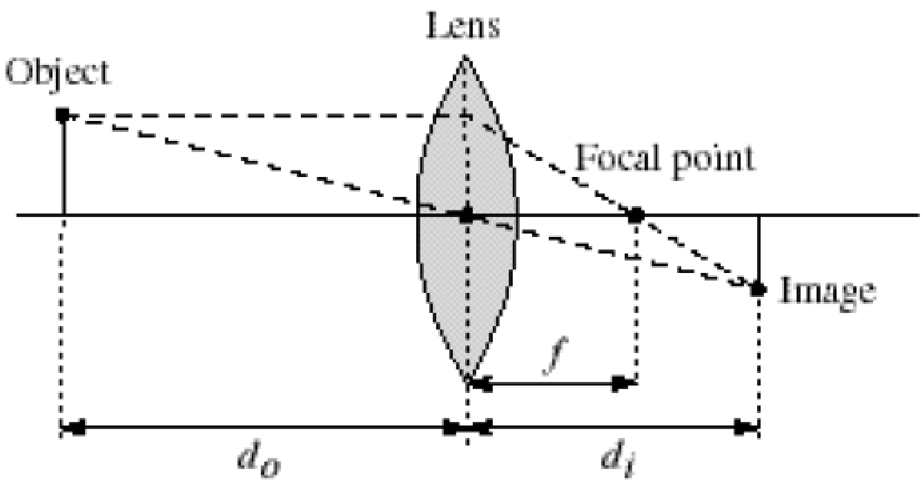


# Problem with lens




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

# Thin lenses



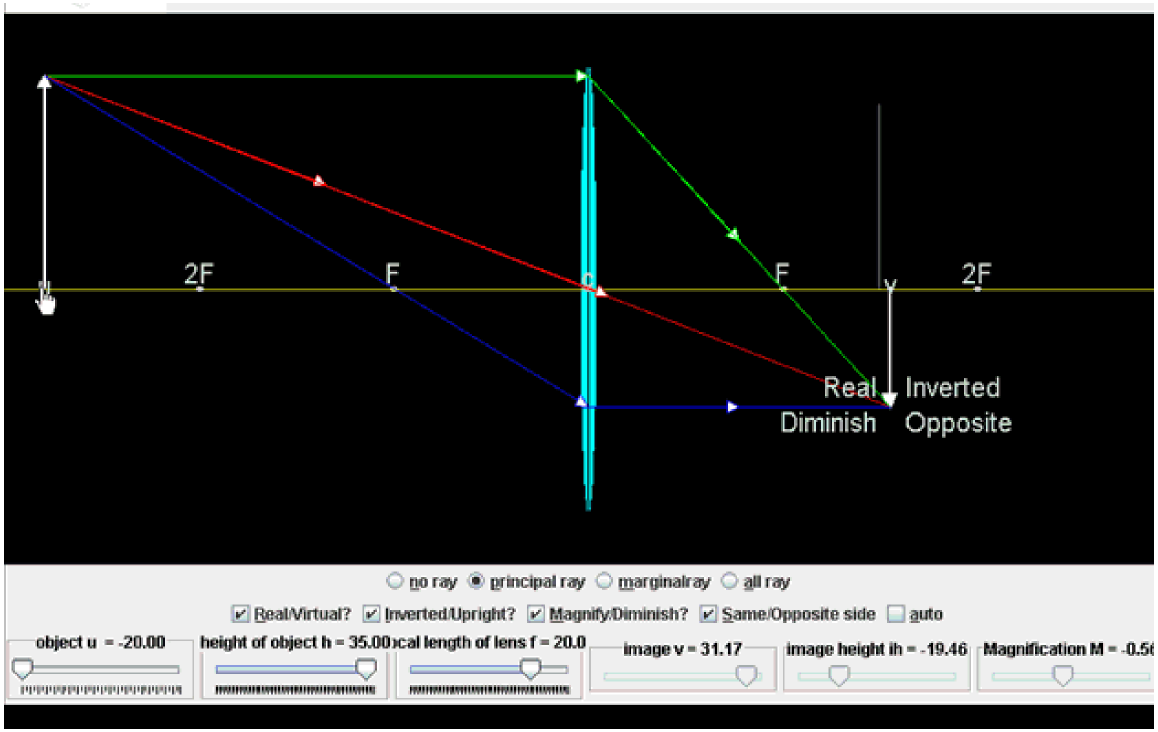

- Thin lens equation:

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

  - Any object point satisfying this equation is in focus
  - How can we change the focus region?

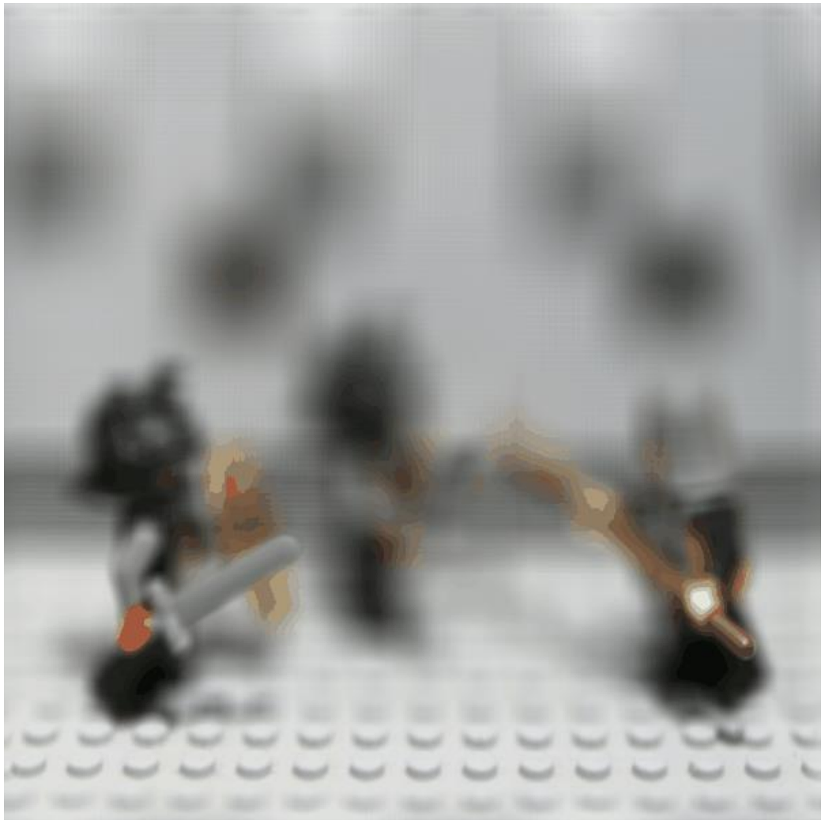
# Varying Focus

- Changing the position of the sensor (image plane)



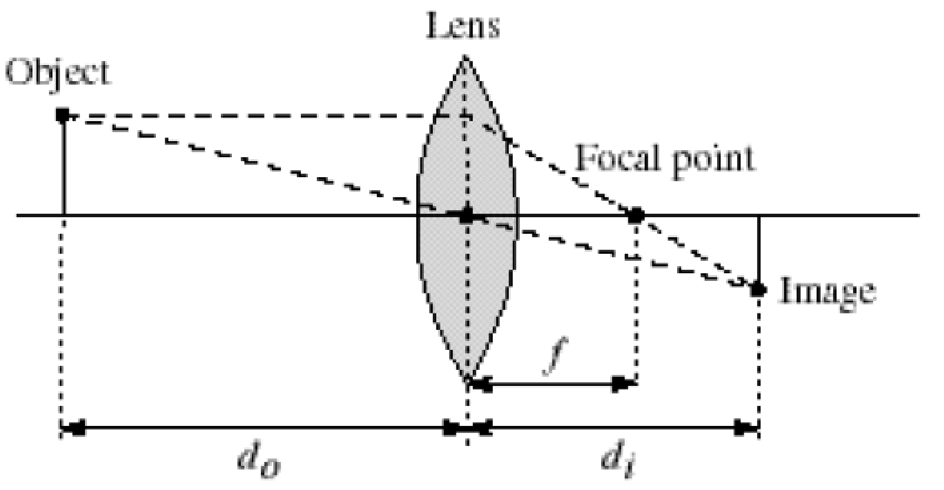
# Varying Focus

- Changing the position of the sensor (image plane)



# Depth of Field

# We have known




- Thin lens equation:

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

  - Any object point satisfying this equation is in focus
  - How can we change the focus region?

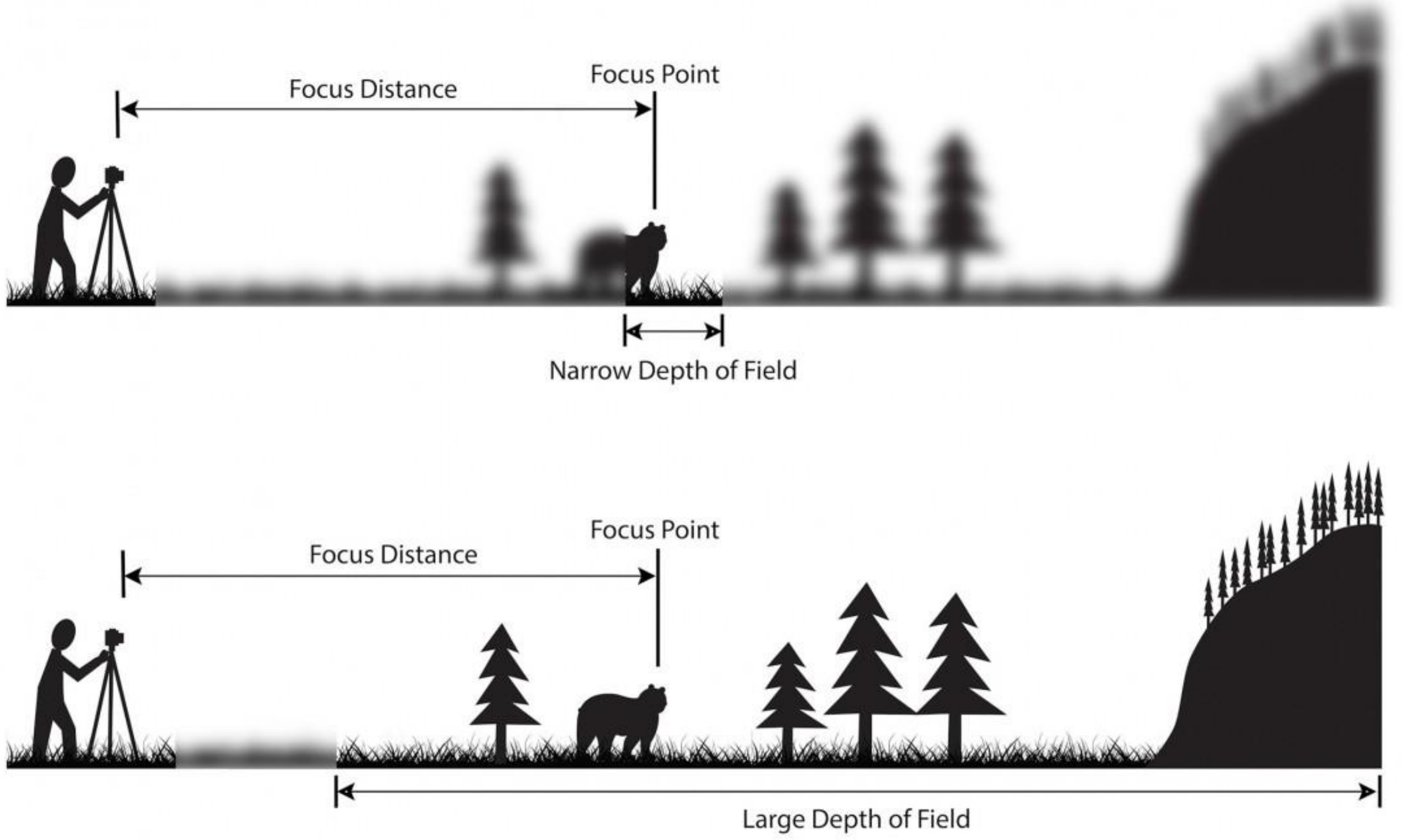
# Depth of Field

- It is not always correct in practice

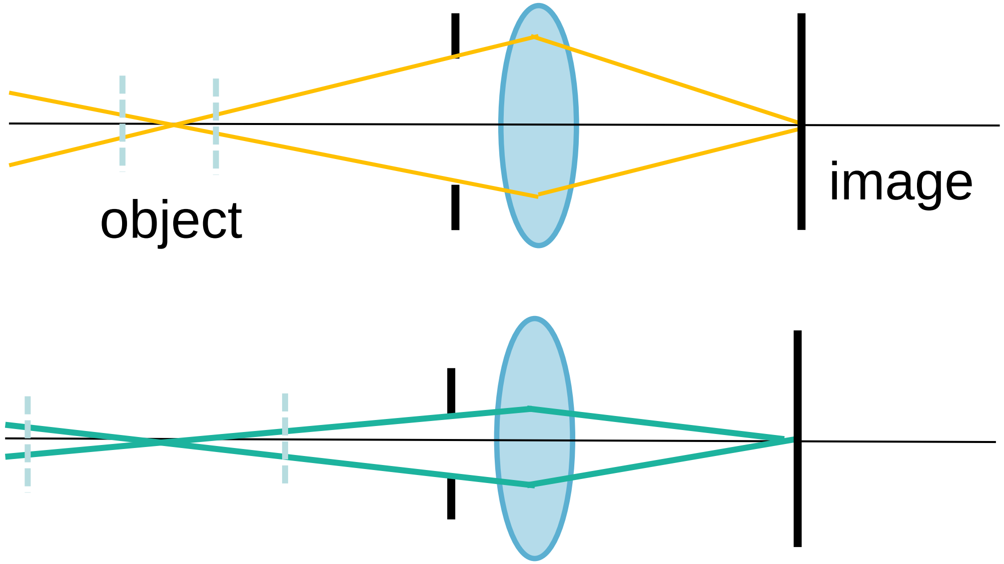
# Depth of Field

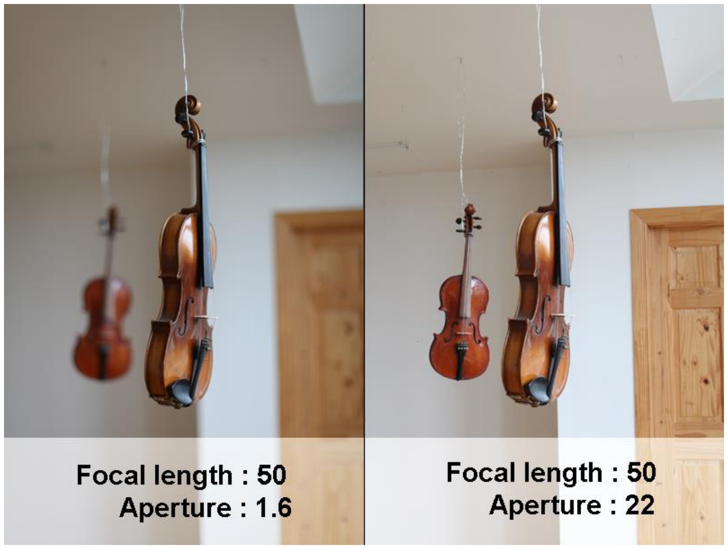
# Reason for lens

# Depth of Field



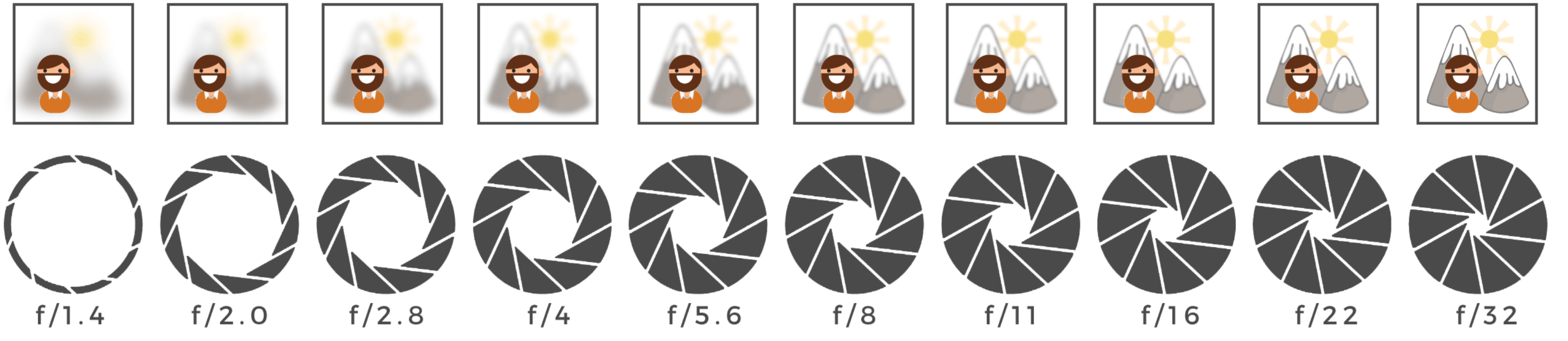
# Aperture controls Depth of Field



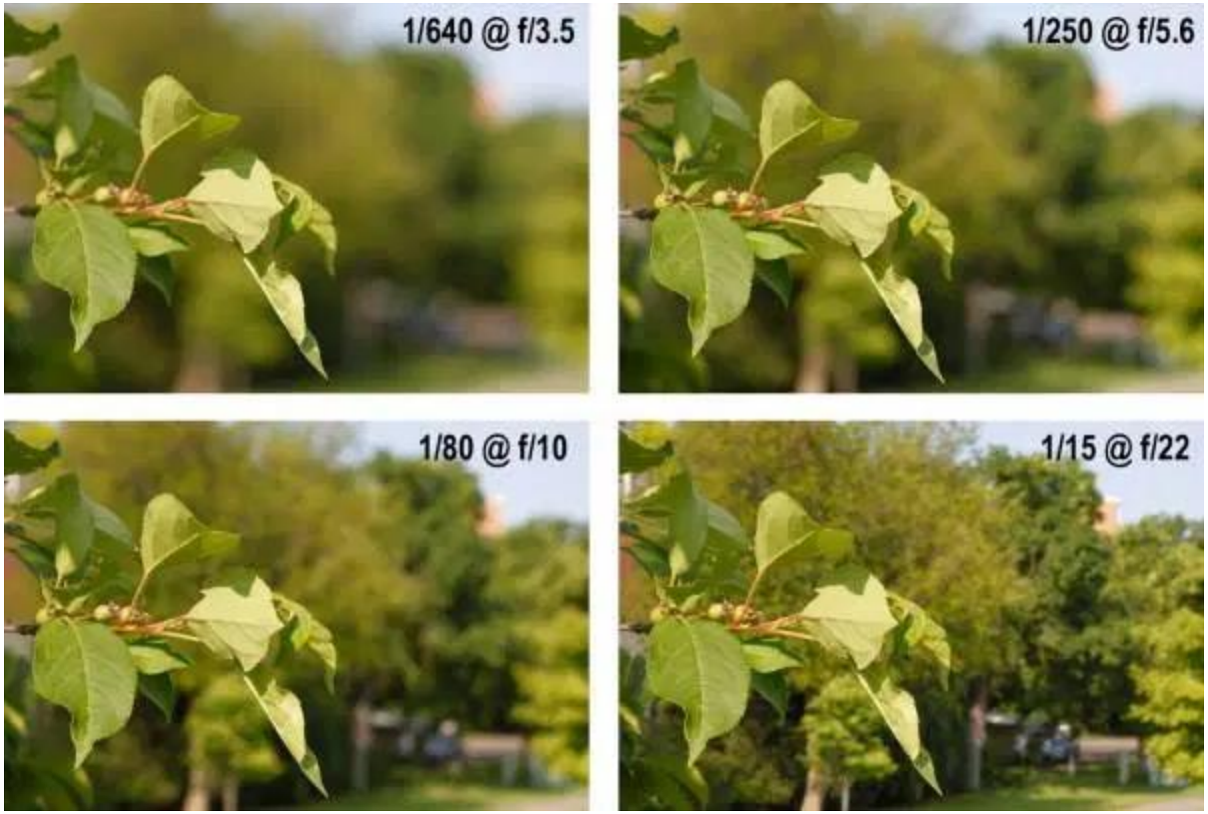

- Changing the aperture size affects depth of field
  - A smaller aperture increases the range in which the object is approximately in focus
  - But small aperture reduces amount of light – need to increase exposure

# F-number




- **F-number**: focal length / aperture diameter
- Aperture size is controlled by the F-number

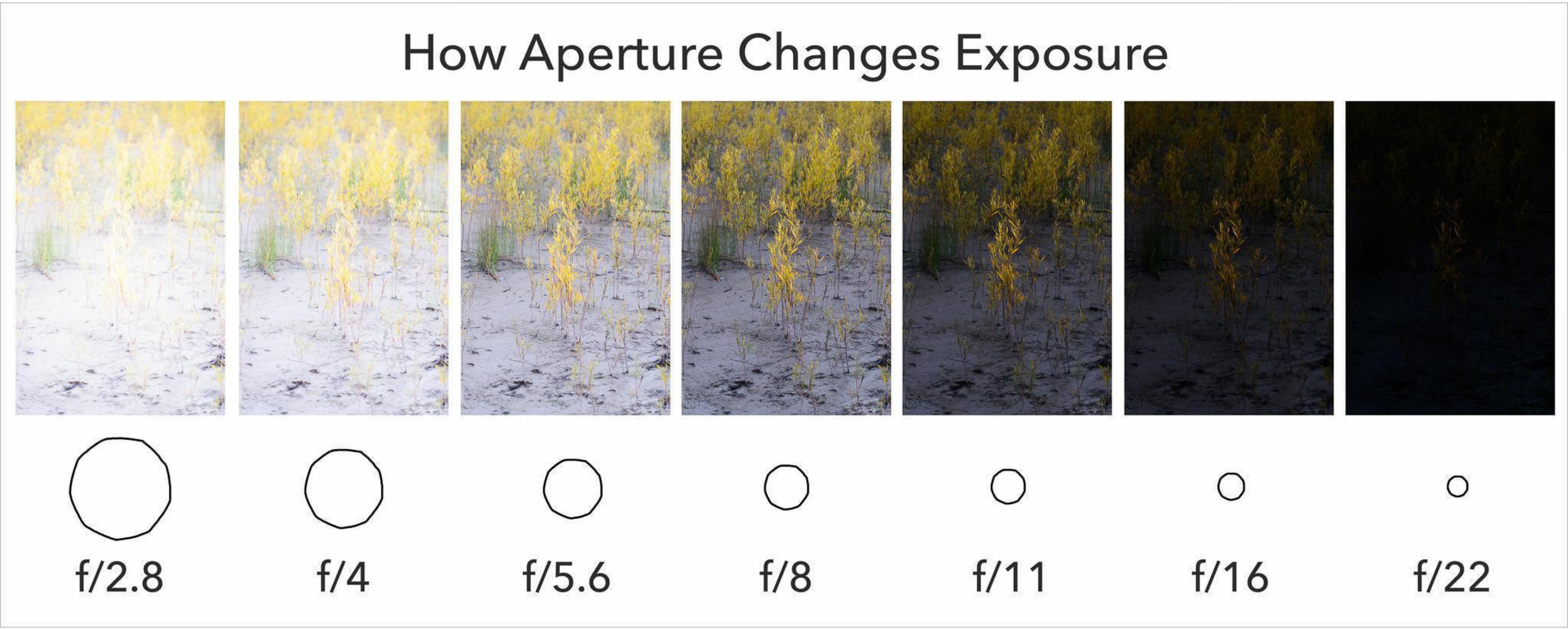
# Varying the Aperture



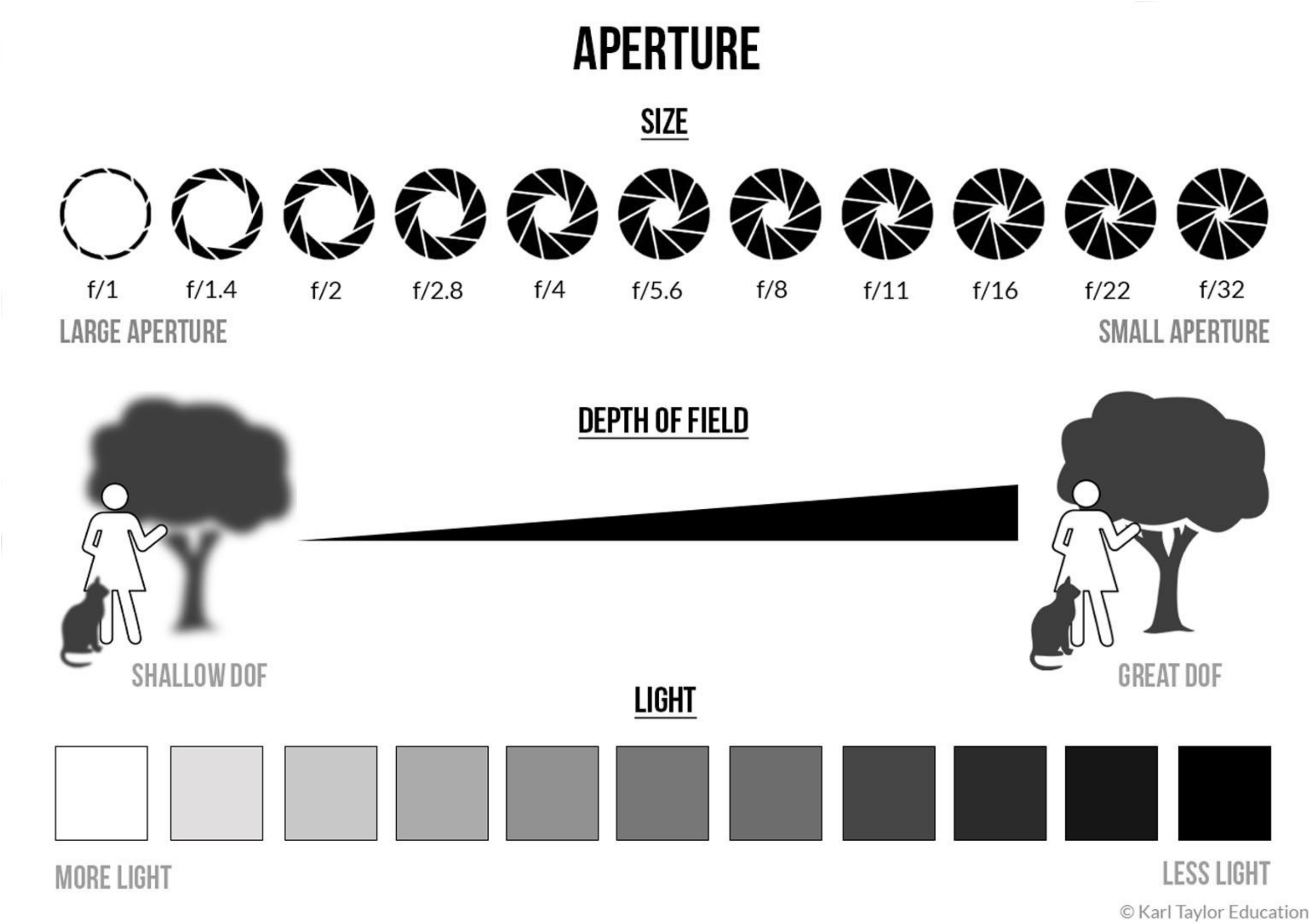
# Varying the Aperture


https://ingridkellyowens.com/wp-content/uploads/2011/07/Depth-of-Field.jpg

# Exposure: shutter speed vs. aperture



# Exposure: shutter speed vs. aperture



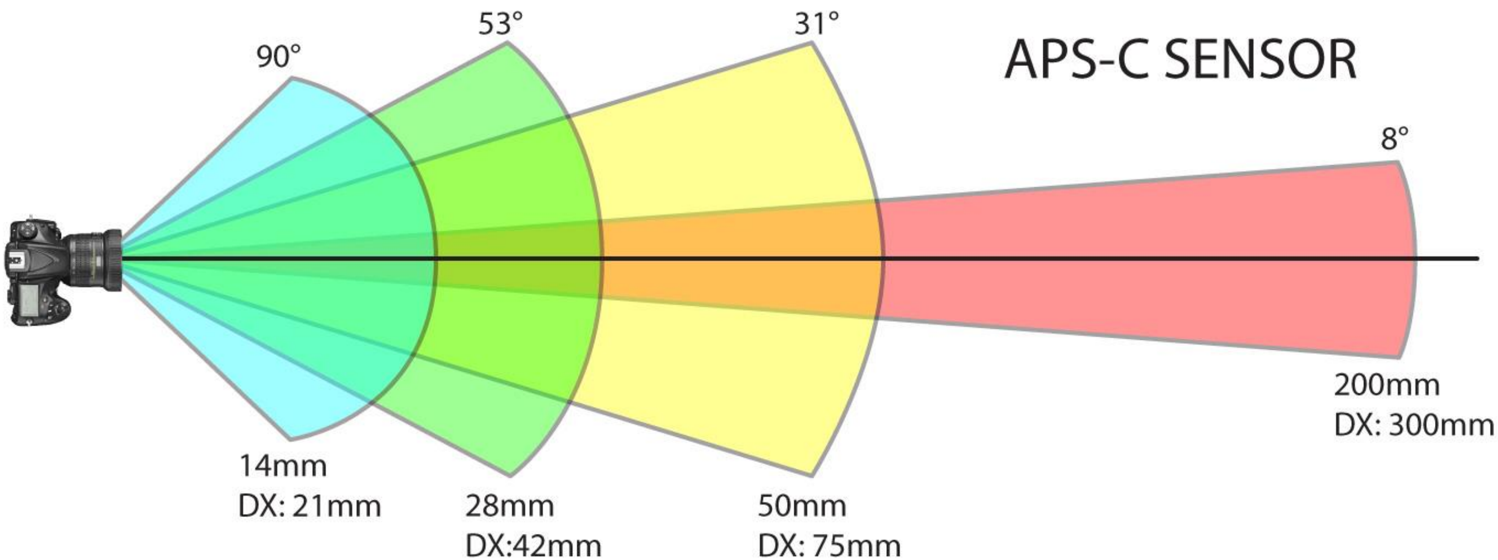
# Exposure: shutter speed vs. aperture

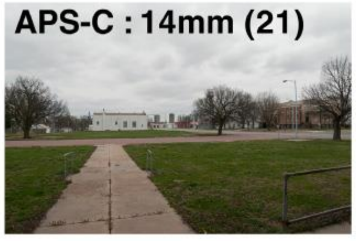


a  slow shutter  vs. a fast shutter speed

# Field of View (Zoom)

# Field of View (Zoom)



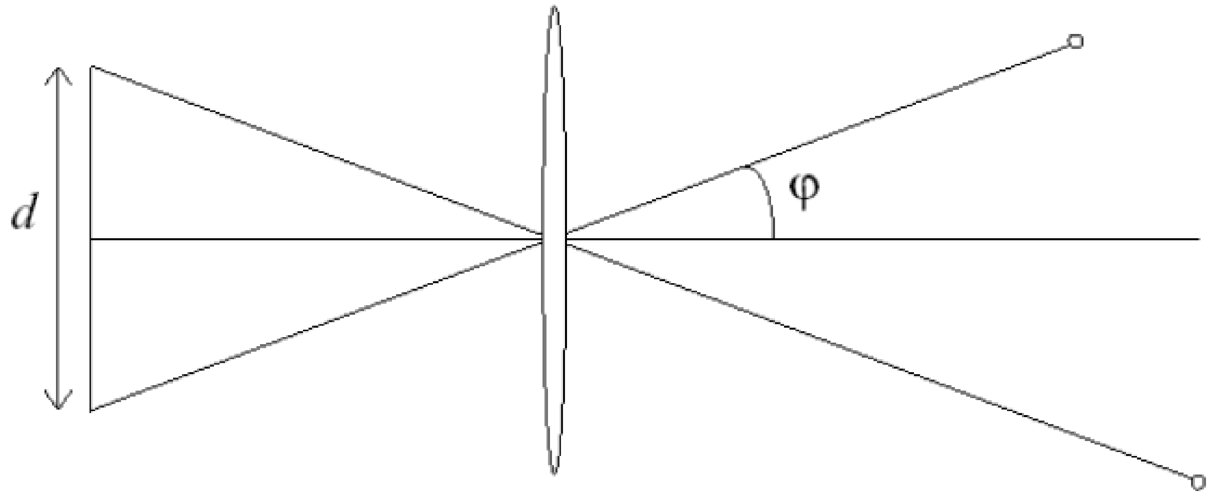



# Field of View (Zoom)

# FOV depends of Focal Length


TheGoodLifePhotographyBlog.com

# FOV depends of Focal Length



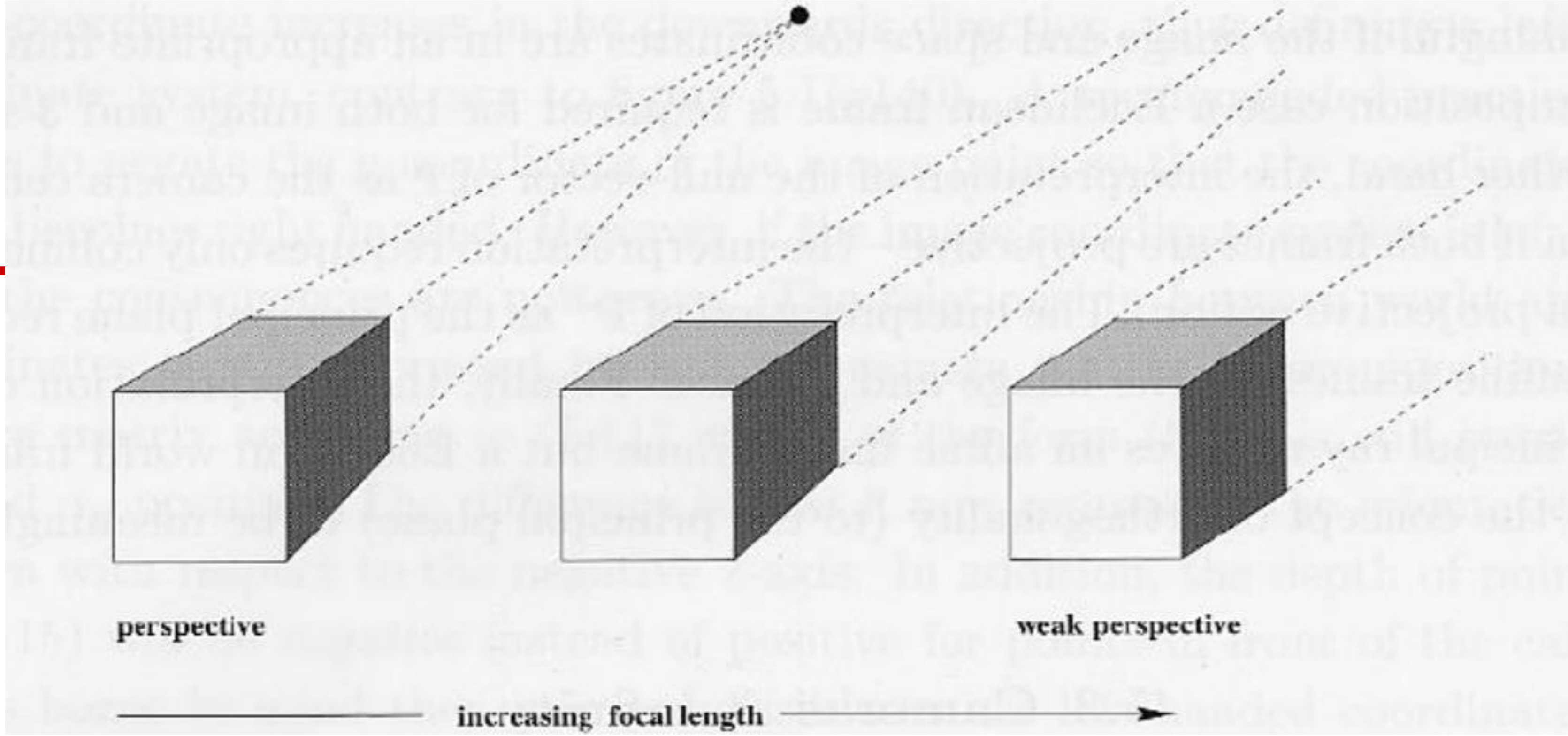

Size of field of view governed by size of the camera retina:

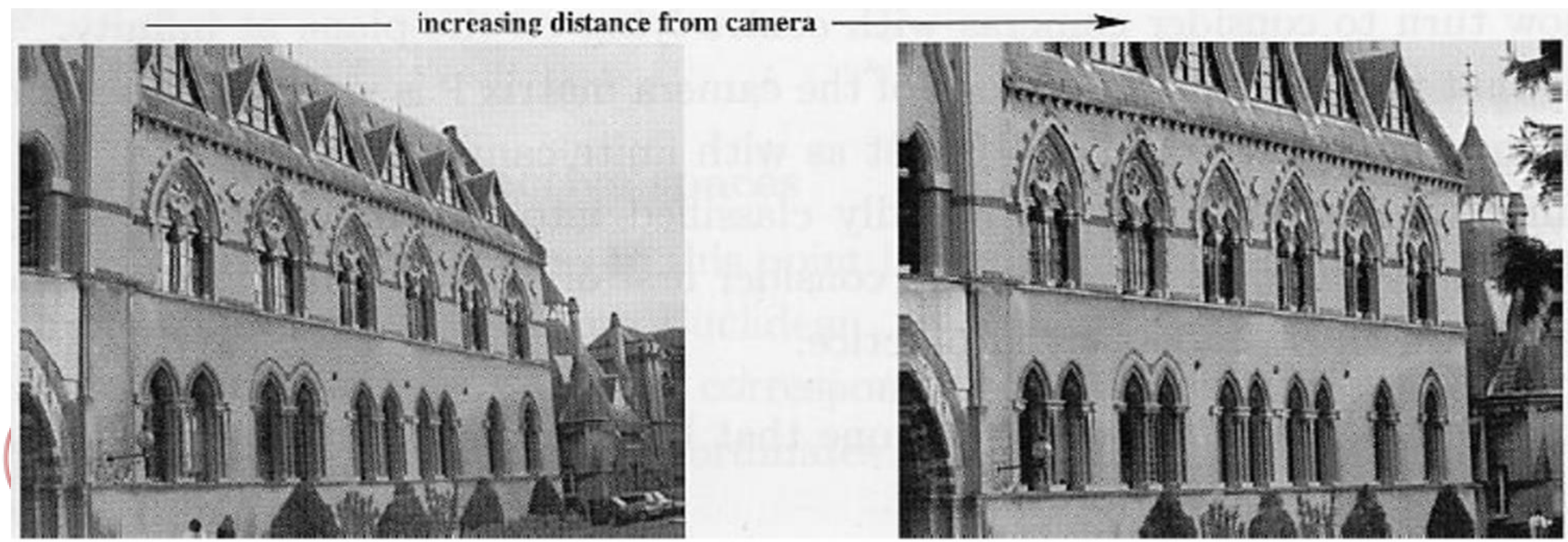
$$\varphi = \tan^{-1}\left(\frac{d}{2f}\right)$$

Smaller FOV = larger Focal Length

# Expensive toys…

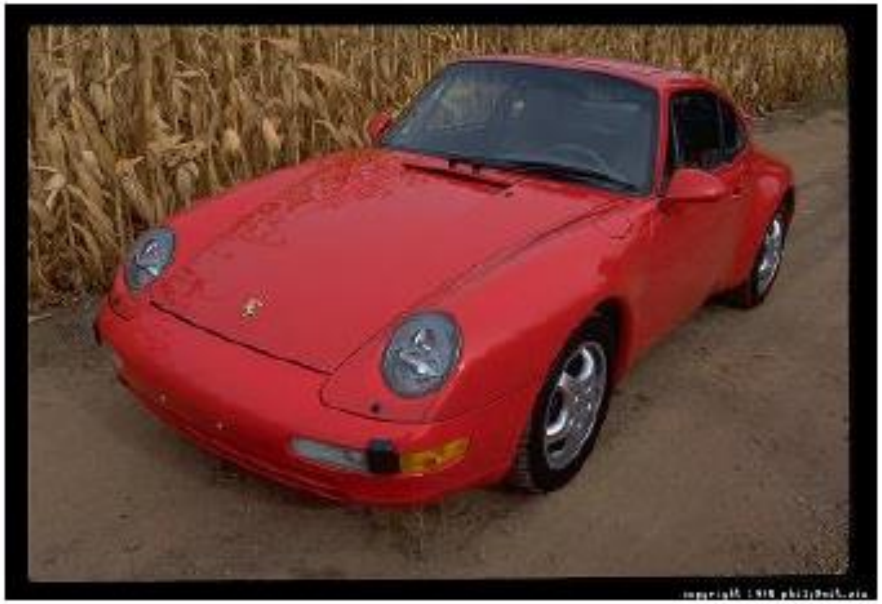

Sigma 200-500mm f/2.8


perspective
weak perspective
increasing focal length


increasing distance from camera

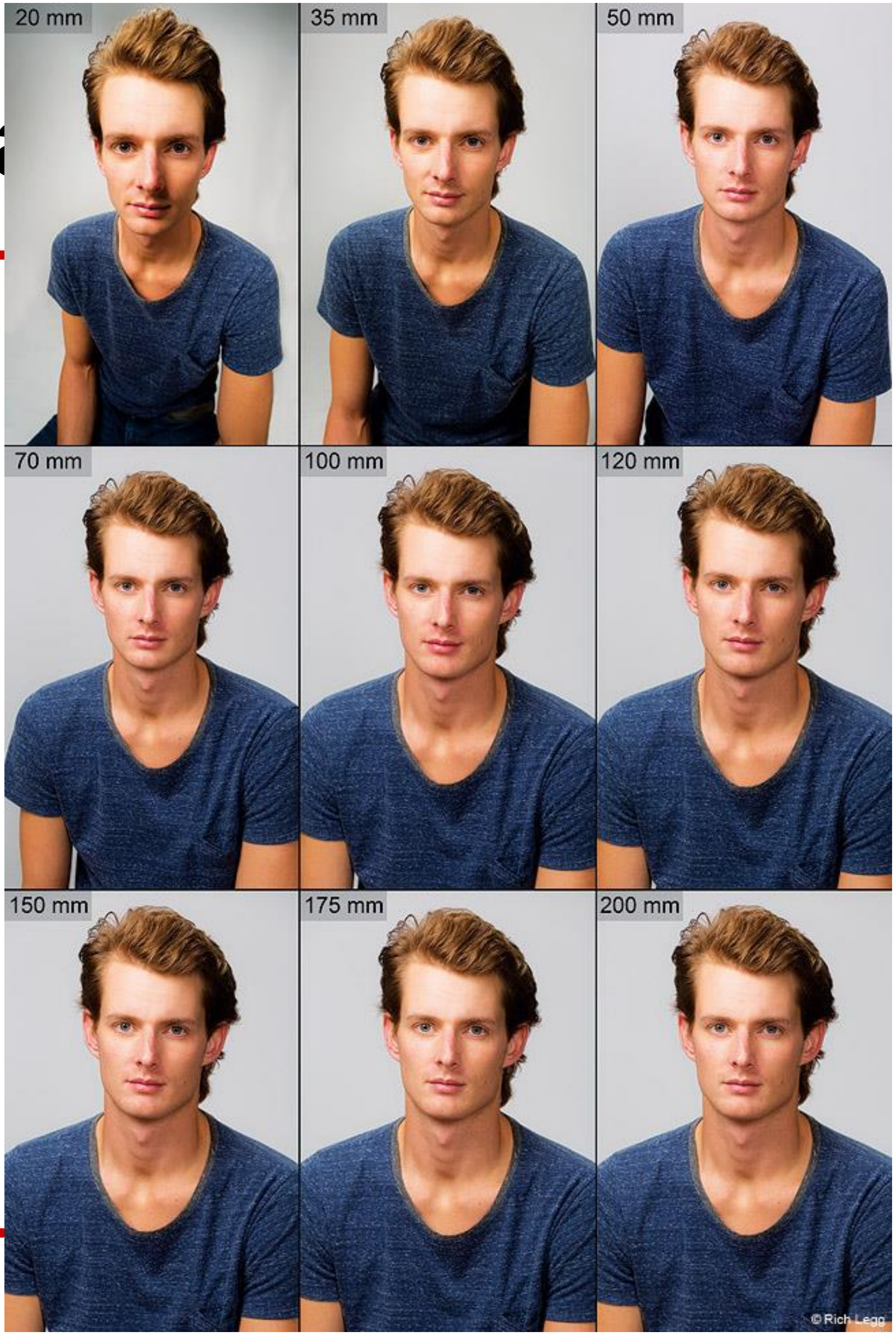
# Field of View / Focal Length

Large FOV
Camera close to car

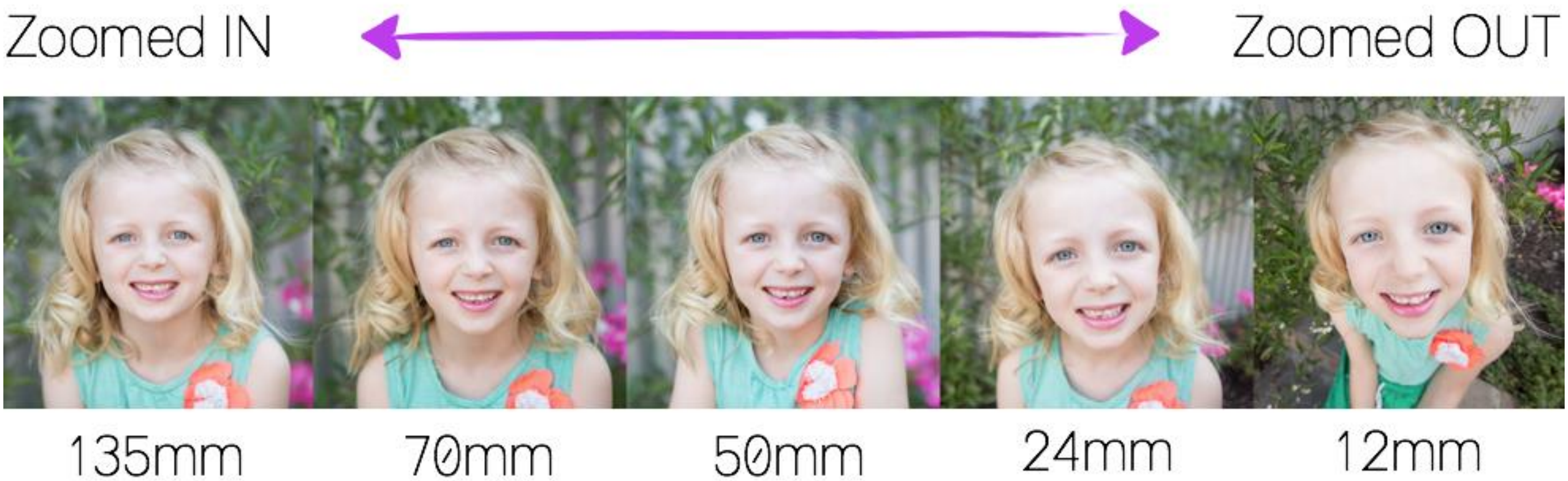


Small FOV
Camera far from the car

# Field of View / Foca



# Field of View / Focal Length




Small FOV
Camera far from the face

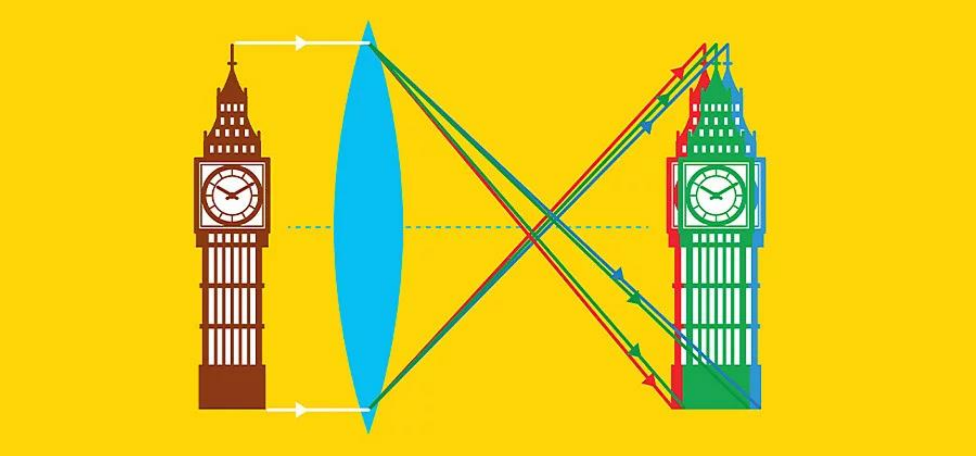
Standard

Large FOV
Camera close to face

# Field of View / Focal Length

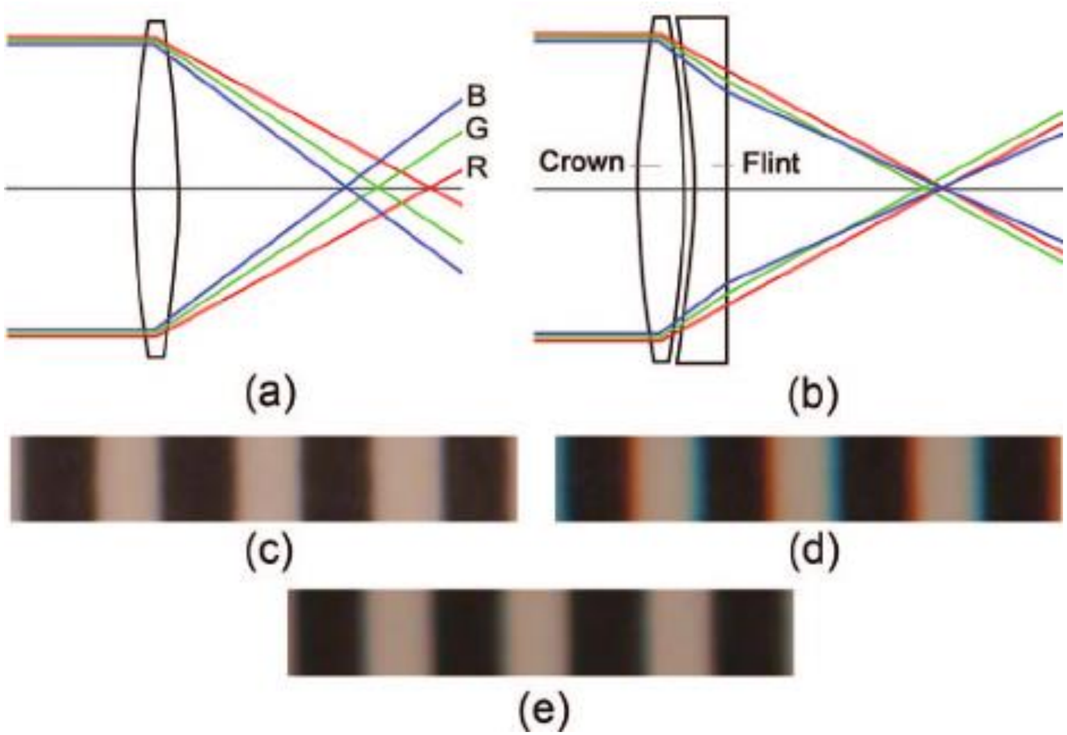
# Lens Flaws: Chromatic Aberration

- Dispersion: wavelength-dependent refractive index
  - Any object point satisfying this equation is in focus(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.

# Lens Flaws: Chromatic Aberration



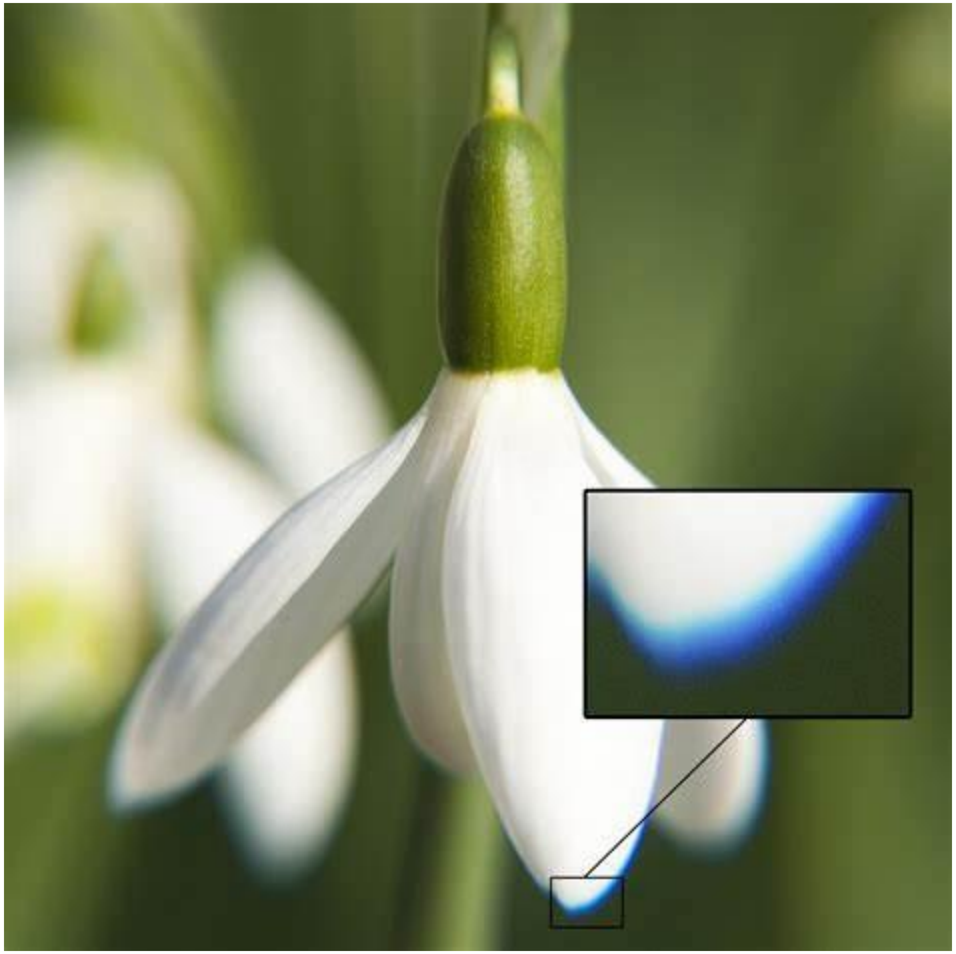

Chromatic aberration and comparison of solutions. (a) Longitudinal chromatic aberration. Different wavelengths have different focal lengths on axis: R, red; G, green; B, blue. (b) Correction of longitudinal chromatic aberration by achromatic doublet. (c) On-axis test chart detail from the 1Ds camera. Chromatic aberration is corrected using UD glass. (d) Off-axis test detail from the same image as (c), showing lateral chromatic aberration. (e) Same as (d) but with digital correction.

# Chromatic Aberration

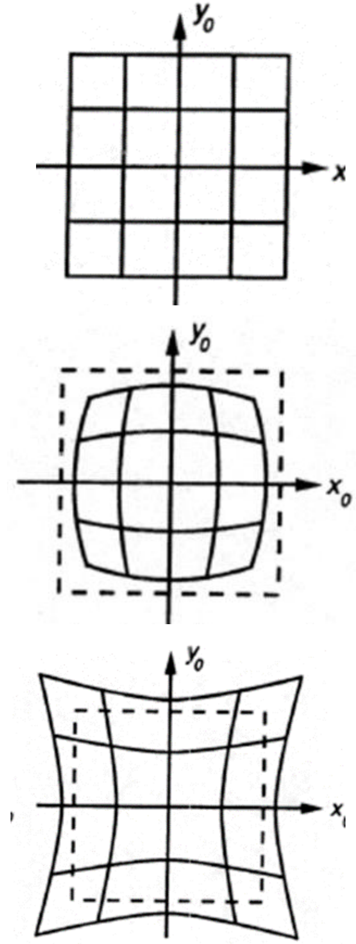
Near Lens Center

Near Lens Outer Edge

# Chromatic Aberration



# Radial Distortion

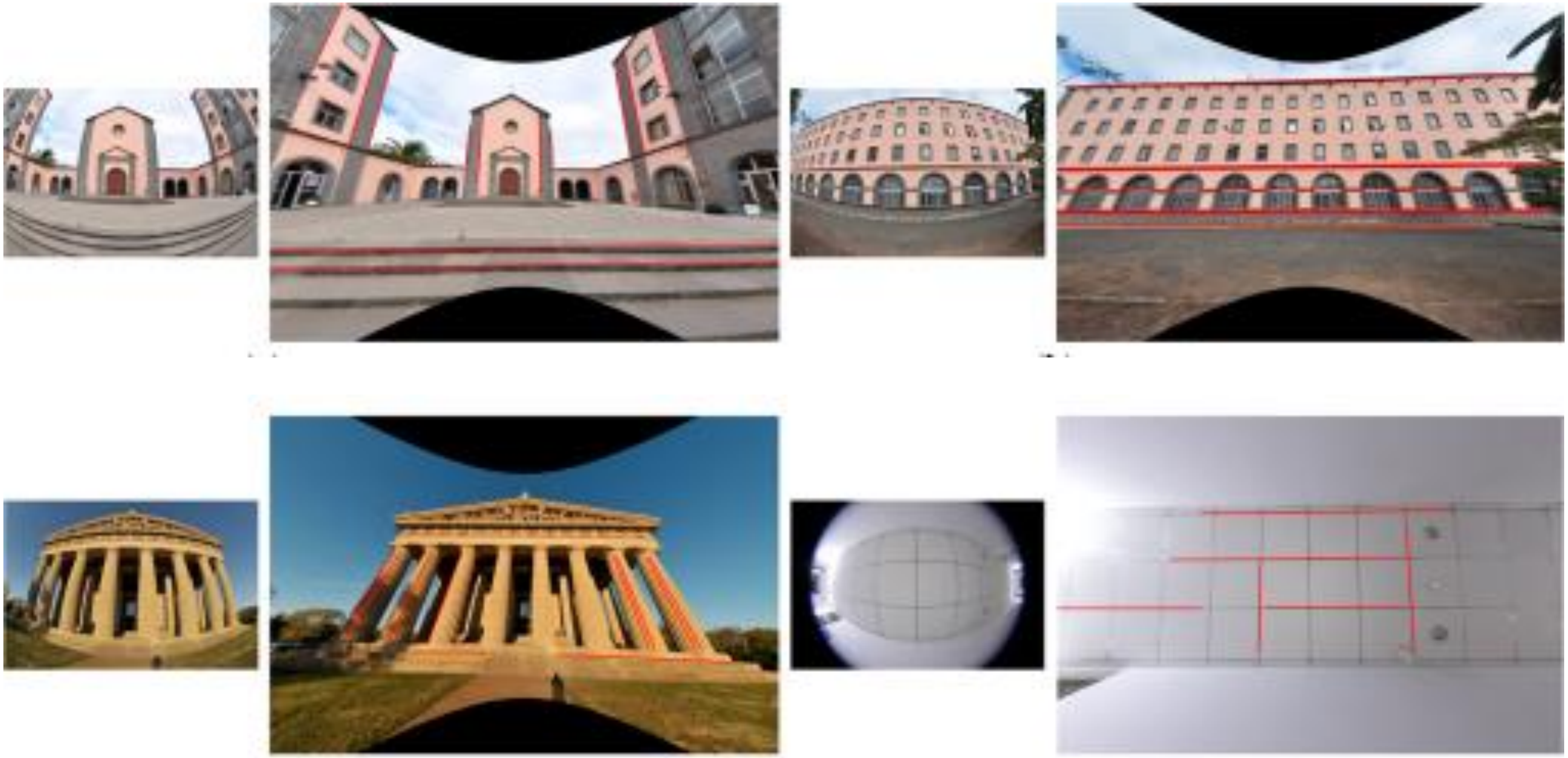



Object

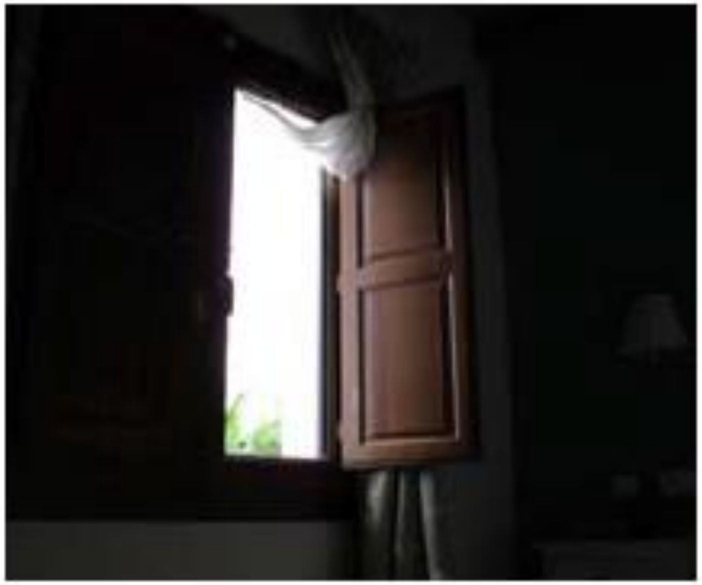
Barrel Distortion

Pincushion Distortion

# Correcting Radial Distortion

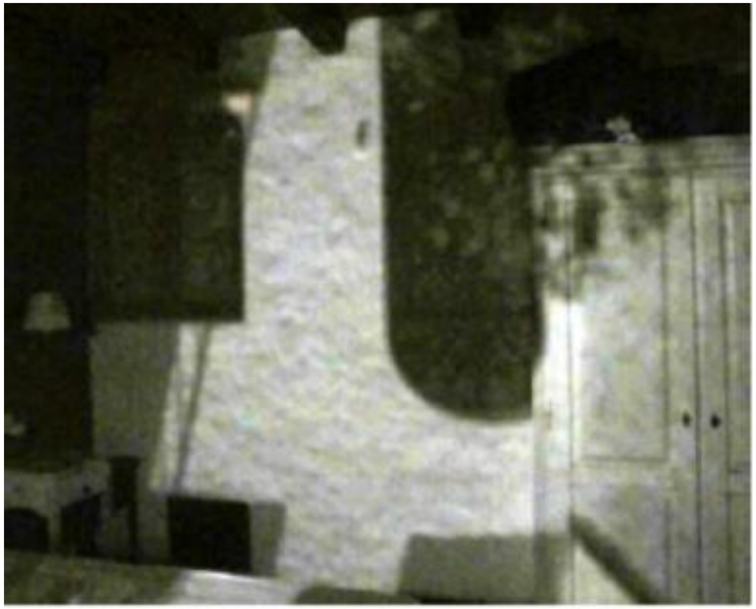


# Accidental Pinhole



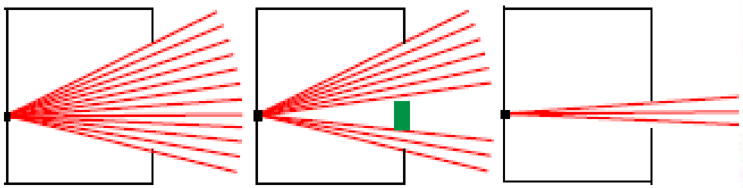
Accidental pinhole and pinspeck cameras: revealing the scene outside the picture

# Accidental Pinhole

# Accidental Pinhole

# Accidental Pinhole



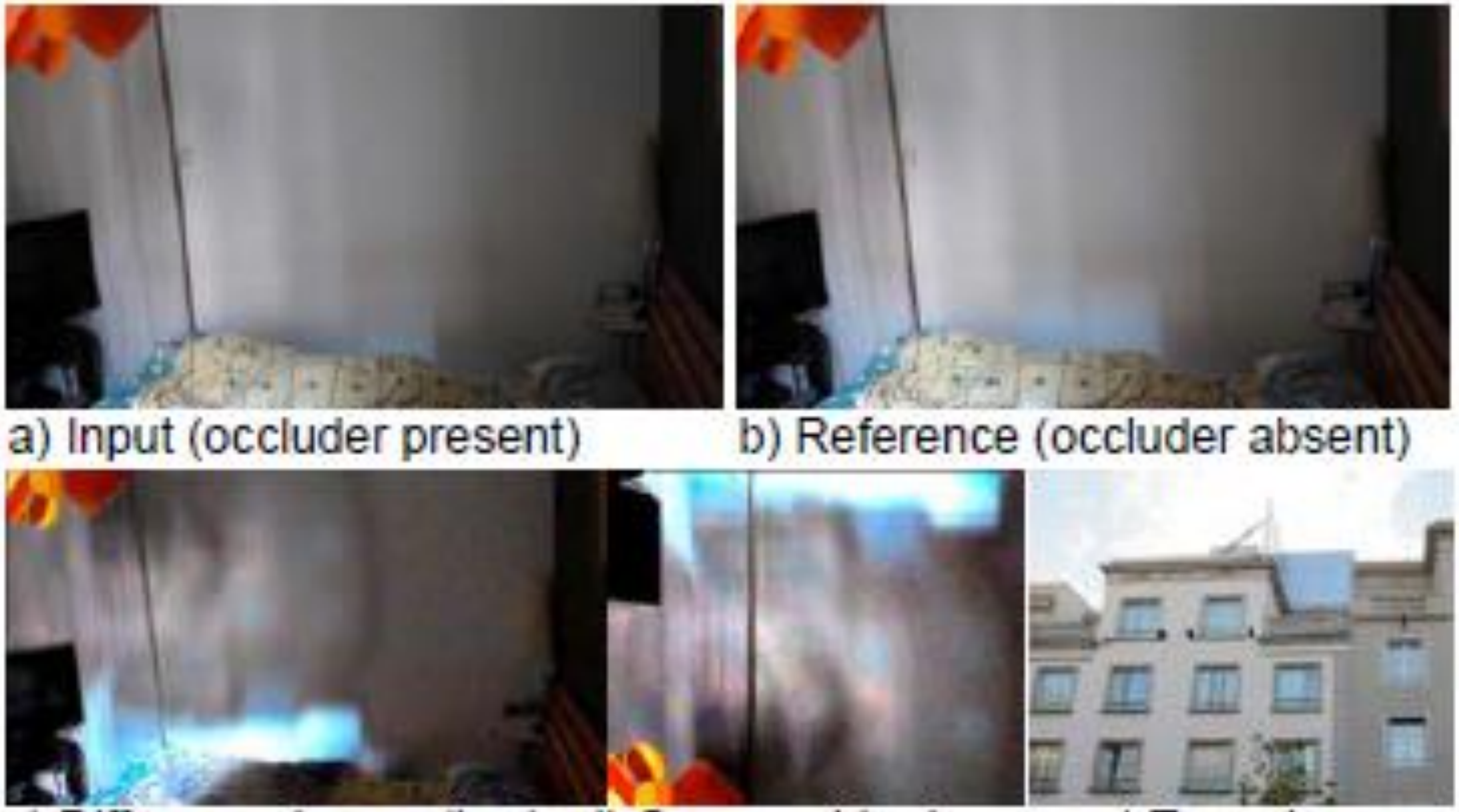
# Accidental Pinhole

a) Difference image

b) Difference upside down

c) True outdoor view

# Accidental Pinhole



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)

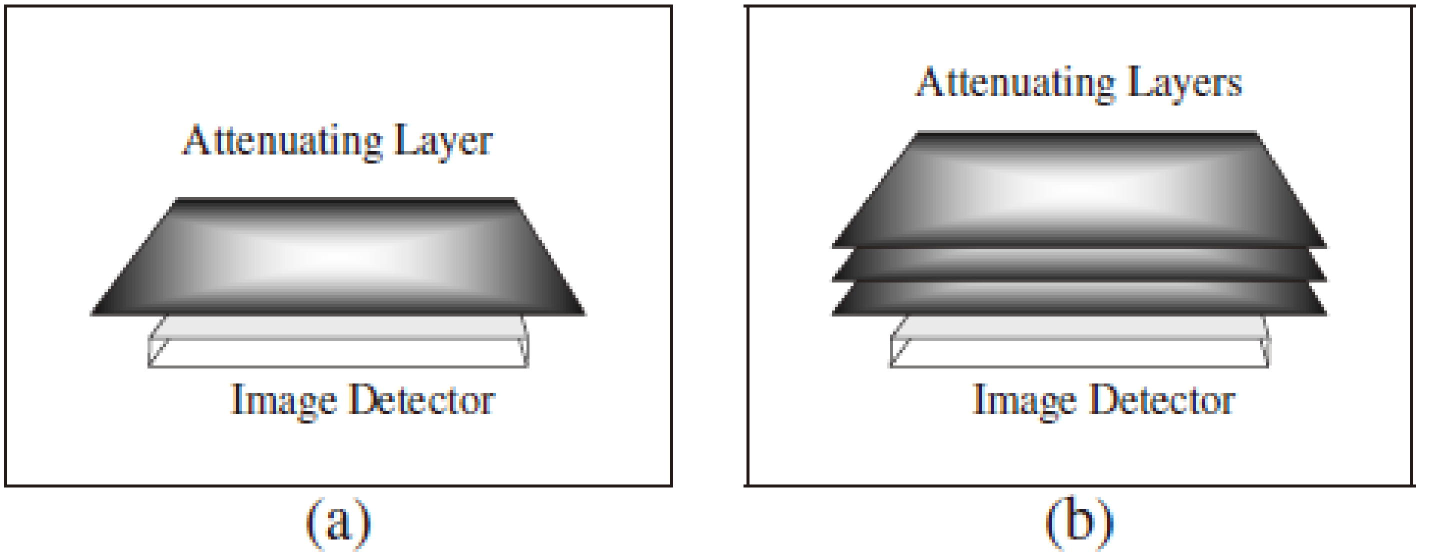



Figure 1. The proposed camera has two components: a detector and an aperture. (a) In its simplest form, the aperture is a light attenuating layer whose transmittances are controllable in space and time. A practical way to implement a controllable attenuating aperture is by using liquid crystal sheets. (b) In its general form, the aperture is a stack of parallel attenuating layers. This approach leads to a flexible imaging system that can achieve a wide range of mappings of scene points to image pixels.

# Lensless Camera (with programmable aperture)

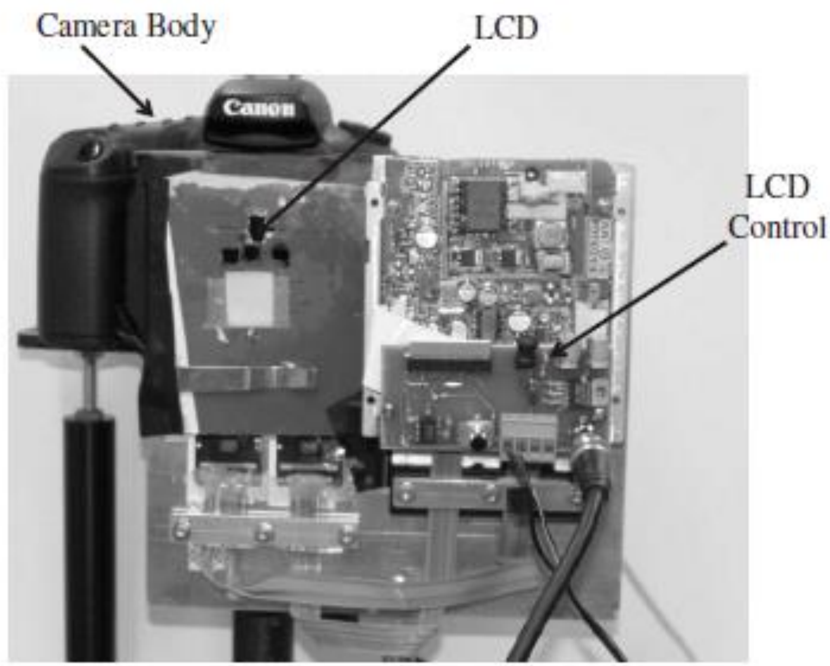



Figure 3. Our camera prototype consists of the body of a Canon EOS-20D digital still camera with an LCD in front of it. To overcome the low contrast ratio of the LCD, most of its unused area was covered with a cardboard. In experiments that required the use of multiple attenuating layers, the additional layers were physical apertures.

# Lensless Camera(with programmable aperture)

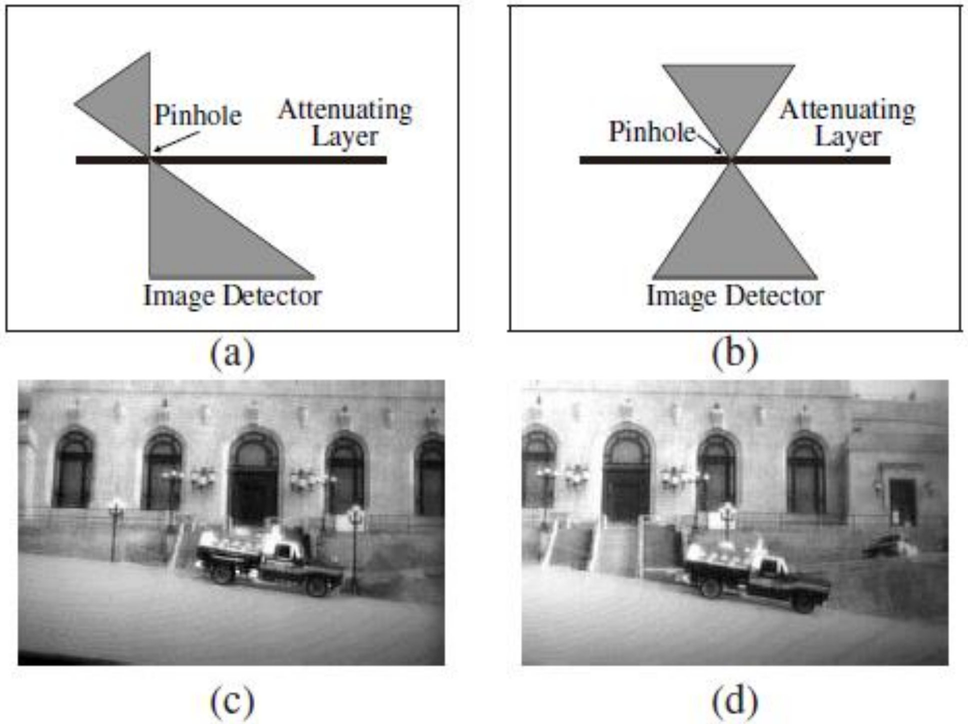
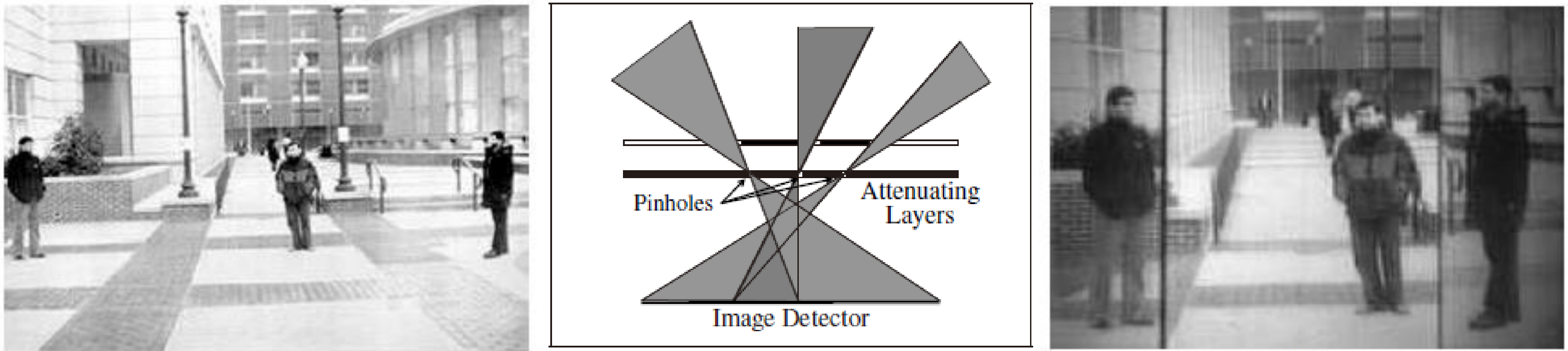



Figure 5. Controllable pinhole camera. By controlling the attenuating aperture, it is possible to shift a pinhole to arbitrary locations from one frame to the next. (a) and (b) show two different pinhole locations and the corresponding fields of view. (c) and (d) show two images captured by our prototype, without physically moving the camera. This allows us to track the moving object without the use of any moving parts, unlike conventional pan-tilt cameras.

# Lensless Camera(with programmable aperture)




(a) (c) (b)

Figure 6. Split field of view imaging. (a) Conventional cameras capture a continuous field of view. (b) In contrast, the proposed camera can split the field of view to disjoint parts and capture only these parts. This way, the camera captures objects of interest with higher resolution and avoids capturing less interesting scene parts. (c) Split field of view imaging is implemented with two or more attenuating layers.

# Lensless Camera (with programmable aperture)

(d) (e)

The aperture is dynamically adjusted to account for moving objects in the scene. In (d) and (e) the car is maintained within the field of view while the background changes.

Thanks

# The 1-D Dilation