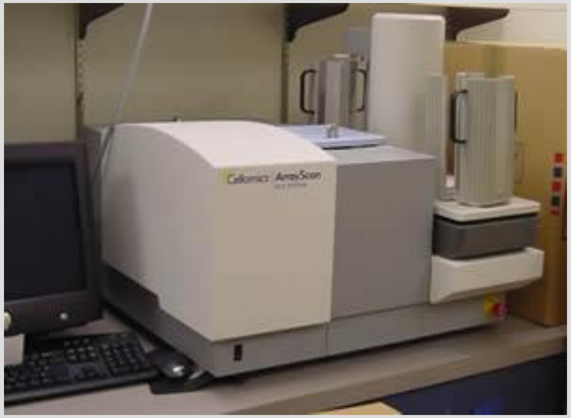
Automation has advanced biology: Microscopy

~1660: Hooke’s microscope
“father of microscopy”



1996: First high-throughput automated microscope hits the market

What can we do with 100,000+ images per day?

* Test a million chemicals to see which impede cancer growth
* Test a million chemicals to see which prevent neural degeneration
* ... conduct any microscopy experiment, for the whole genome or for a million chemicals

Anne Carpenter, http://www.cellprofiler.org/

image from wikipedia.org   image from cellomics.com

Computer Vision

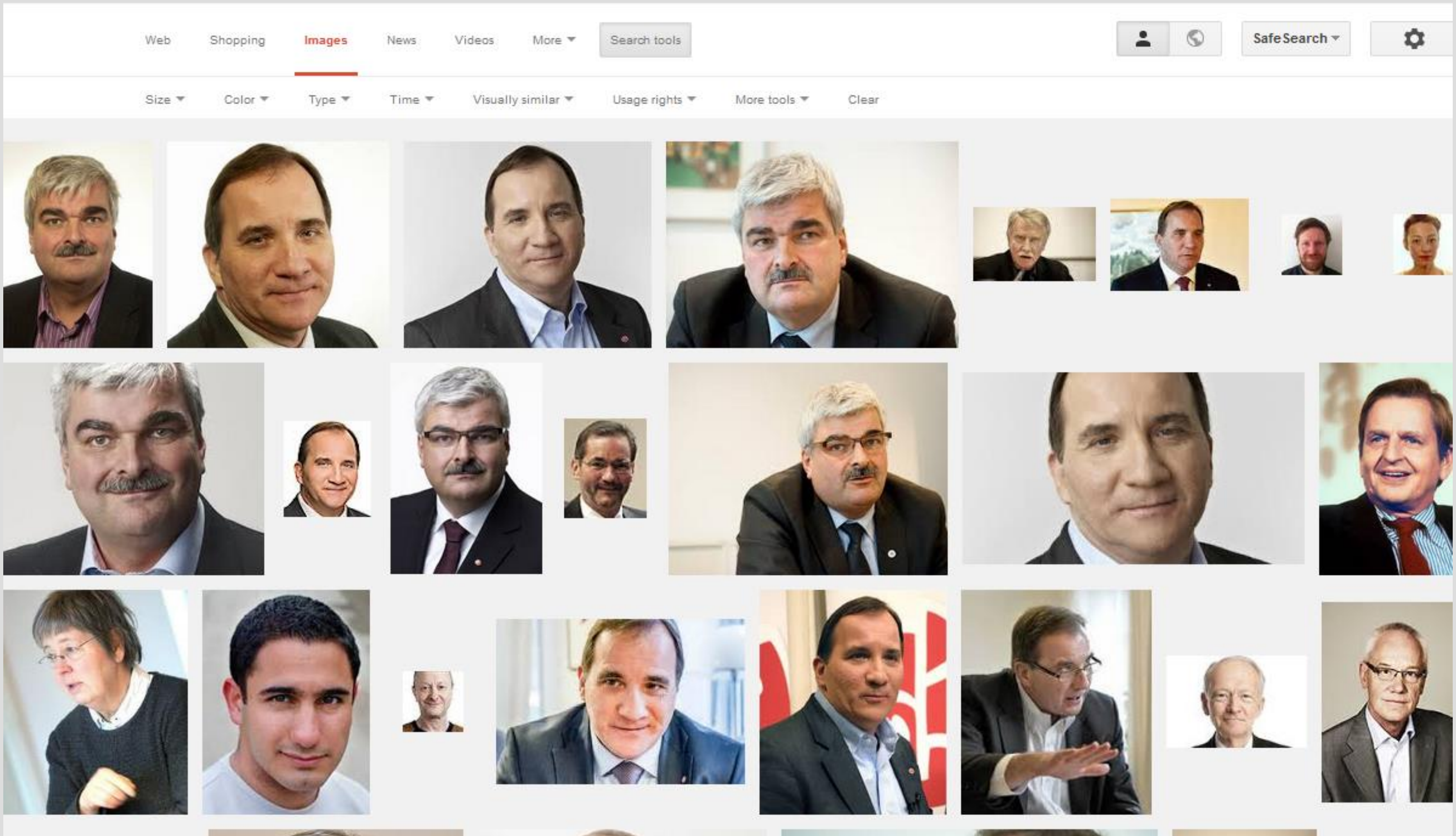
The aim of Computer Vision is to create systems that to some degree ”understand” the contents of an image and act accordingly

- Autonomous navigating machines (“robots with eyes”)
- Recognition and classification of objects
- Retrieval of the 3D-geometry of the scene



Pattern recognition

Example: Google image search



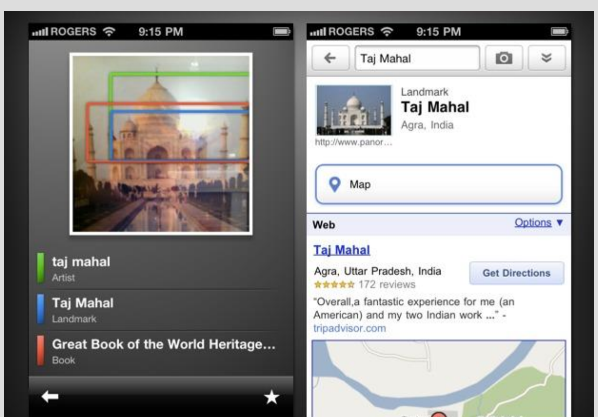
Examples

Version 1 — 21×21

This reads, "Ver1"

Version 40 — 177×177

This reads, "Version 40 QR code can contain up to 1852 chars."



Google Goggles

Summary

- Dark/Light vision – rods & cones
- Retina is a sensor with built-in processing (compression)
- Visual processing comes in different forms: perception-action, higher level interpretation
- Different vision systems in nature: black-white&color, lens&pinhole, single&multiple eyes
- Non-standard cameras with more channels, more lenses etc
- Imaging techniques that produce image-type information (CT, MRI, …)
- Different areas:
    - Image processing and image restoration (Image to Image)
    - Image analysis (Image to content)
    - Computer vision (Image sensors as part of another system)
    - Pattern recognition/Machine Learning (System learns from input)

Basic Facts about Cameras

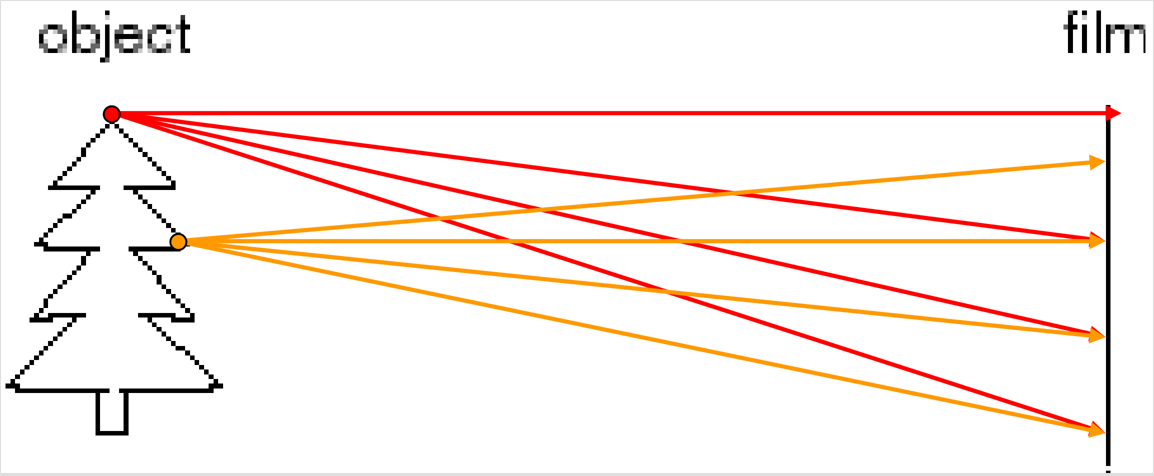
Reiner Lenz

2015

Overview

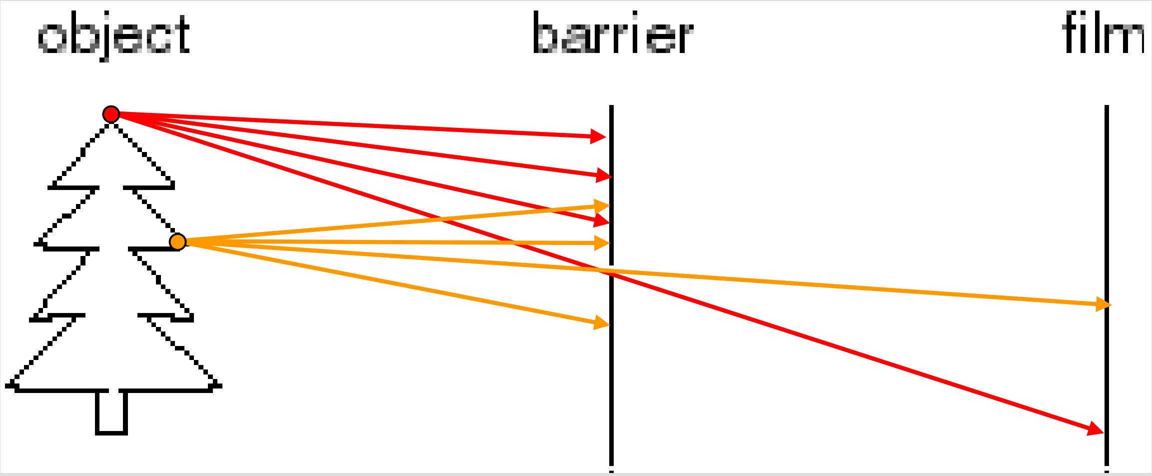
- Why we need a camera
- Pinhole camera
- Aperture
- Lens – Focus
- Depth of field
- Field of View
- Exposure Time
- Sensor
- ISO
- Color
- Post-Processing
- Distortions

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?

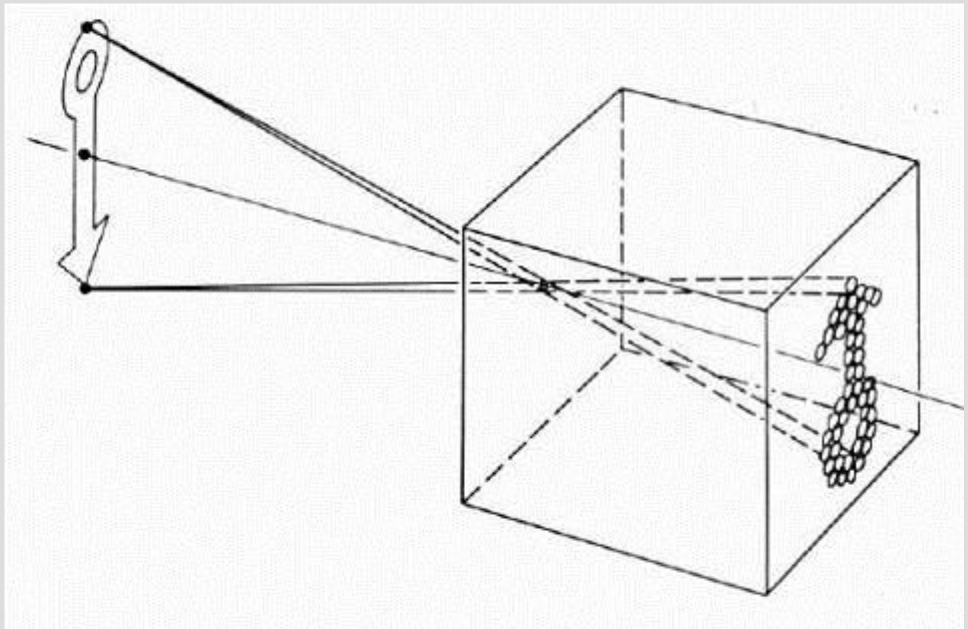
Pinhole camera



- 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

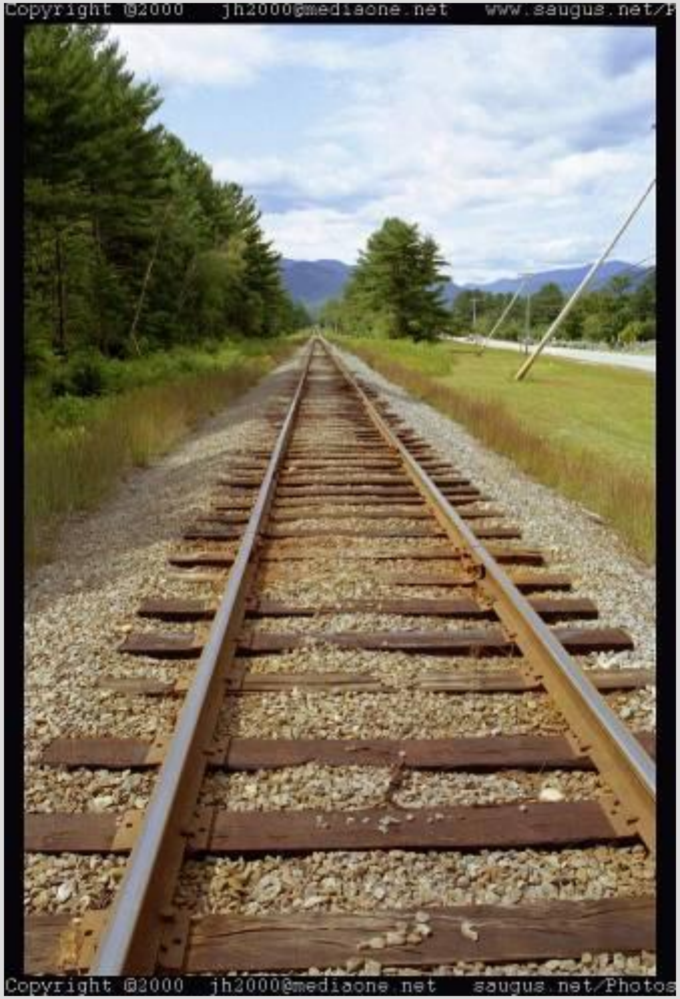
Pinhole camera model



- 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

Funny things happen…



Parallel lines aren't…

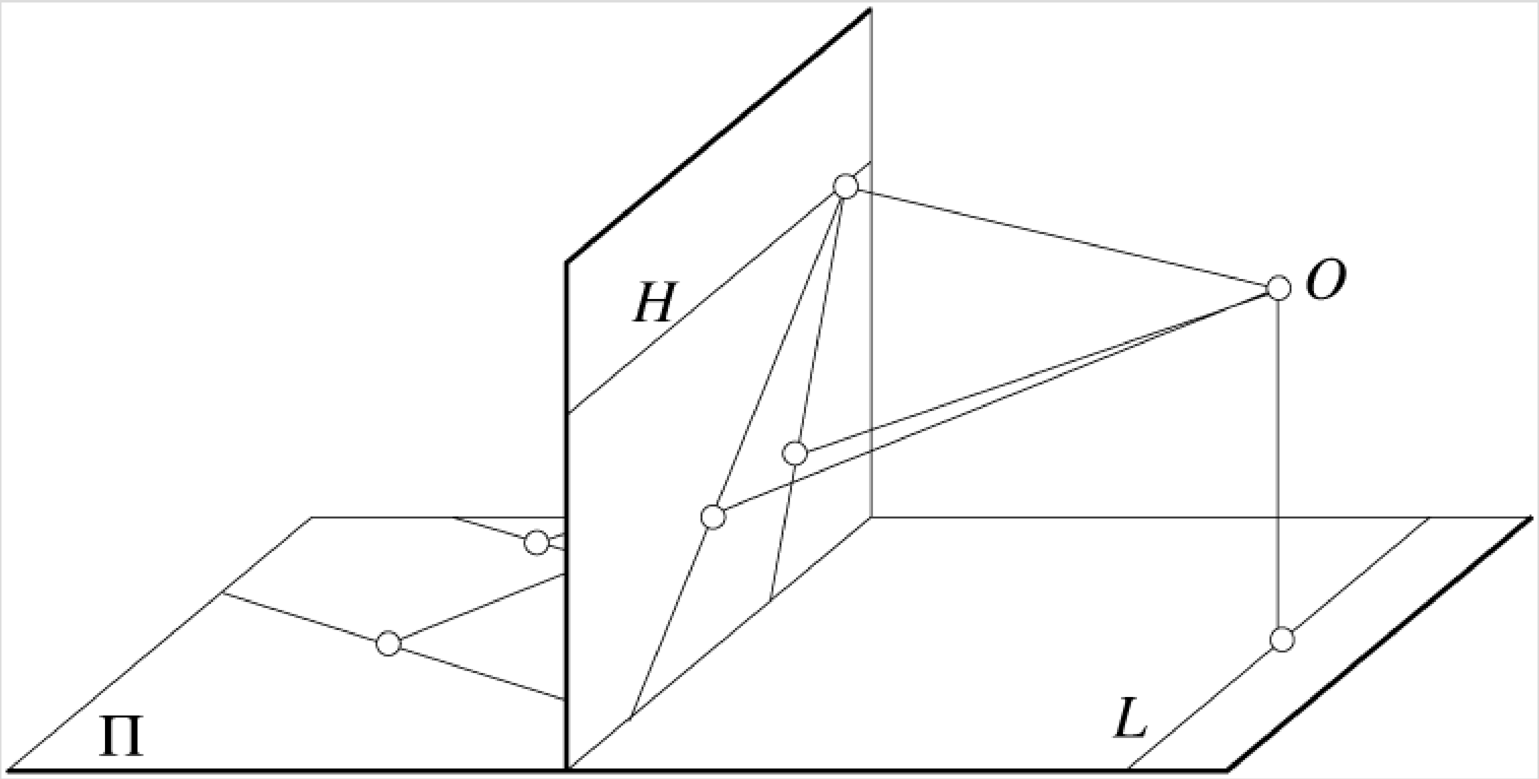


Figure by David Forsyth

Lengths can’t be trusted...

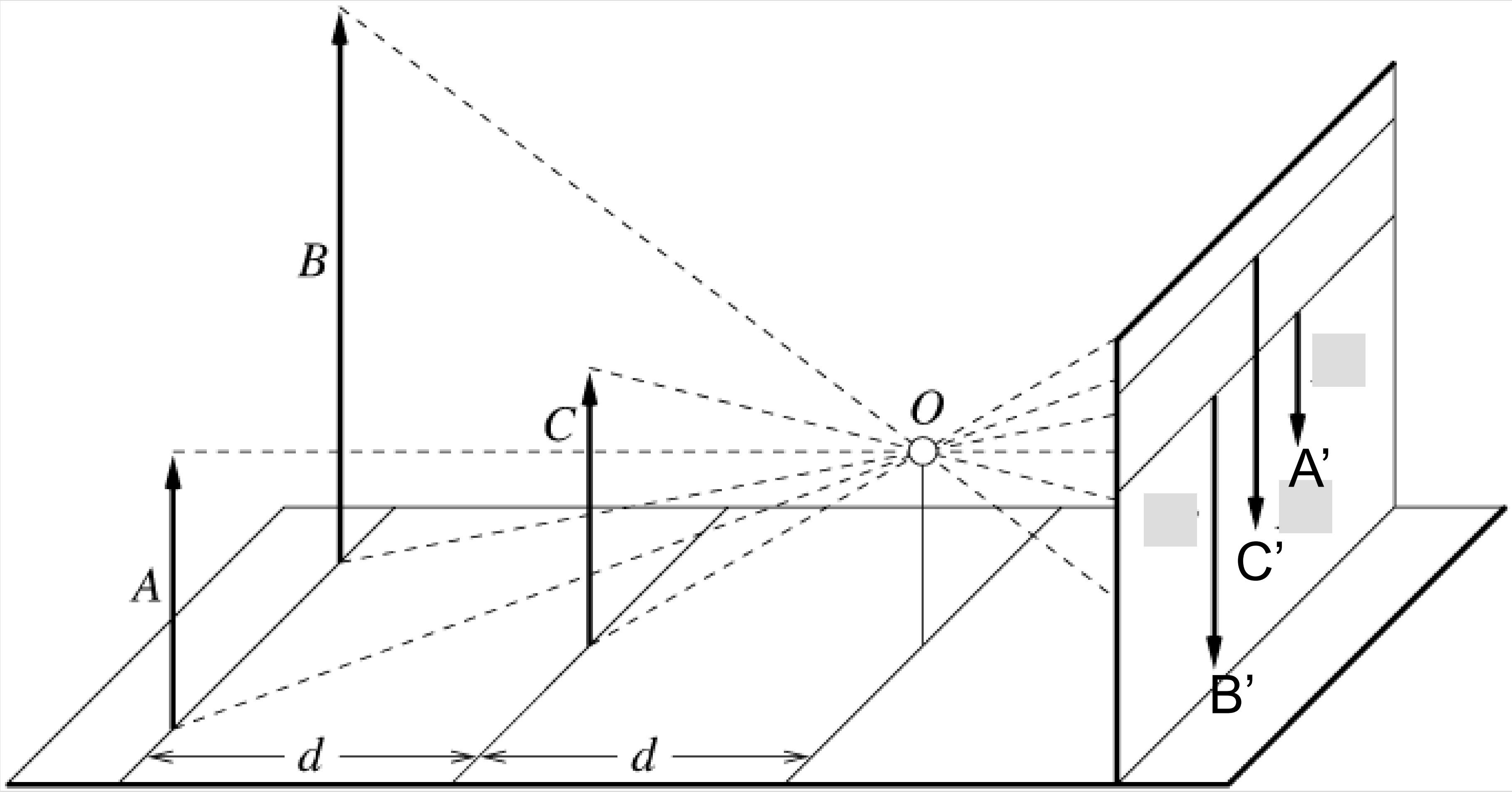
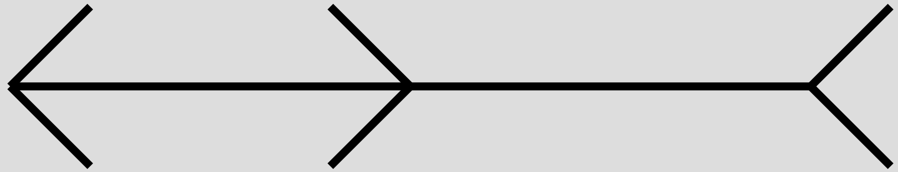
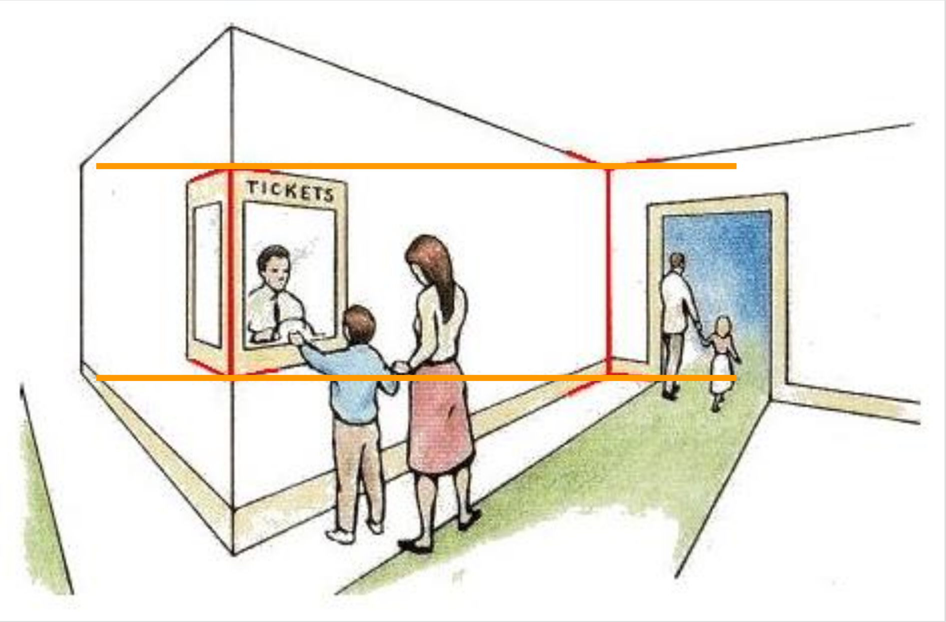


Figure by David Forsyth

…but humans adopt!



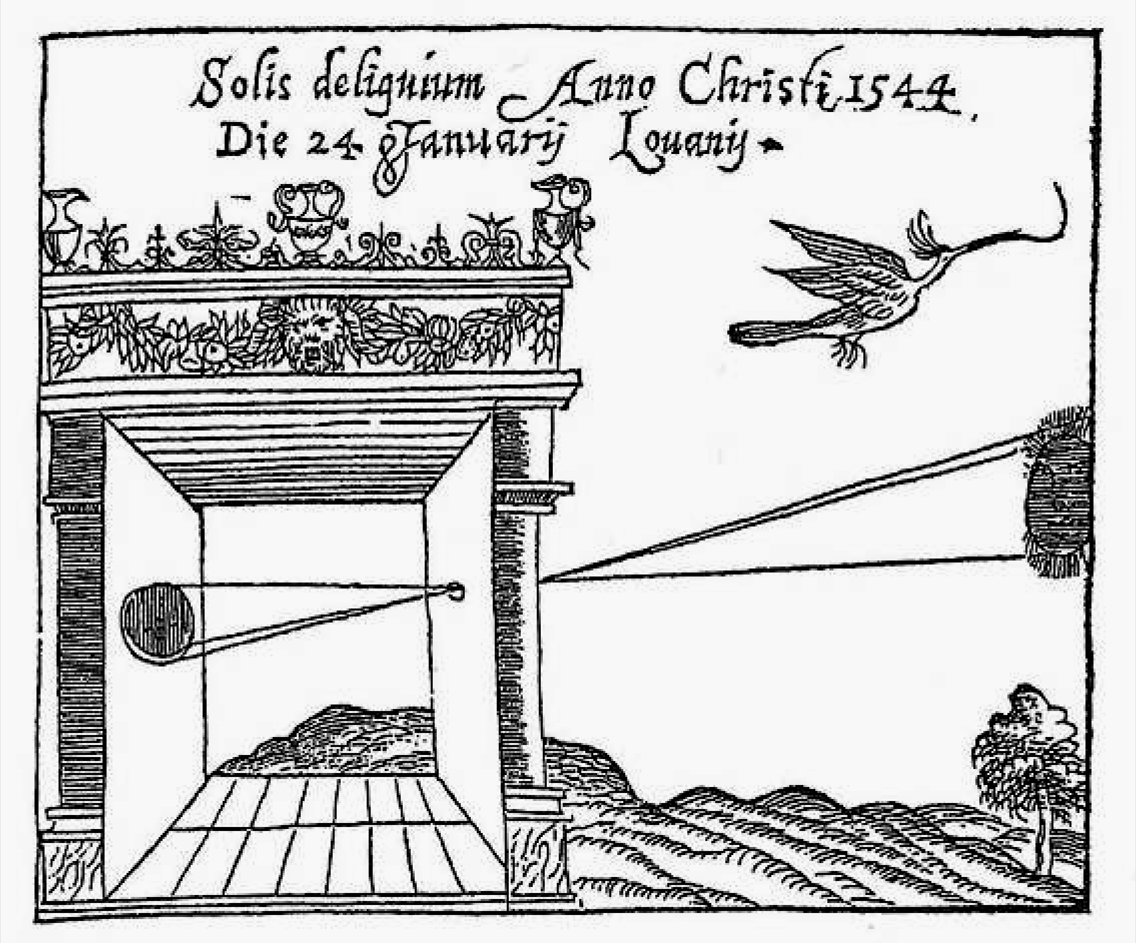
Müller-Lyer Illusion



We don’t make measurements in the image plane

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

Camera Obscura

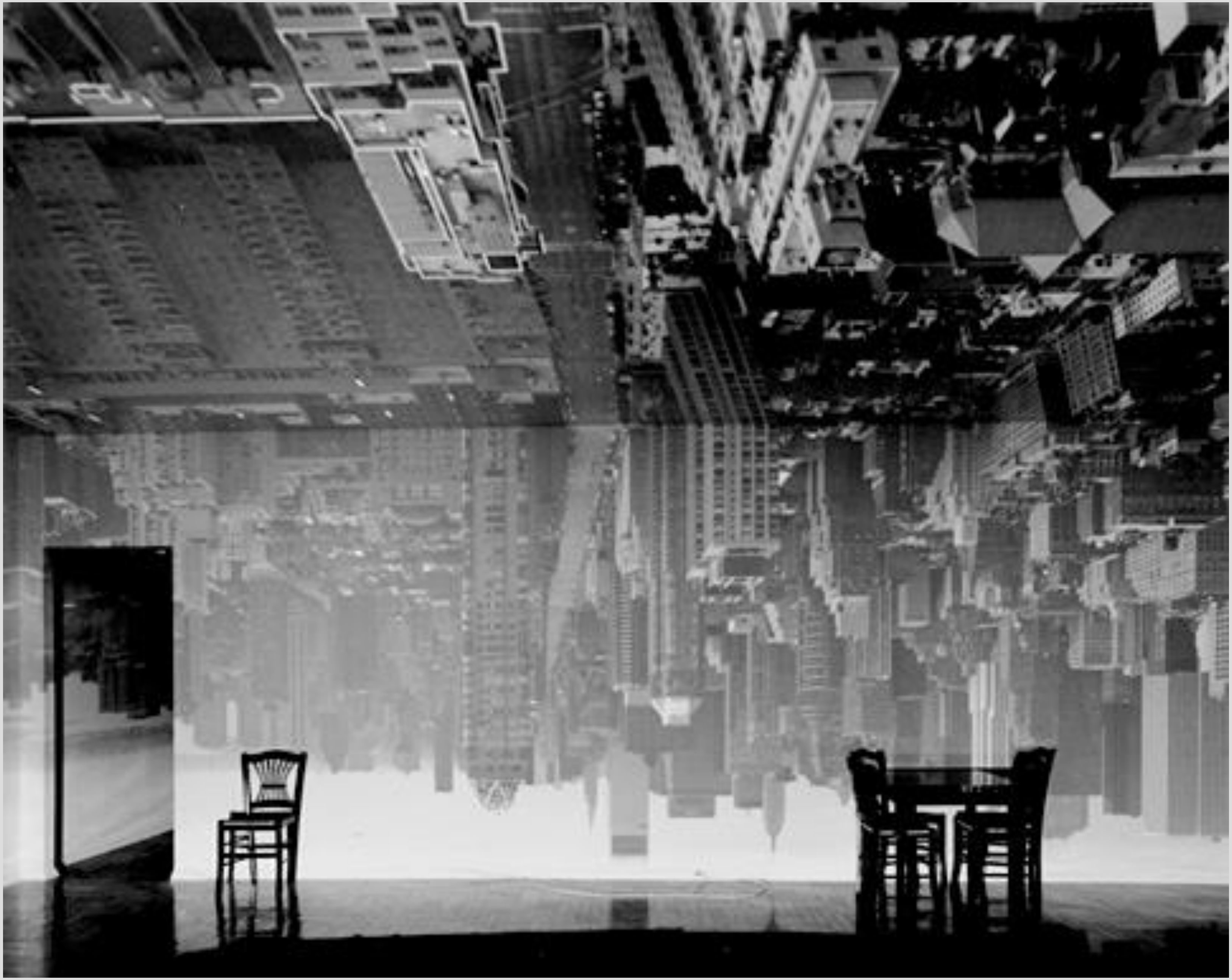


Camera Obscura, Gemma Frisius, 1558

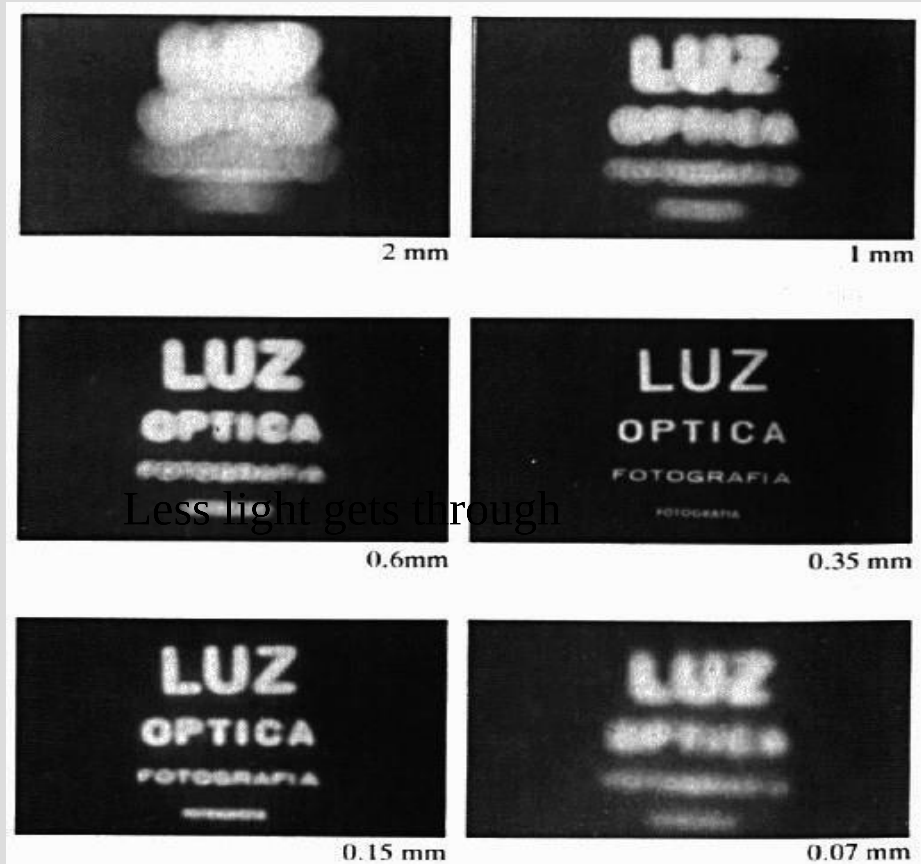
- The first camera
  - Known to Aristotle
  - First written description in 1553

http://www.abelardomorell.net/

I made my first picture using camera obscura techniques in my darkened living room in 1991. In setting up a room to make this kind of photograph, I cover all windows with black plastic in order to achieve total darkness. Then, I cut a small hole in the material I use to cover the windows. This allows an inverted image of the view outside to flood onto the walls of the room. I would focus my large-format camera on the incoming image on the wall and expose the film. In the beginning, exposures took five to ten hours.



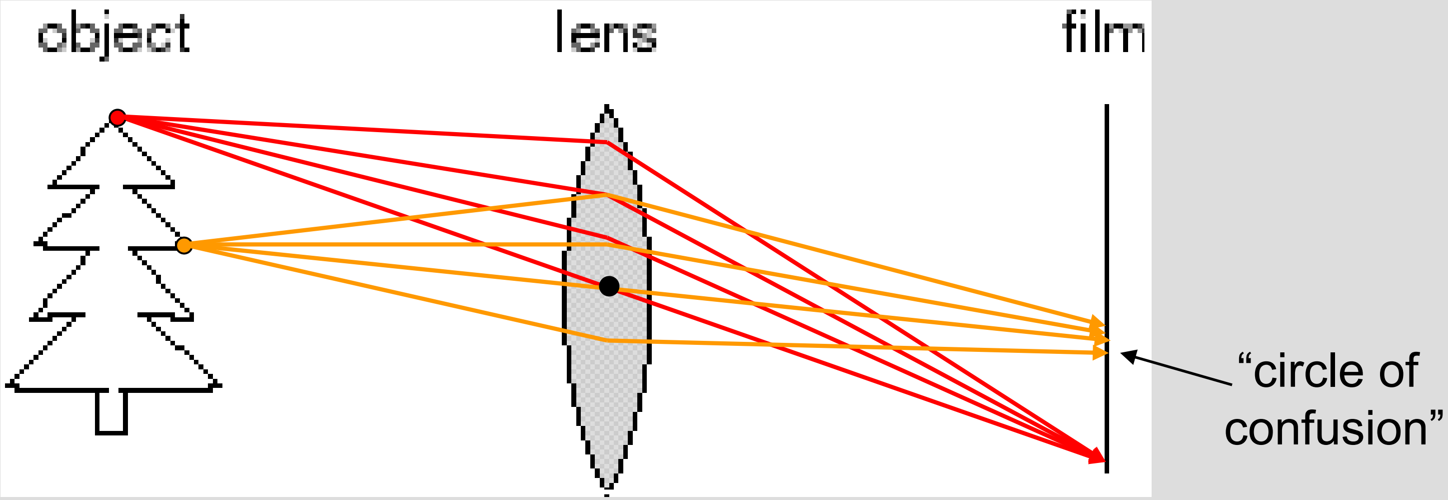
Shrinking the aperture



Less light gets through

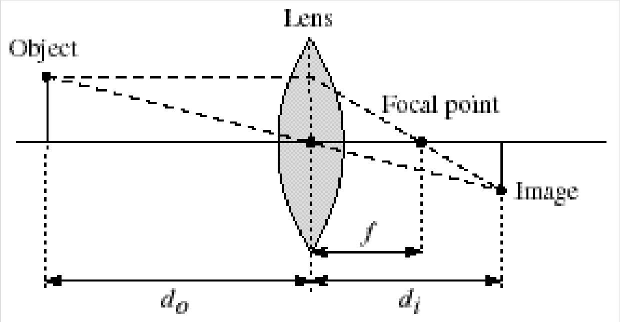
- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effects…

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
  - Changing the shape of the lens changes this distance

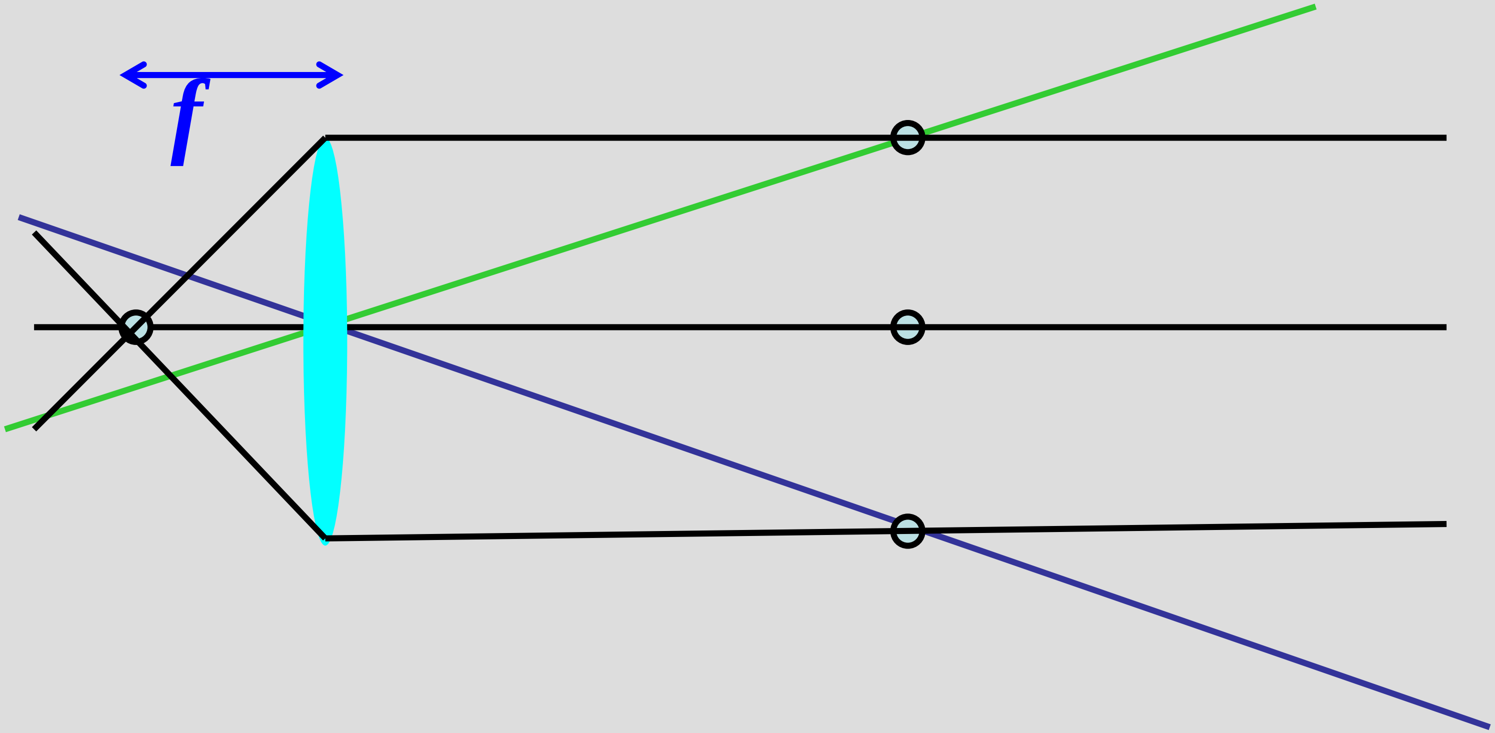
Thin lenses



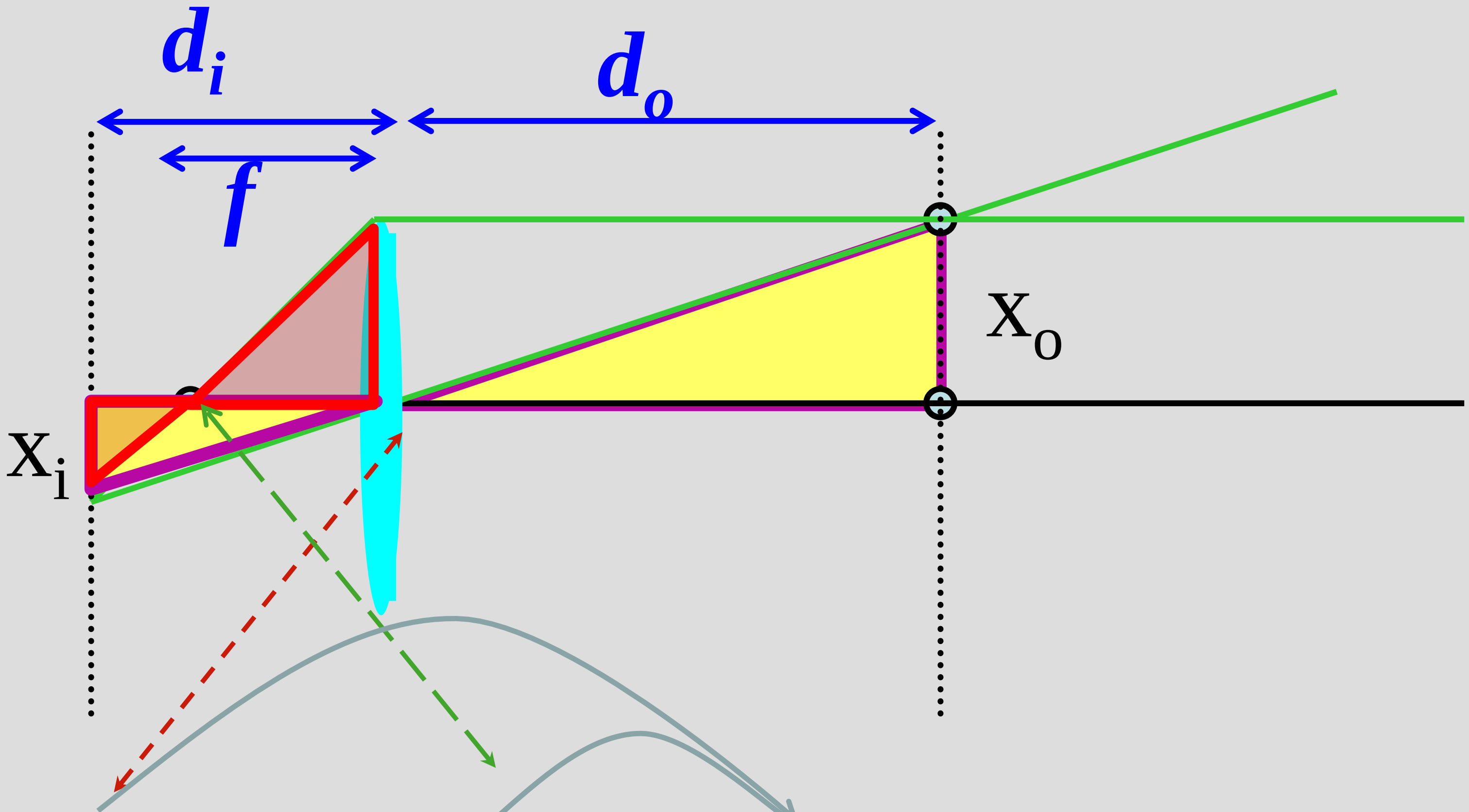
- Thin lens equation: $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$
  - Any object point satisfying this equation is in focus
  - Thin lens applet http://graphics.stanford.edu/courses/cs178/applets/gaussian.html

Ray Tracing and Lenses

- Rays through the center are straight lines (green)
- Parallel Rays focus on a single point (black) in focus plane given by f



General Position



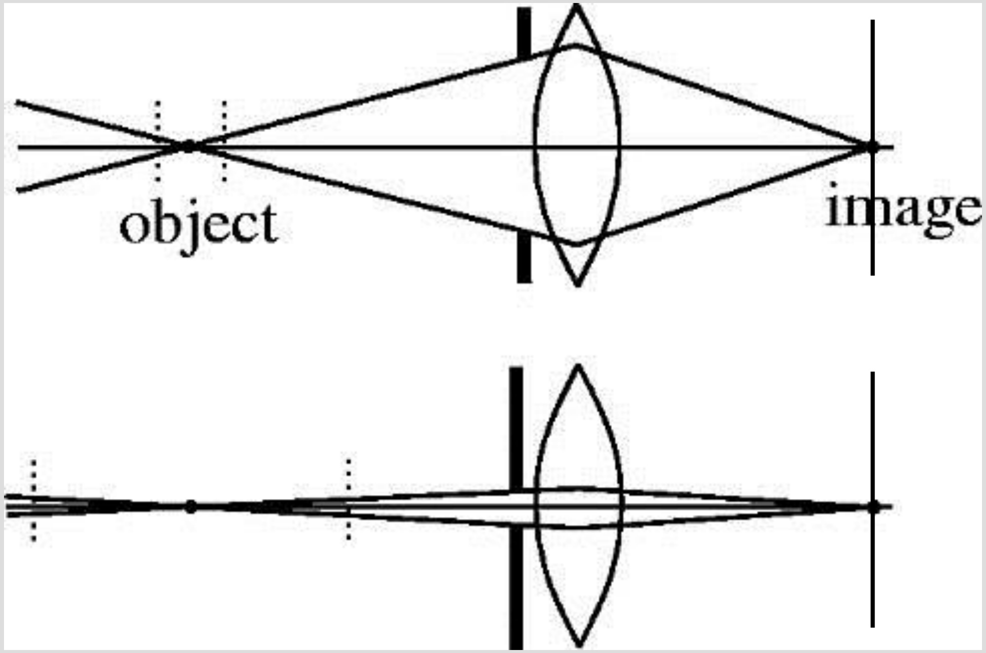
$x_i/d_i = x_o/d_o$ $\quad$ $x_i/(d_i - f) = x_o/f$ $\quad$ $d_i/d_o = x_i/x_o = (d_i\text{-}f)/f \Rightarrow d_i/d_o = d_i/f - 1$

Depth of Field

Depth of field refers to the range of distance that appears acceptably sharp.

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

Aperture controls Depth of Field

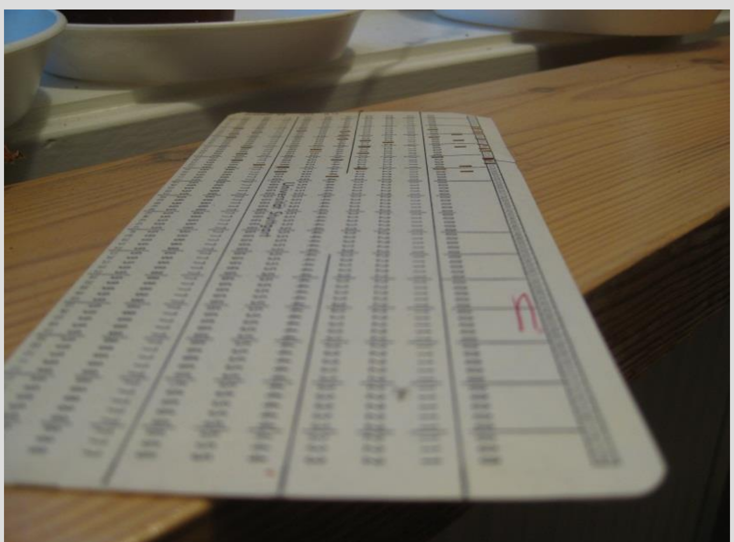


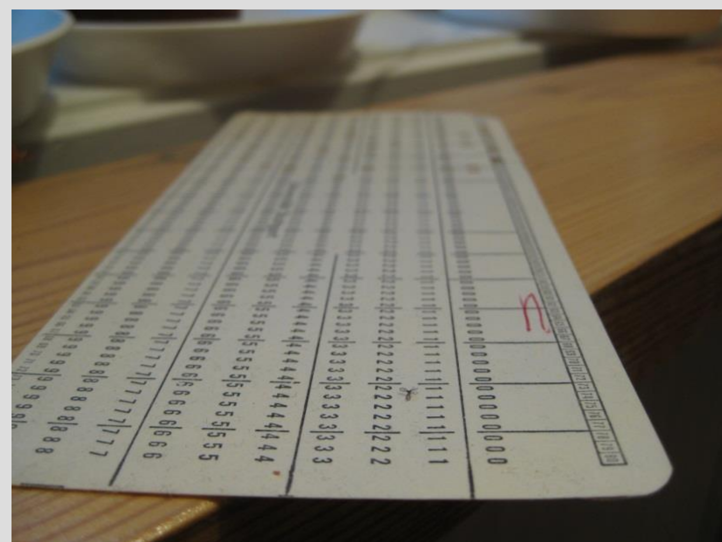
- Changing the aperture size affects depth of field
  - A smaller aperture increases the range in which the object is approximately in focus
  - But small aperture reduces amount of light – need to increase exposure

Example


Depth
of Field


DEPTH OF FIELD
DEPTH OF FIELD
DEPTH OF FIELD
DEPTH OF FIELD
DEPTH OF FIELD





Aperture & DoF

Large aperture = small DOF

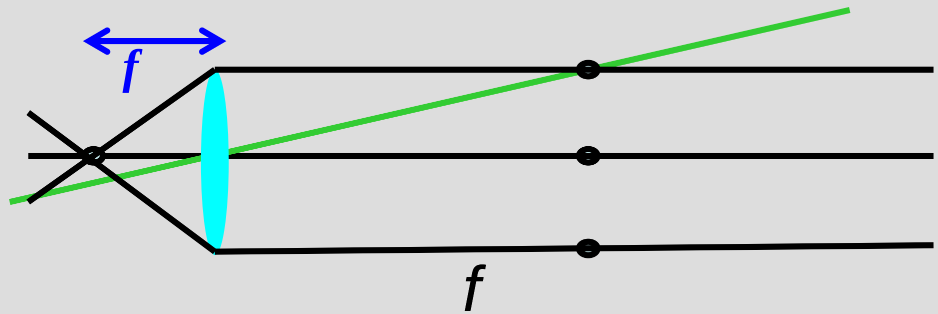
Small aperture = large DOF

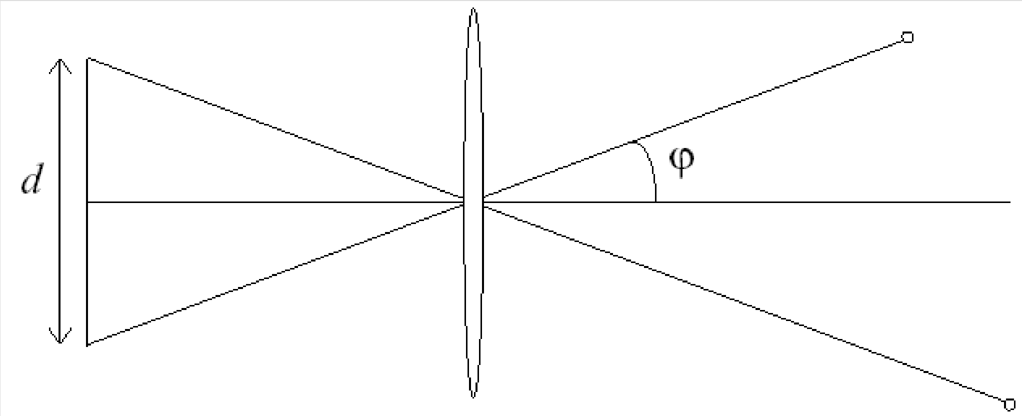
Field of View (FoV)

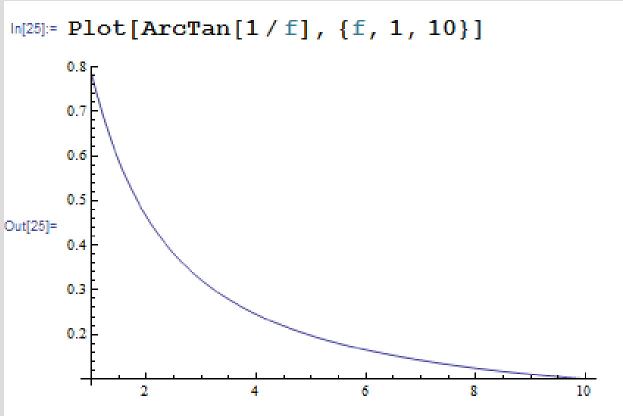
In photography, **angle of view** describes the angular extent of a given scene that is imaged by a camera. It is used interchangeably with the more general term **field of view**.

Wikipedia

FoV depends of Focal Length





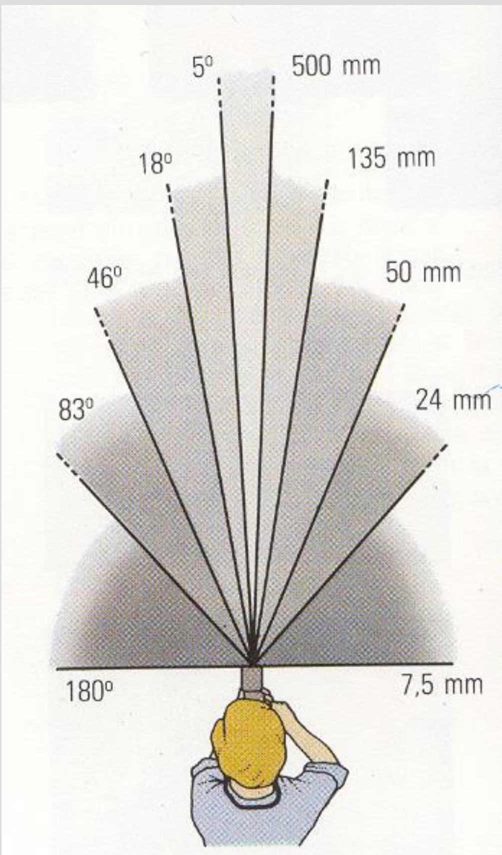


Size of field of view governed by size of the camera retina:

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

Smaller FoV = larger Focal Length

FoV – Zoom



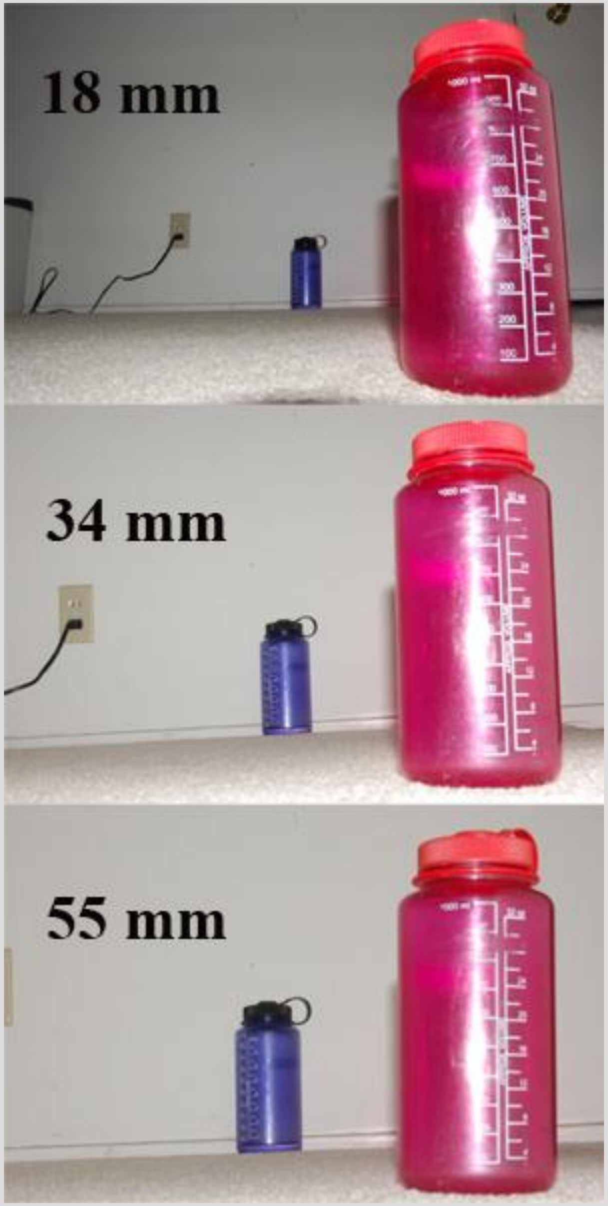

28 mm lens, 65.5° × 46.4°


50 mm lens, 39.6° × 27.0°

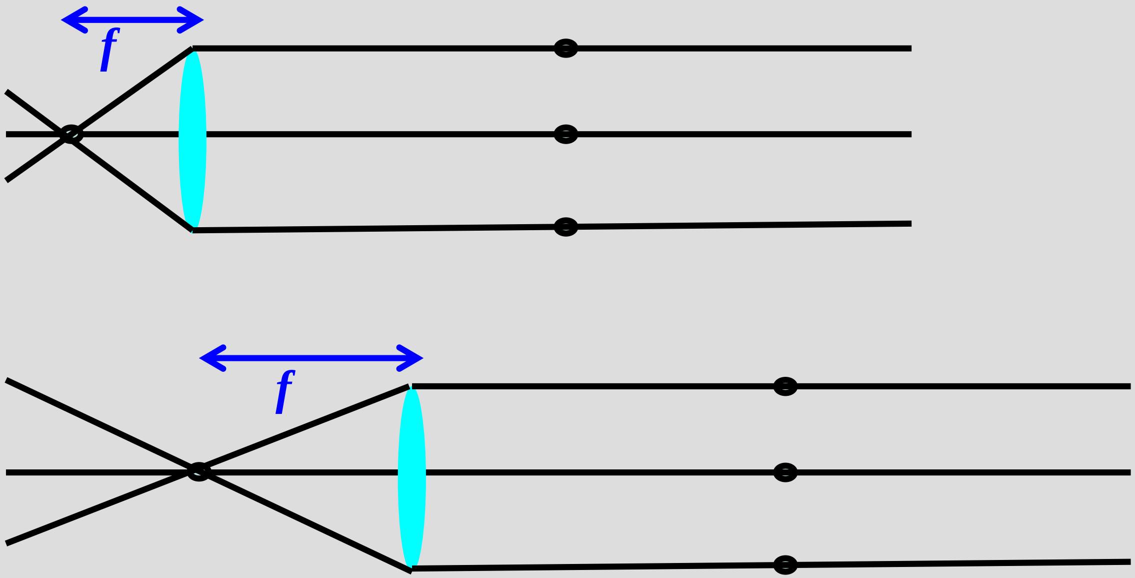

70 mm lens, 28.9° × 19.5°


210 mm lens, 9.8° × 6.5°

FoV - Perspective



Varying focal lengths at identical field size achieved by different camera-subject distances. Notice that the shorter the focal length and the larger the angle of view, perspective distortion and size differences increase.

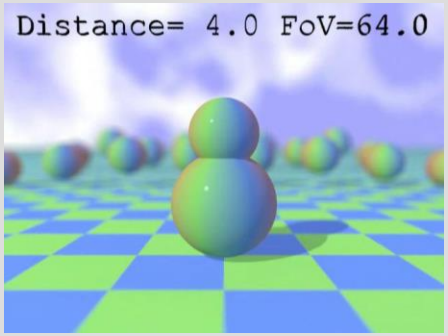


http://en.wikipedia.org/wiki/File:Focal_length.jpg

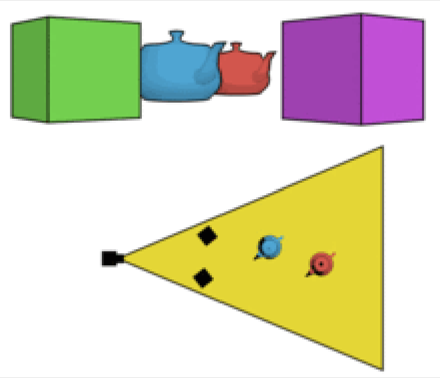
FoV Perspective Applet Stanford

http://graphics.stanford.edu/courses/cs178/applets/thinlens.html

Vertigo – Dolly Zoom



http://en.wikipedia.org/wiki/File:DollyZoomTest.ogv



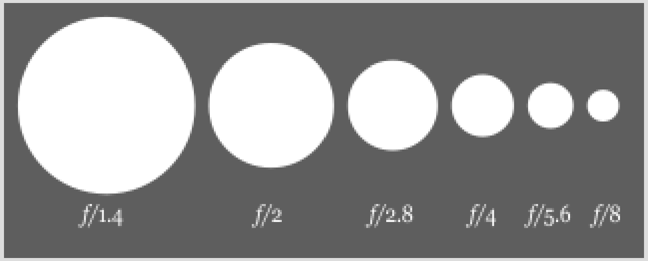
http://en.wikipedia.org/wiki/File:Contra-zoom_aka_dolly_zoom_animation.gif

http://www.youtube.com/watch?v=iv41W6iyyGs http://vimeo.com/84548119

Real Lenses

Aperture (f number)

- Expressed as ratio between focal length and aperture diameter:
- diameter = f / <f number>
- Small f number means large aperture



Amount of Light

Two basic ways to control the amount of light

Select aperture

Select exposure time

Usually fractions of a second

1/30, 1/60, 1/125, 1/250 …

Rule-of-thumb for hand-held shots:

1/focal length

500mm tele = 1/500

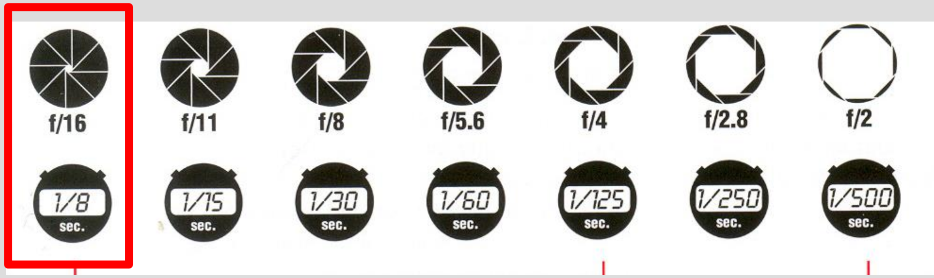
The same exposure is obtained with an exposure twice as long and

an aperture area half as big

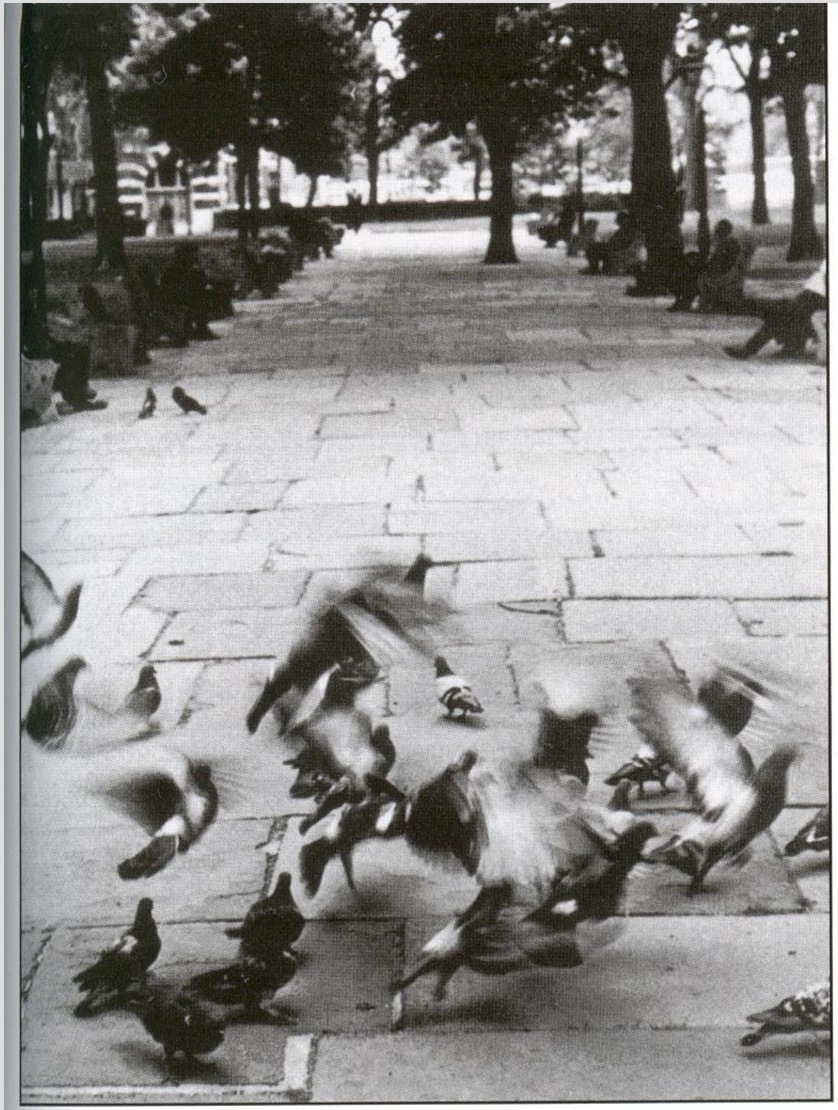
(therefore $\sqrt{2}$ steps in aperture)

Illustration

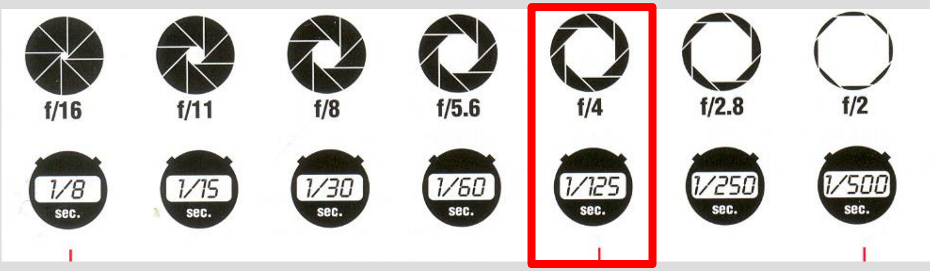
Small aperture (deep depth of field), slow shutter speed (motion blurred). *In this scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons sharp. It also meant that a tripod had to be used to hold the camera steady.*



From Photography, London et al.

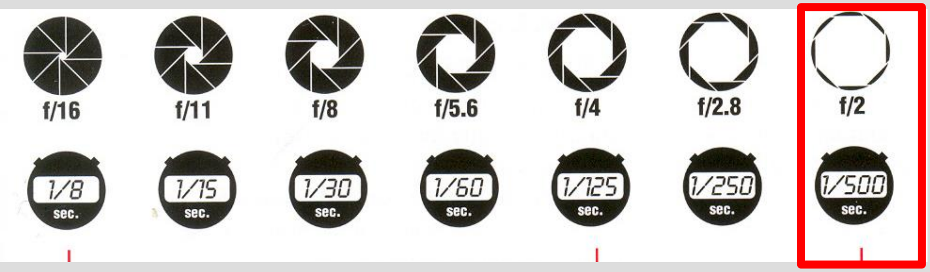


Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). *A medium aperture (f/4) and shutter speed (1/125 sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.*



From Photography, London et al.

Large aperture (shallow depth of field), fast shutter speed (motion sharp). A fa shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little dept of field that the background is now out of focus.

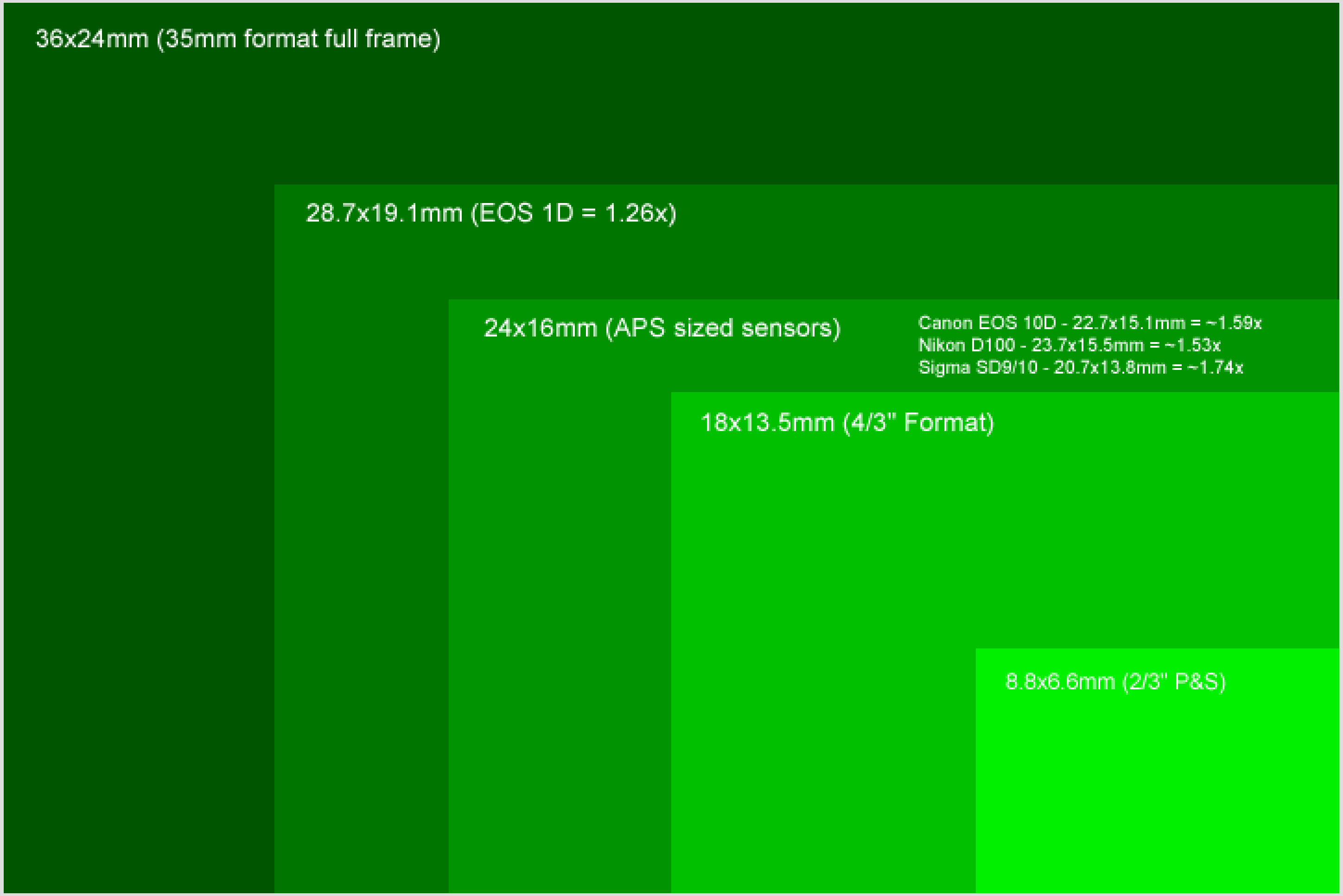


From Photography, London et al.

Effect of Shutter speed

Jaques Henri Lartigue, Grand Prix of the Automobile Club of France, 1912

Digital Sensors - Size



http://www.photozone.de/sensor-dimensions

Smaller Sensor = Cropping

	Sensor size (mm)	Resolution (pixels)	Pixel size (microns*)	Crop Factor
EOS 350D	22.2 x 14.8	3456 x 2304	6.4	1.6x
EOS 20D	22.5 x15	3504 x 2336	6.4	1.6x
EOS 5D	35.8 x 23.9	4368 x 2912	8.2	1x
EOS 1D Mk II N	28.7 x 19.1	3520 x 2336	8.2	1.3x
EOS 1Ds Mk II	36 x 24	4992 x 3328	7.2	1x

* 1 micron is one millionth of a meter or 1/1000 mm

Full frame DSLR
Red crop is 2745 x 1830 pixels with 5D

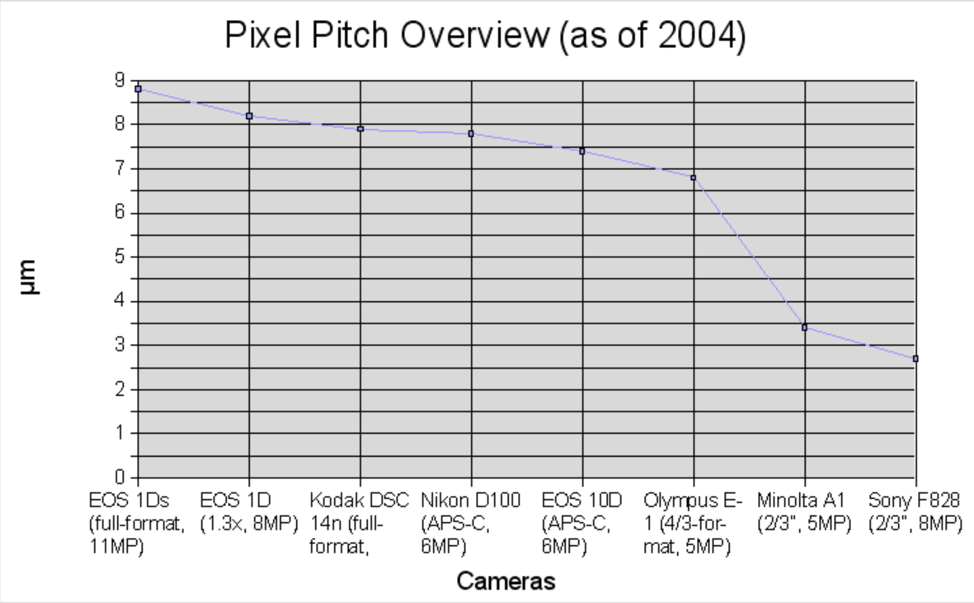
1.6x crop factor DSLR
3520 x 2336 pixels with 20D

http://www.photozone.de/sensor-dimension

Megapixel

A larger area of a sensor element means usually lower noise

http://www.photozone.de/pixel-pitch



Megapixels vs Print-Size

Technology - Technology

"How many megapixels do I really need for my purposes" - a quite common question. The following table provides an overview of megapixels in relation to the max. recommended print size - *ROUGHLY*. A print resolution of 300dpi corresponds to magazine quality. "Acceptable" prints don't require 300dpi but e.g. 2MP will not scale to something like 20x30cm without a severe loss of quality.

Megapixels	Resolution	common print size (rougly 300dpi)
2 MP	1600x1200	10x13cm / 4x6"
3 MP	2048x1536	13x18cm / 5x7"
4 MP	2400 x 1600	18x23cm / 6x8"
6 MP	3000x2000	20x30cm / 7x10"
8 MP	3600x2400	30x40cm / 10x14"
12 MP - better more	4200x2800	40x60cm / 16x24"

ISO

For films ISO specifys how sensitive the file is 200 ISO is twice as sensitive as 100 ISO

For digital sensors ISO chemistry is replaced by a change of parameters that map sensor measurements to pixel values

Higher ISO values imply higher noise levels

ISO


And so it was indeed: she was now only ten inches high, and her face brightened up at the thought that she was now the right size for going through the little door into that lovely garden. First, however, she waited for a few minutes to see if she was going to shrink any further: she felt a little nervous about this; 'for it might end, you know,' said Alice to herself, 'in my going out altogether, like a candle. I wonder what I should be like then?' And she tried to fancy what the flame of a candle is like after the candle is blown out, for she could not remember ever having seen such a thing.
ISO 80


ISO12800

Color

Sensor elements are color blind:

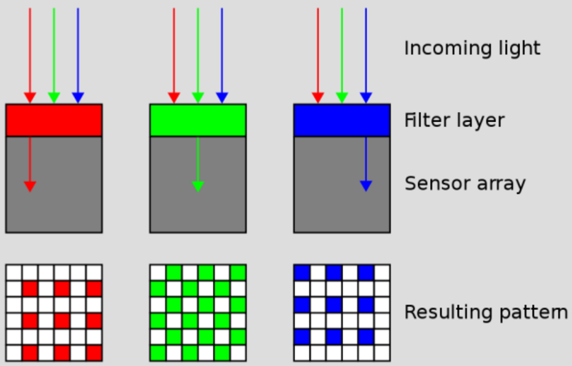
They convert (incoming photons/ time interval) to a number

After the photon has interacted with the sensor

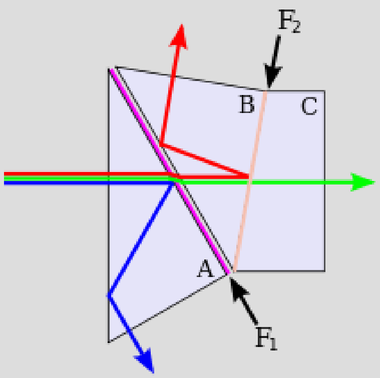
all information about the wavelength of the photon is lost

Color Sensors

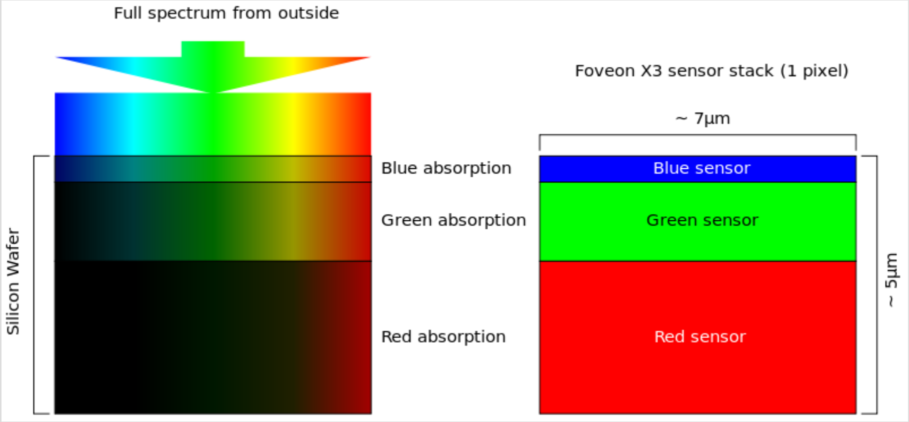
Most common Bayer
filter on a single sensor



Most expensive
three sensors and a prism



Foveon (Sigma) sensor

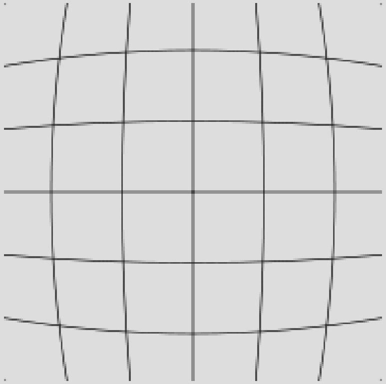


Nothing is Perfect

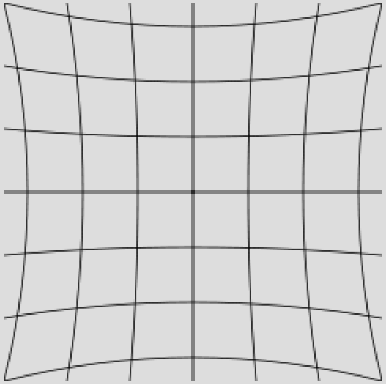
Chromatic Aberrations

Not all colors are focused on the same point

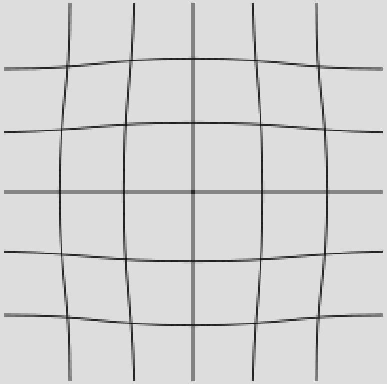
Geometrical Distortions



Barrel



Pincushion



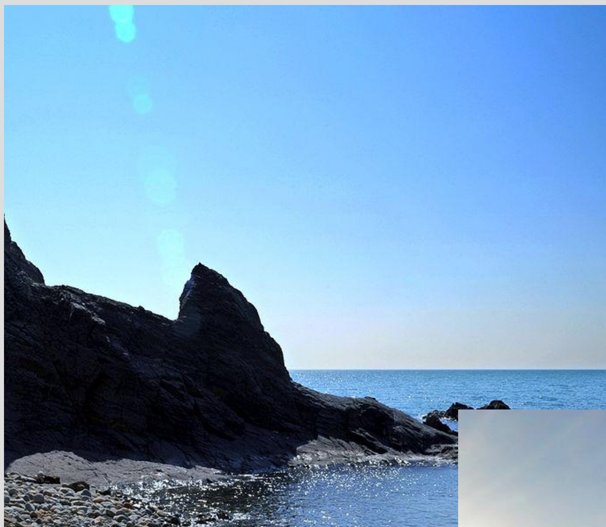
Mustache

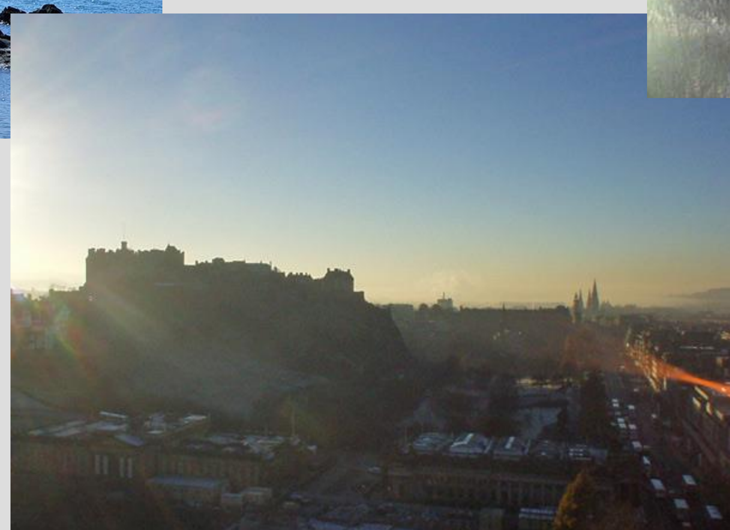
Vignetting

Lower intensity the corners

Lens Flare

Lens flare is the light scattered in lens systems through generally unwanted image formation mechanisms, such as internal reflection and scattering from material inhomogeneities in the lens. (Wikipedia)





Summary

- Why do we need a camera
- Basic properties of a pinhole camera, thin lenses
- Role of aperture size
- Depth of field (DoF)
- Field of view (FoV)
- Dolly Zoom
- Amount of light (aperture and exposure time)
- ISO
- Bayer pattern and color sensors
- Nothing is perfect: aberrations – distortions - errors