Image Formation

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COMP 4900D

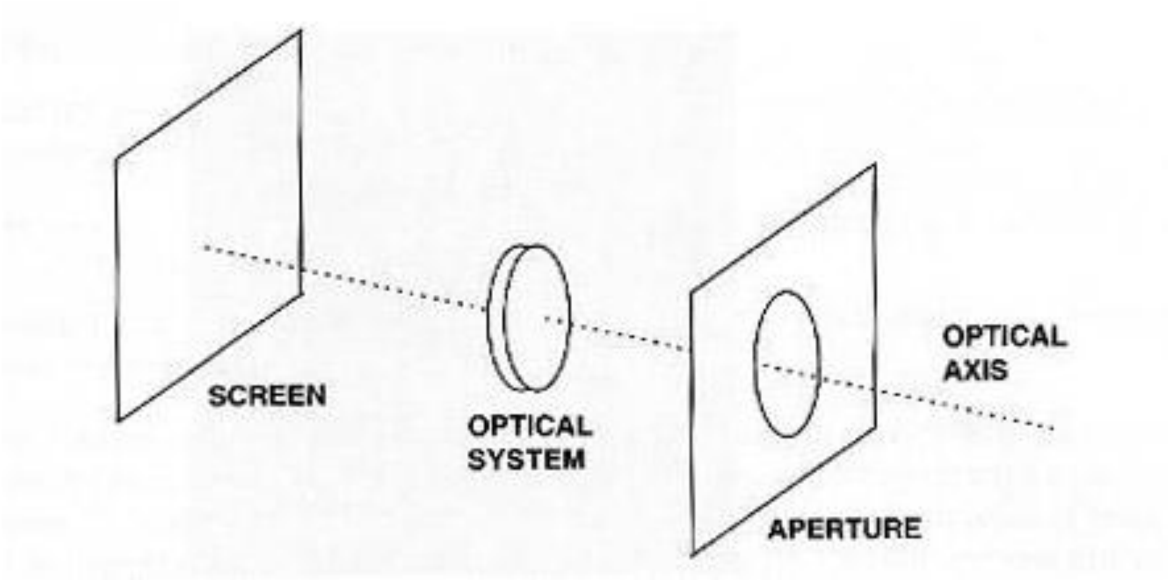
Winter 2011

Image Formation

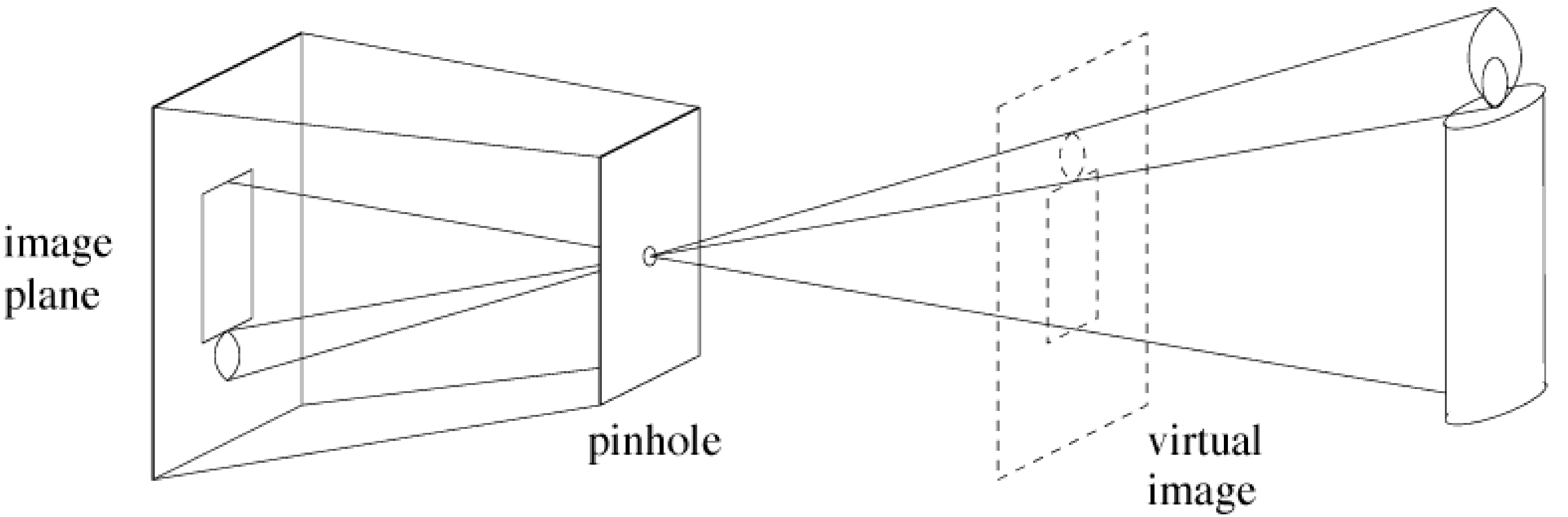
- Two type of images
  - Intensity– image encodes light intensities (passive sensor)
  - Range (depth)– image encodes shape and distance
    - Created from processing passive images or by an active sensor
- Intensity image is a function of three things
- Optical parameters of the lens
  - Lens type, focal length, field of view, angular apertures
- Photogrammetric (Radiometric) parameters
  - Type, direction and intensity of the illumination
  - Reflectance properties of the viewed surface
  - Characteristics of the image sensor
- Geometric parameters
  - Type of projection, position and orientation of camera

Elements of an imaging device

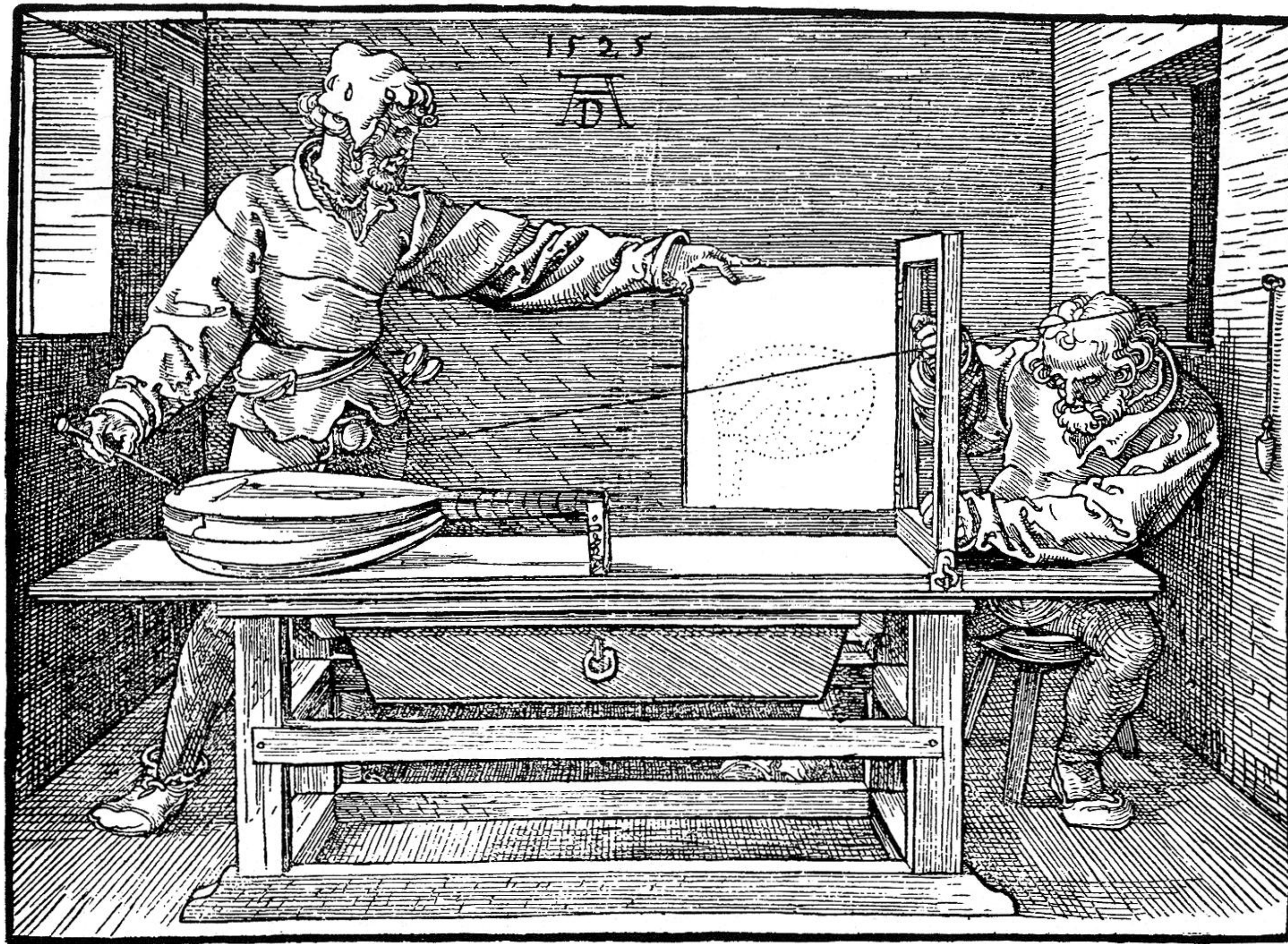
Light rays coming from outside world and falling on the photoreceptors in the retina.



Pinhole Camera

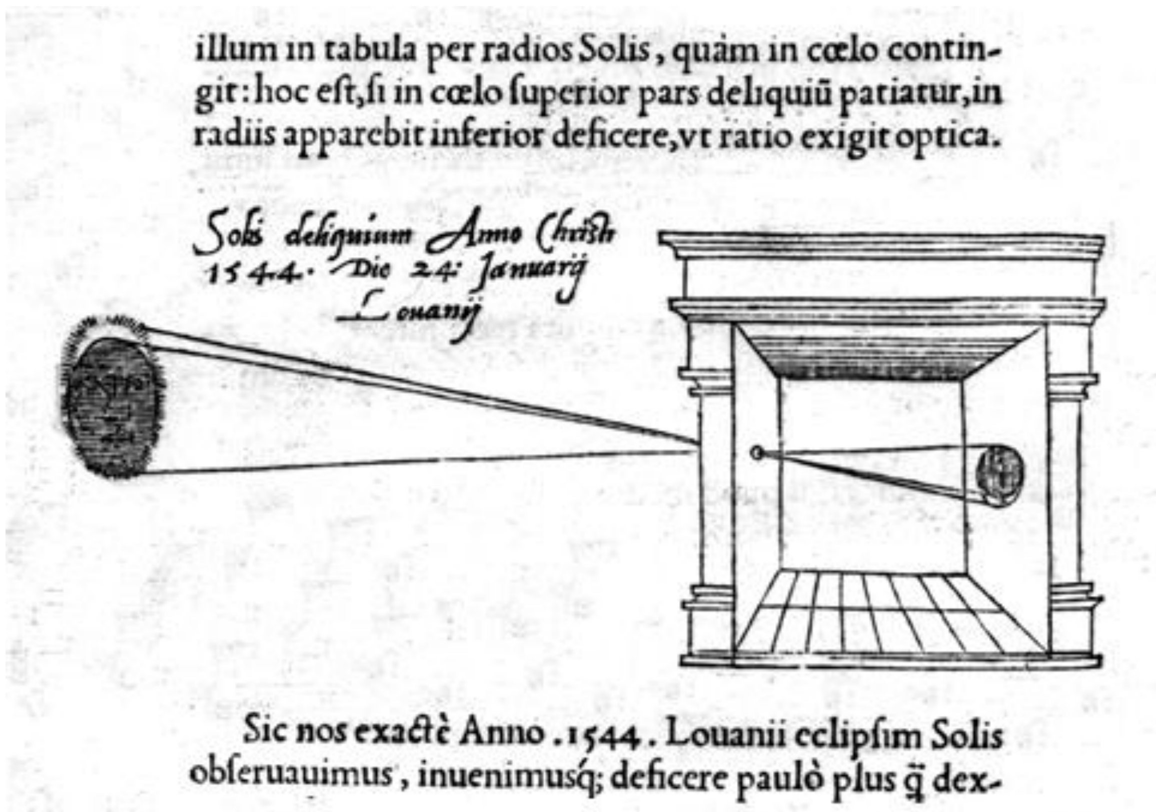


Perspective Projection



Draughtsman Drawing a Lute, Albrecht Dürer, 1525

Camera Obscura


illum in tabula per radios Solis, quàm in cœlo contin-
git: hoc eſt, ſi in cœlo ſuperior pars deliquiũ patiatur, in
radiis apparebit inferior deficere, vt ratio exigit optica.

Sic nos exactè Anno .1544. Louanii eclipſim Solis
obſeruauimus, inuenimusq; deficere paulò plus q̃ dex-

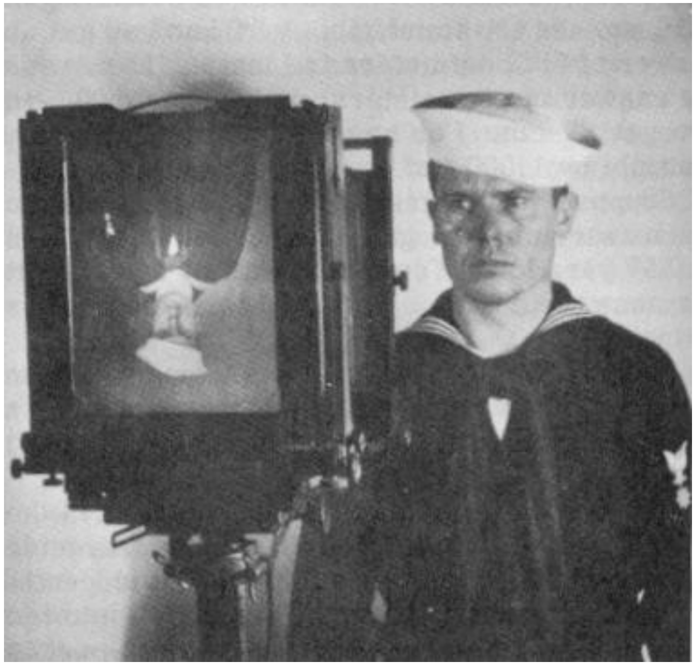
Camera Obscura, Reinerus Gemma Frisius, 1544

Camera Obscura: Latin ‘dark chamber’

Camera Obscura

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.

Photographic Camera

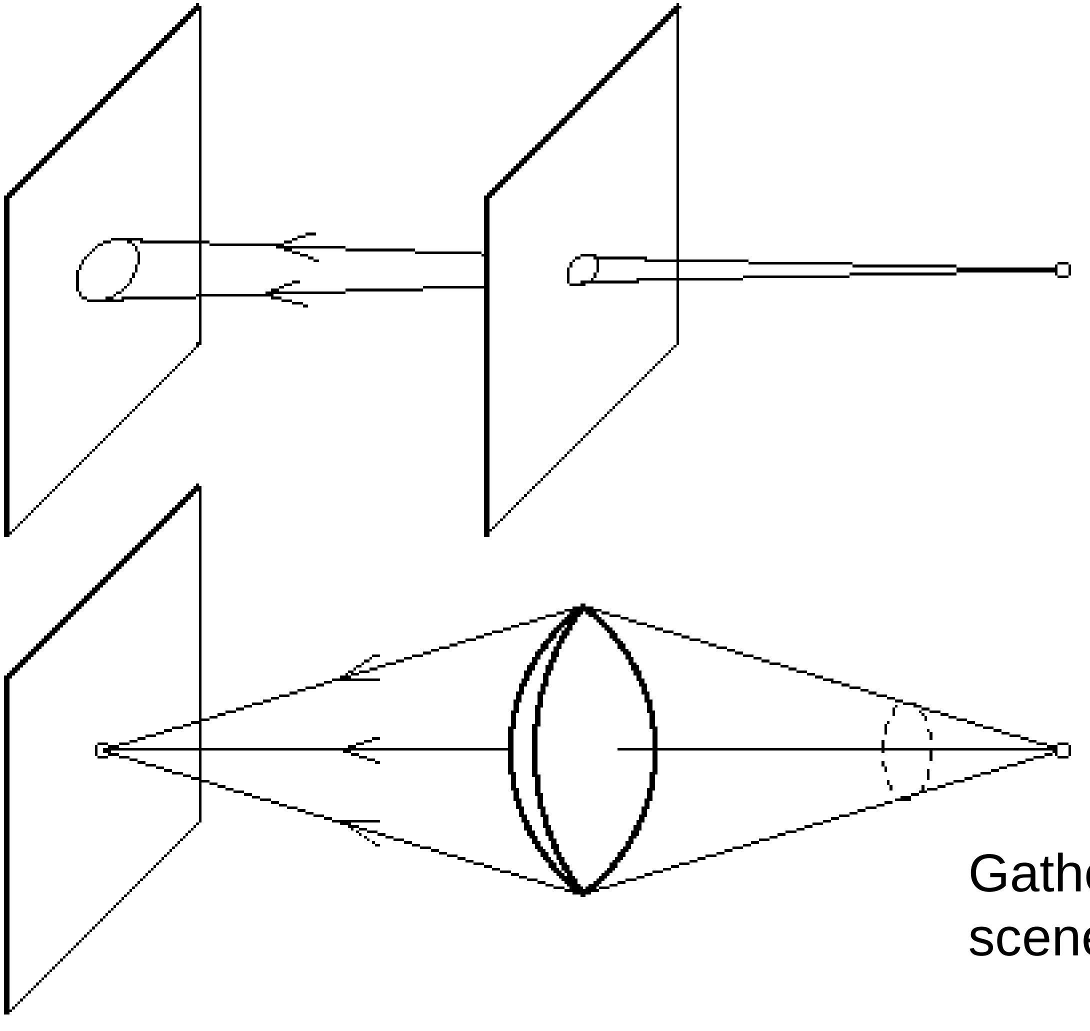


Photographic camera: Joseph Nicéphore Niepce, 1816

First Photograph

First photograph on record, *la table servie*, obtained by Niepce in 1822.

Why Lenses?



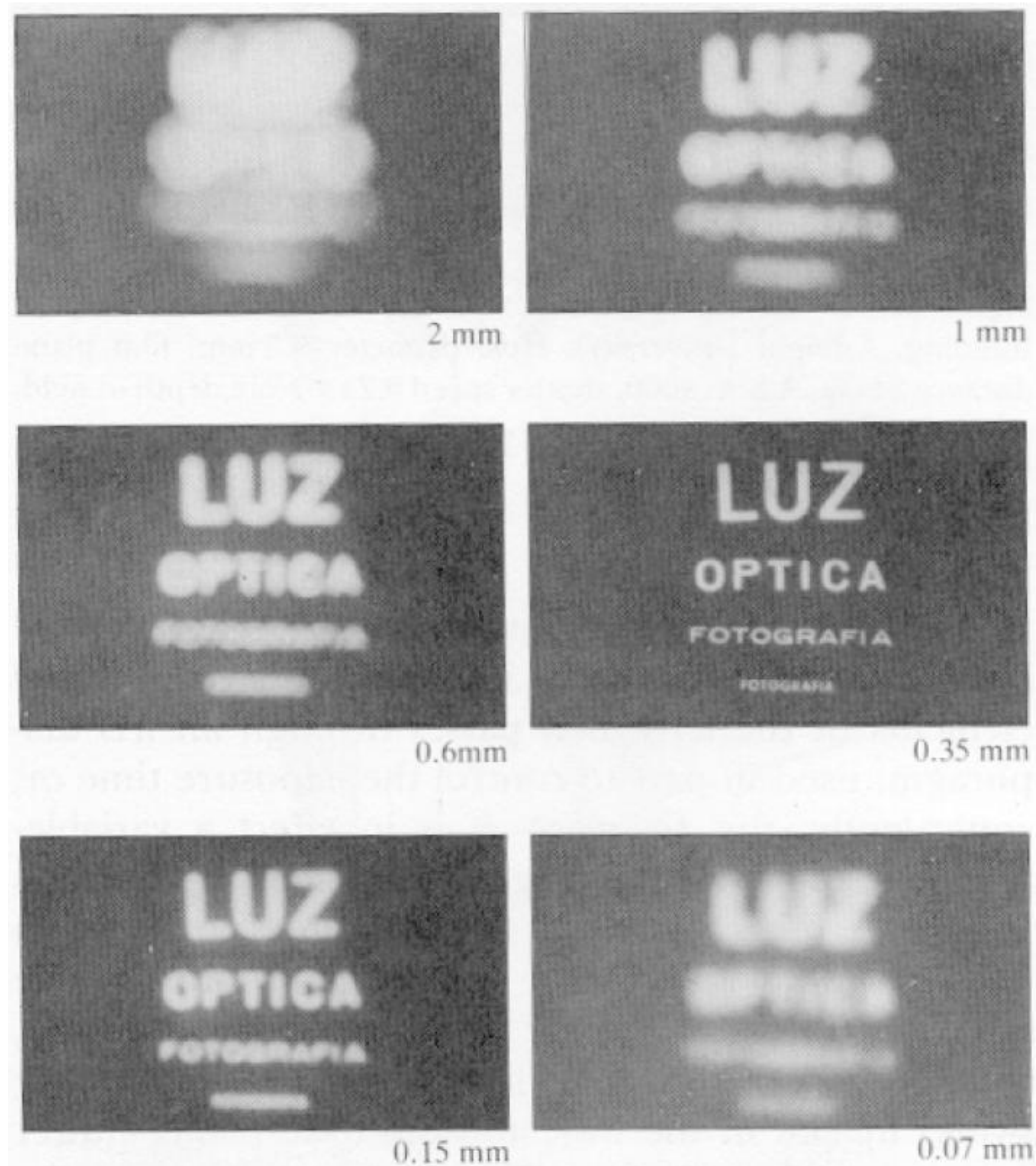
Gather more light from each scene point

Why Lenses?

•Pinhole too big - many directions are averaged, blurring the image

•Pinhole too small - diffraction effects blur the image

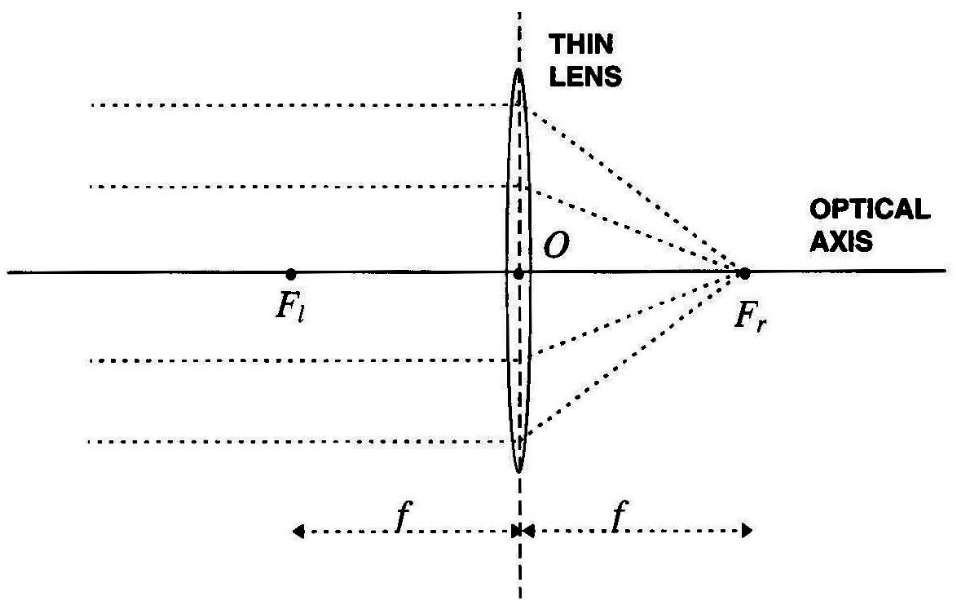
•Generally, pinhole cameras are *dark*, because a very small set of rays from a particular point hits the screen.



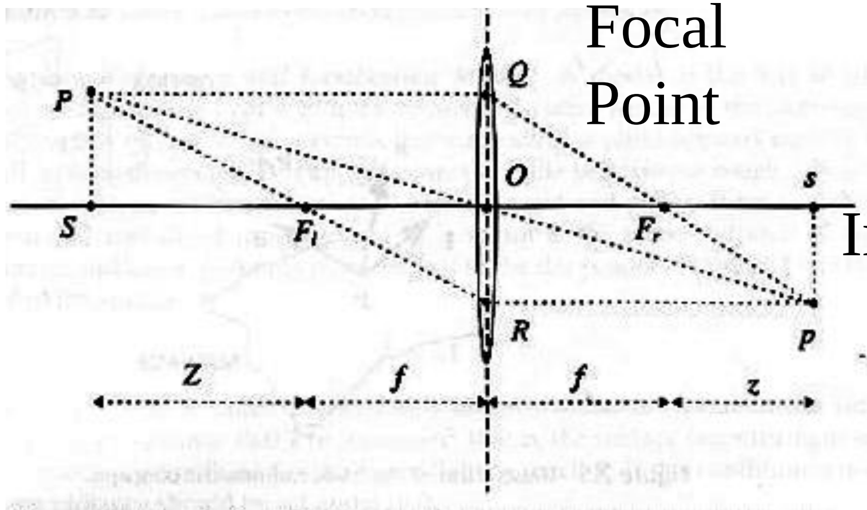
Camera with Lens - Thin Lens Model

- Lens thickness small compared to focal length
- Basic properties

1. Any ray entering the lens parallel to the axis on one side goes through the focal point on the other side.
2. Any ray entering the lens from the focal point on one side emerges parallel to the axis on the other side.



Fundamental Equation of Thin Lenses



$$\hat{Z} = Z + f \qquad \hat{z} = z + f$$

Effective Focal length

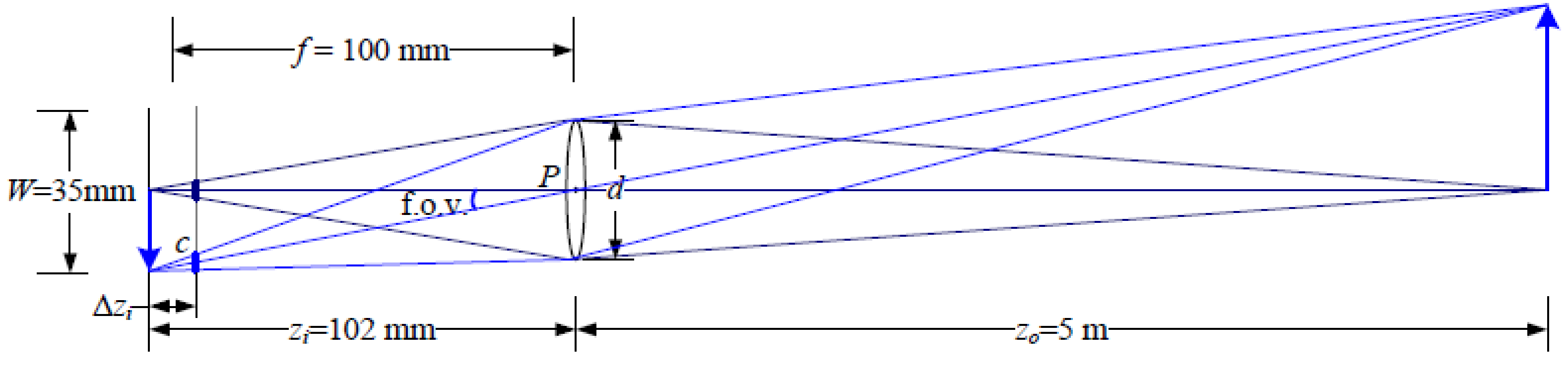
$$\frac{1}{\hat{Z}} + \frac{1}{\hat{z}} = \frac{1}{f}$$

Any point satisfying this equation is in focus

Proof uses similar triangles: $PSF_l \sim ORF_l$ and $QOF_r \sim spF_r$ and fact that $|PS| = |QO|$ and $|sp| = |OR|$

Thin Lenses

- As the point goes to infinity the focal length approaches f, the value for a pin hole camera
- For a lens we can adjust focus ring to move the lens and aperture ring to change aperture
- Both of these adjustments affect what is called the depth of field

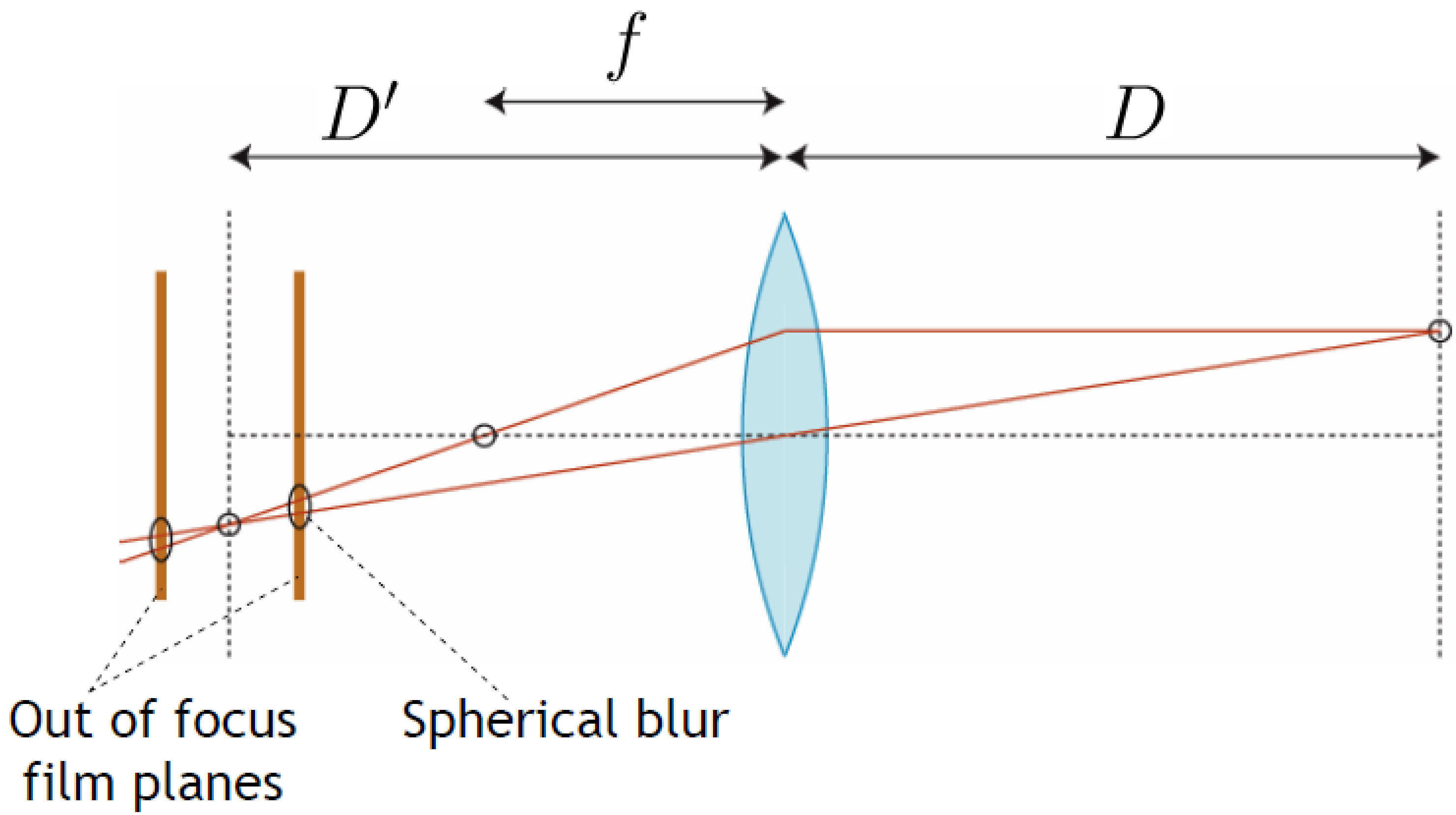


Thin lens applet:

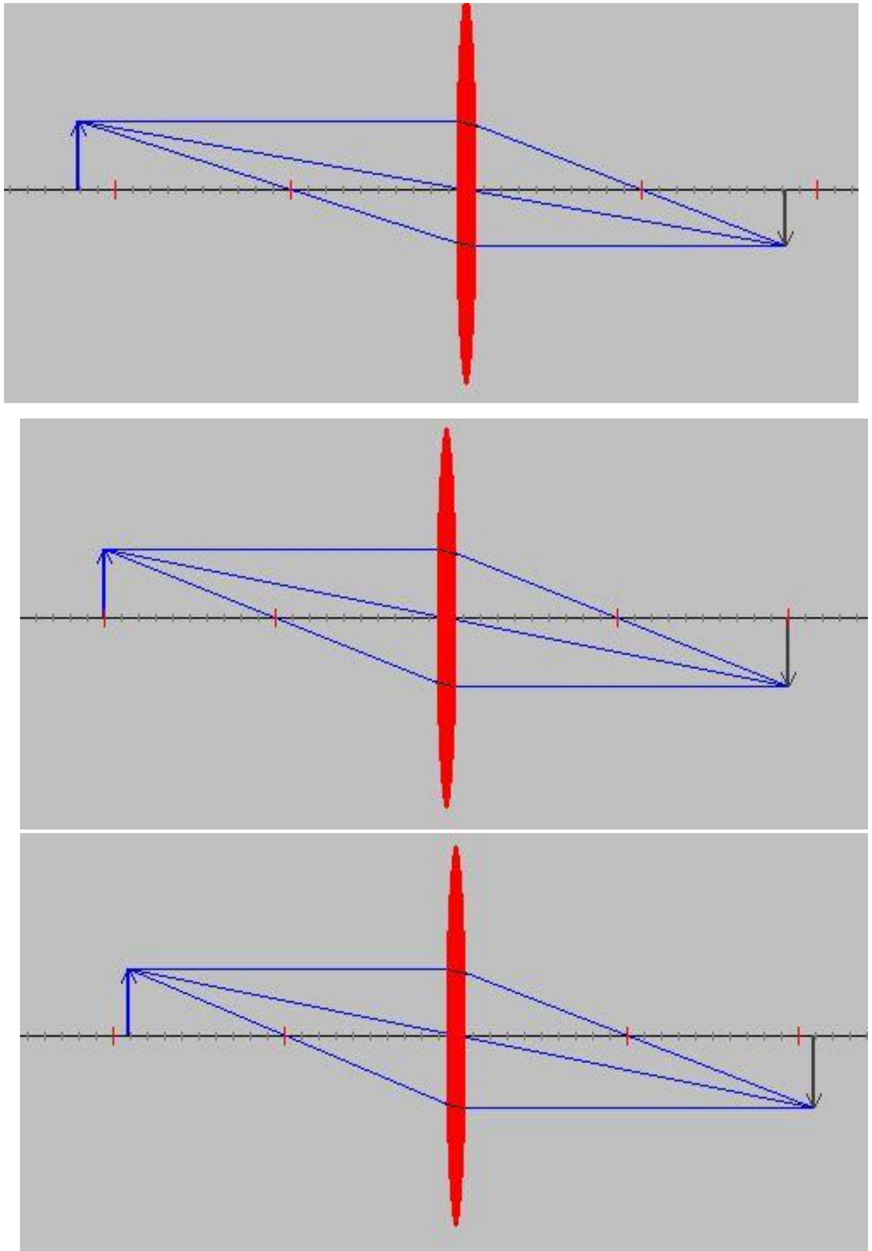
http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html

Depth of field

- Point is in focus over a given distance which is called the depth of field



Depth of field

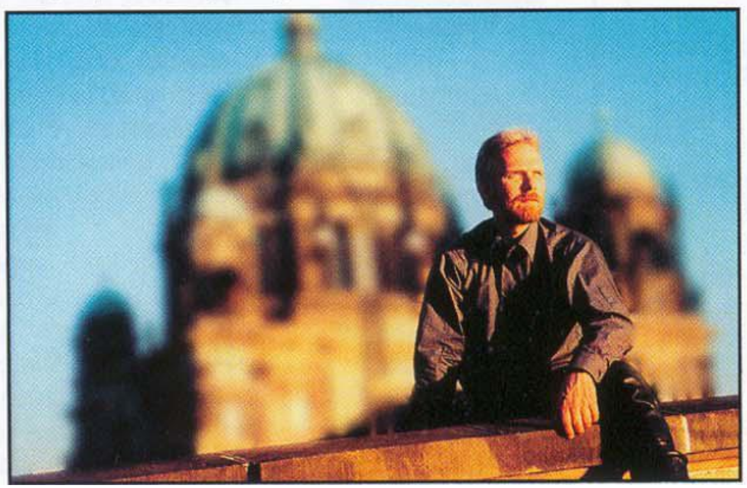


Depth of field

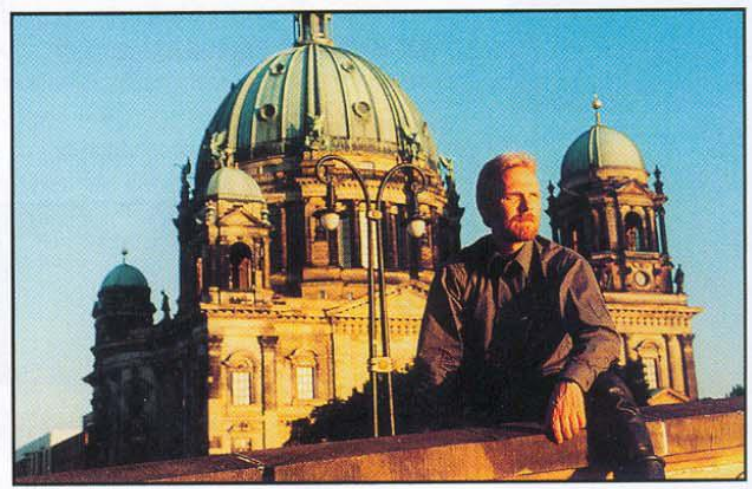
Aperture size

- Blurriness of out of focus objects depends on the aperture size
- Larger aperture means smaller depth of field but it also lets in more light

Large aperture opening



Small aperture opening



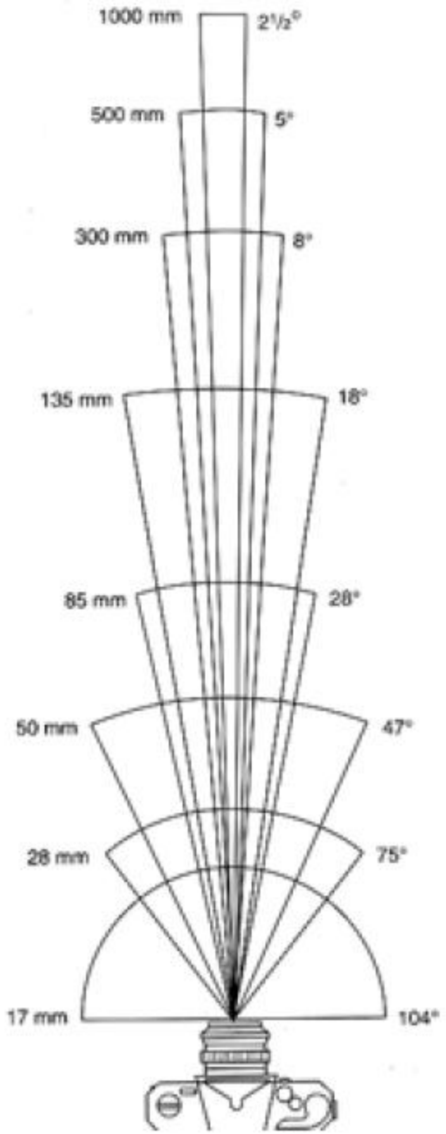
Varying the aperture

Large apeture = small DOF

Small apeture = large DOF

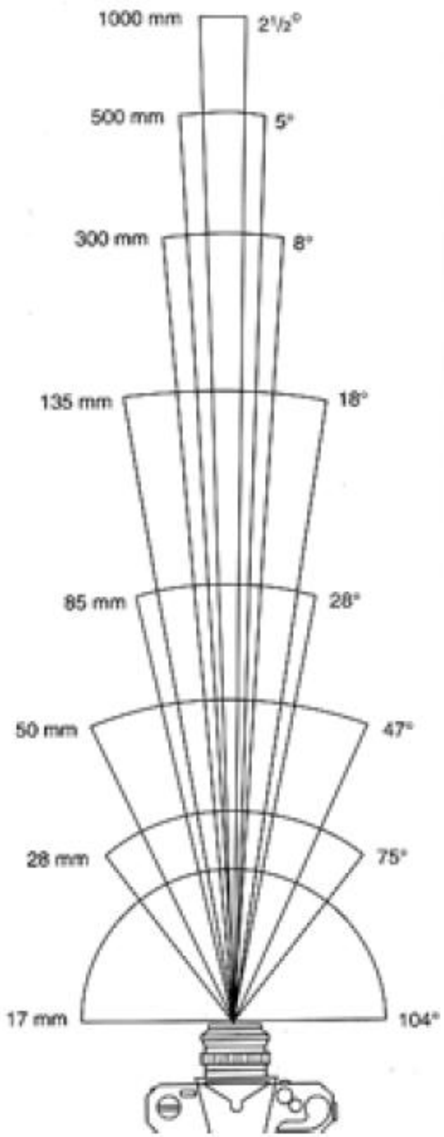
Nice Depth of Field effect

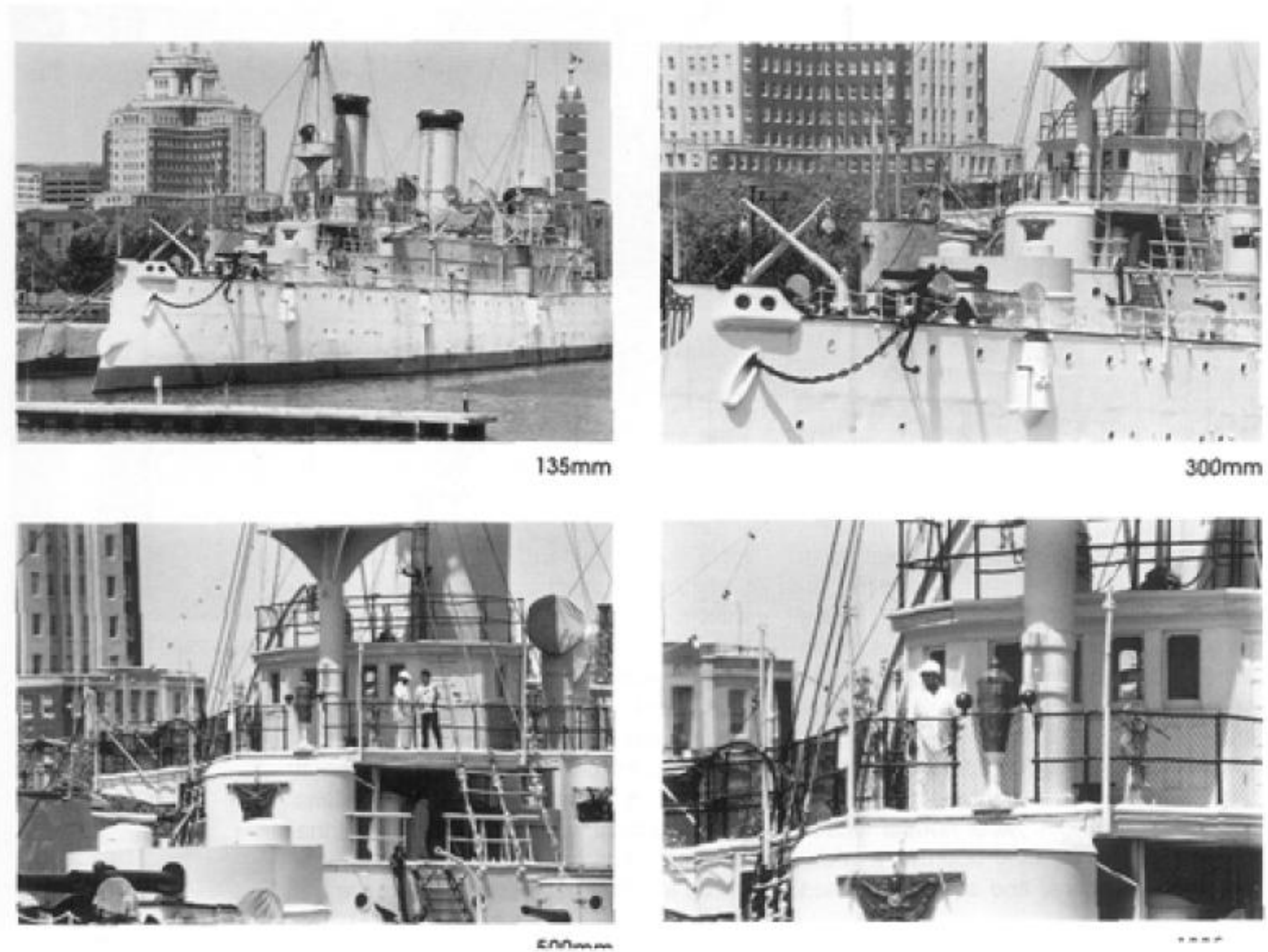
Field of View (Zoom)



From London and Upton

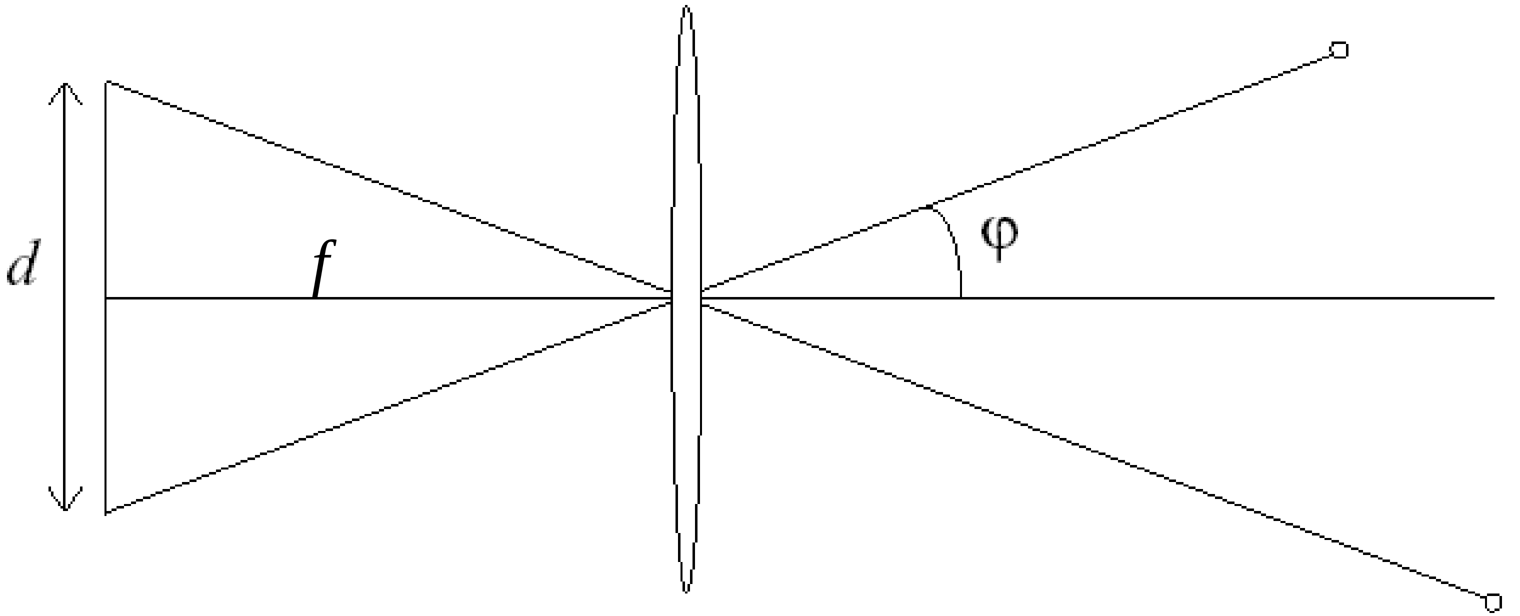
Field of View (Zoom)





From London and Upton

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

Field of View / Focal Length

Large FOV, small f
Camera close to car

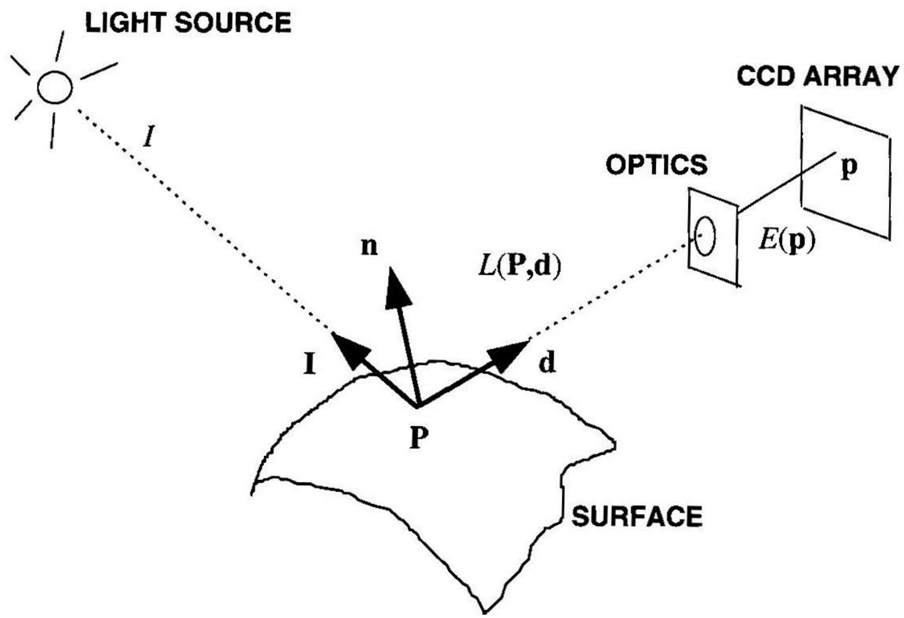
Small FOV, large f
Camera far from the car

Small field of view has wide angle,
but more perspective distortion

Basic radiometry

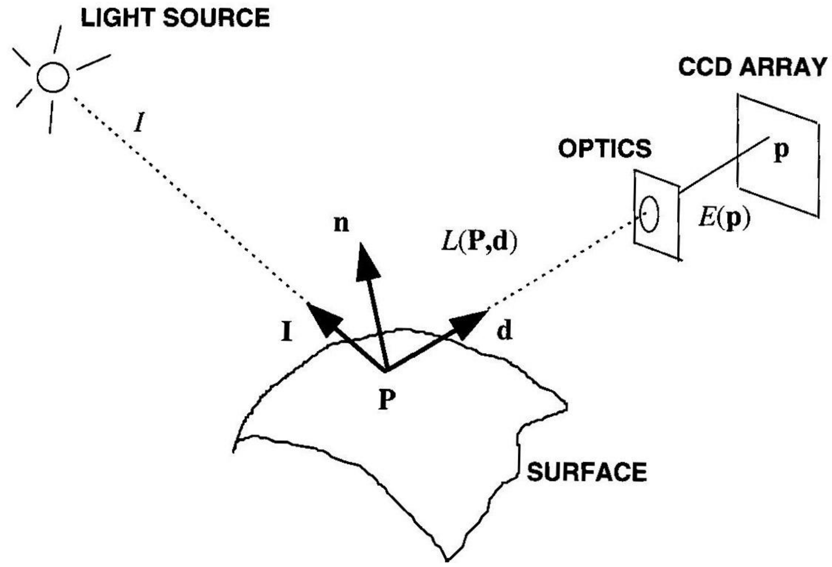
Image Irradiance: the power of light, per unit area and at each point p of the image plane.

Scene (surface) Radiance: the power of the light, per unit area, ideally emitted by each point p of a surface in 3-D space in a given direction.



Surface Reflectance for Lambertian

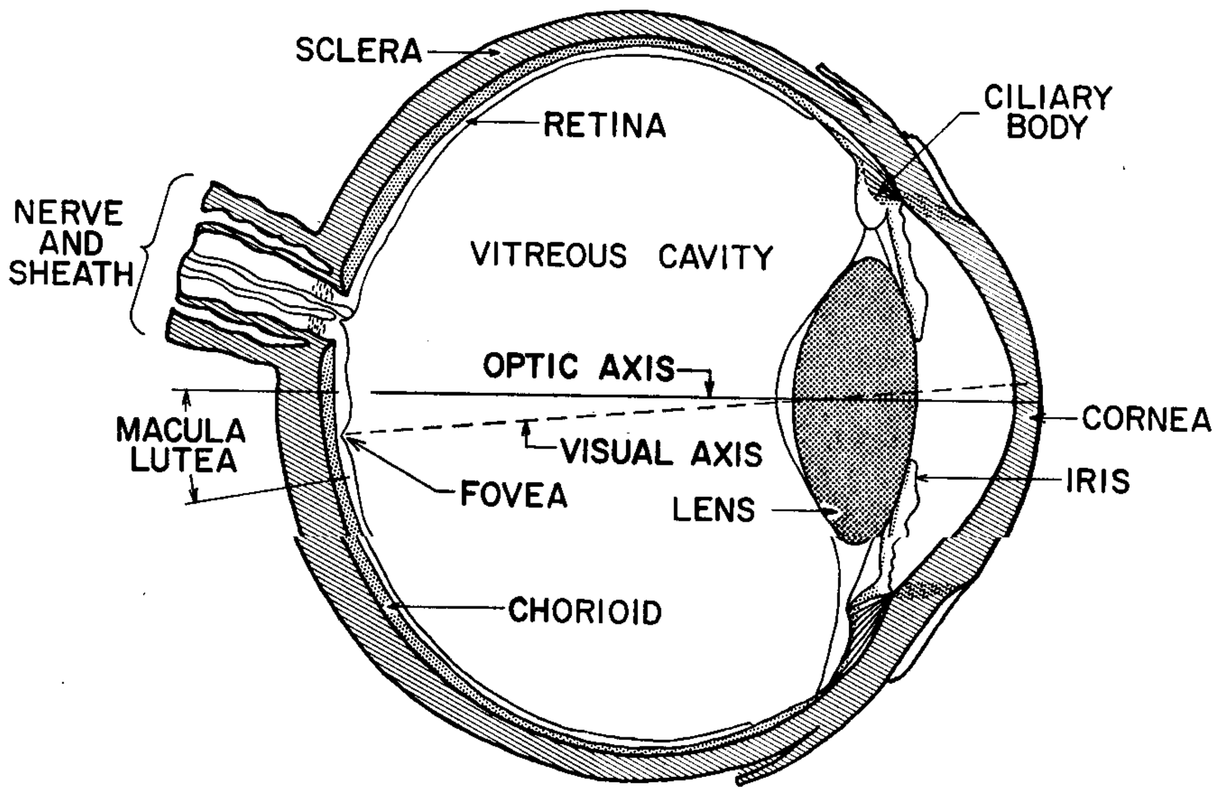
$$\mathbf{L} = \rho \mathbf{I}^T \mathbf{n}$$



ρ is called surface albedo and it depends on the surface material And L is scene irradiance

Lambertian model: each surface point appears equally bright from all viewing directions. Non specular surface.
Specular model: this is not true, looks brighter from some viewing directions (mirrors are very specular)

Human Eye


SCLERA
RETINA
CILIARY BODY
NERVE AND SHEATH
VITREOUS CAVITY
OPTIC AXIS
MACULA LUTEA
CORNEA
VISUAL AXIS
FOVEA
IRIS
LENS
CHORIOID

CCD (Charge-Coupled Device) Cameras

Small solid state cells convert light energy into electrical charge (sensing elements always rectangles and are usually square)

The image plane acts as a digital memory that can be read row by row by a computer

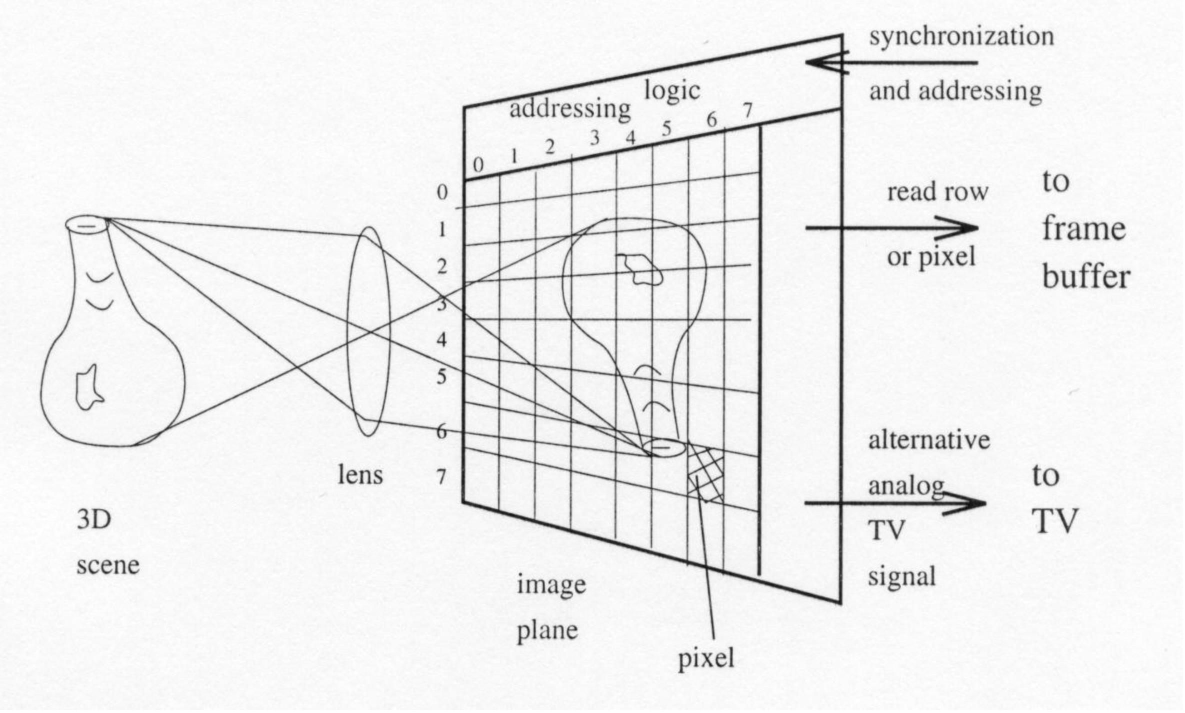
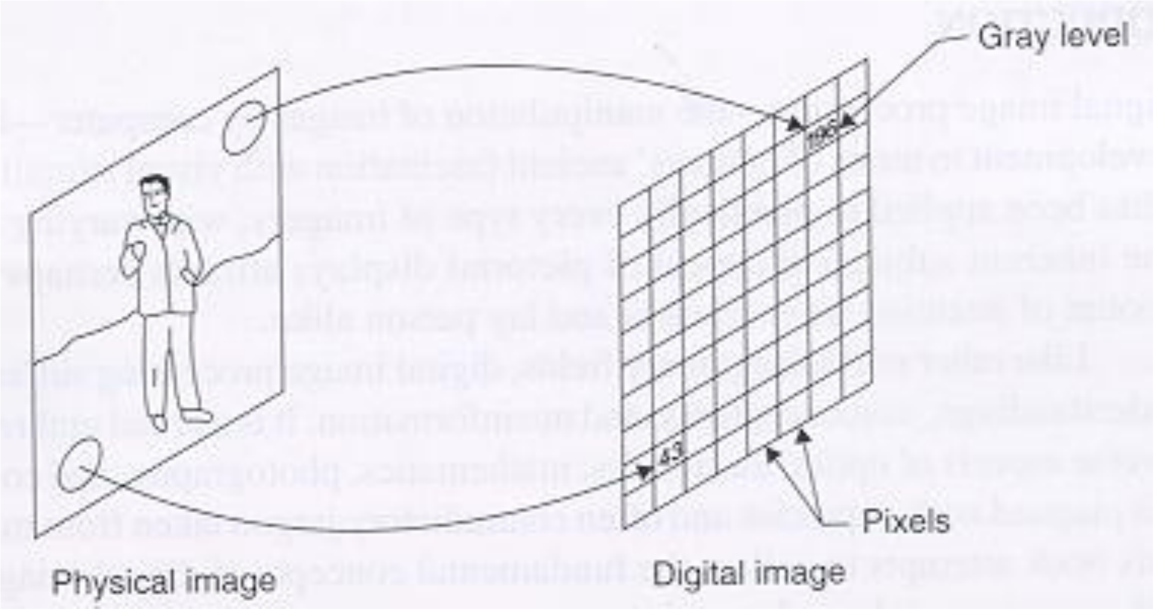


Image Digitization

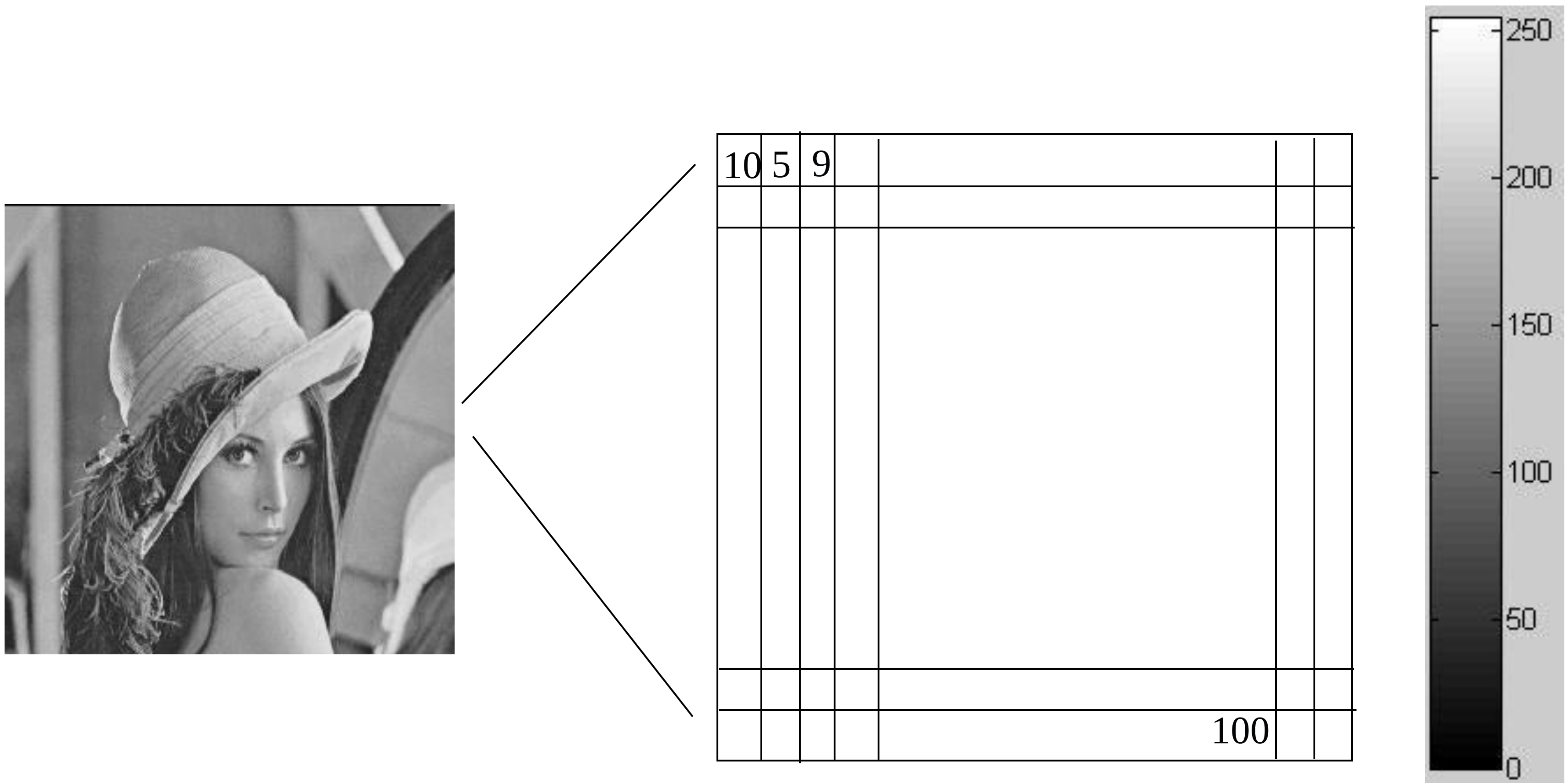


Sampling – measuring the value of an image at a finite number of points.

Quantization – representing the measured value at the sampled point, by an integer.

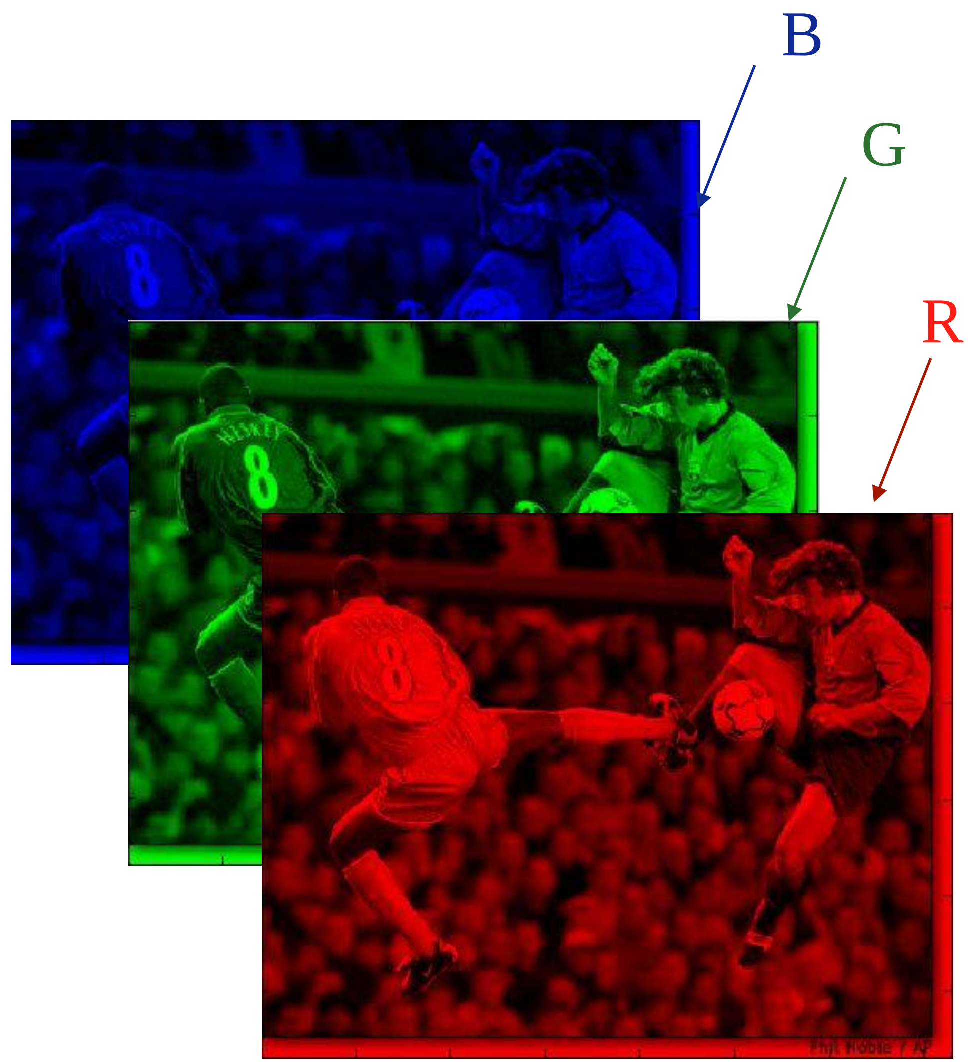
Pixel – picture element, usually in the range [0,255]

Grayscale Image



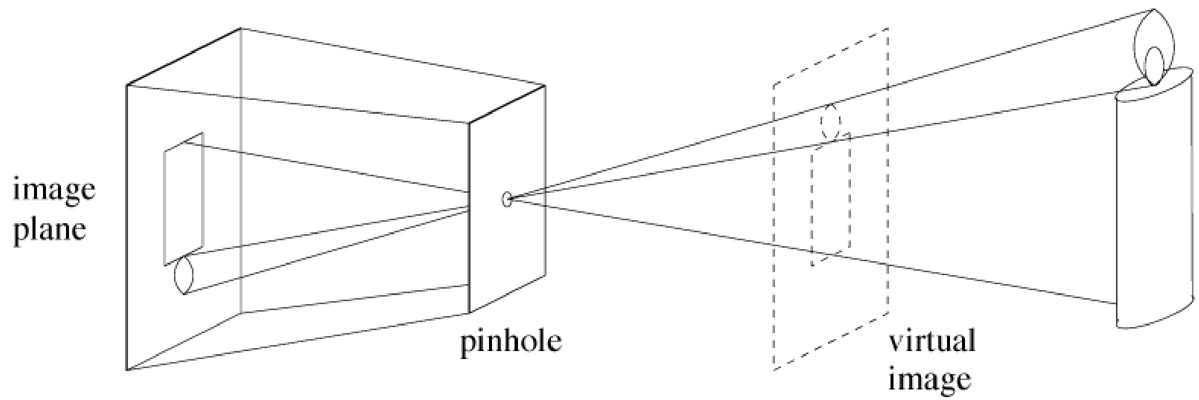
A digital image is represented by an integer array E of m-by-n.
E(i,j), a pixel, is an integer in the range [0, 255].

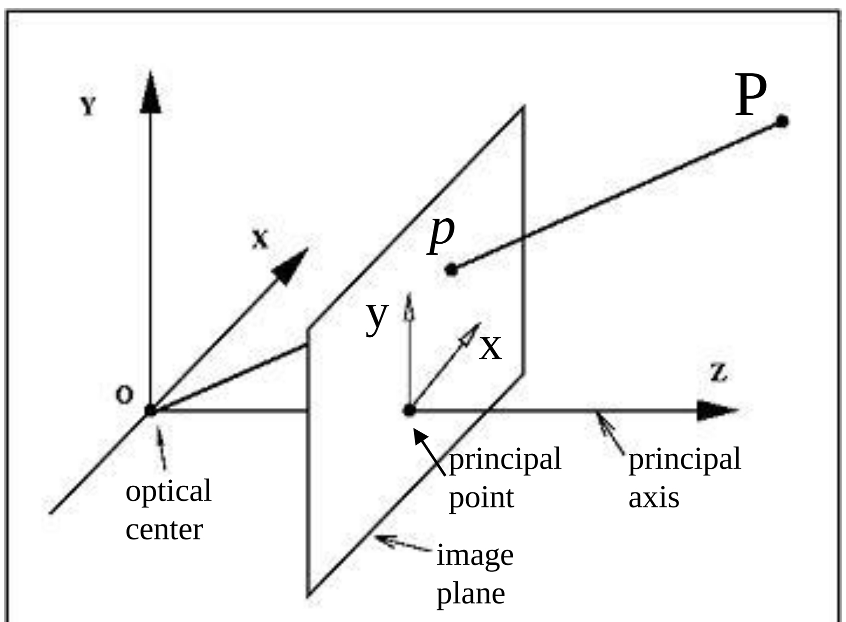
Color Image



Geometric Model of Camera

Perspective projection

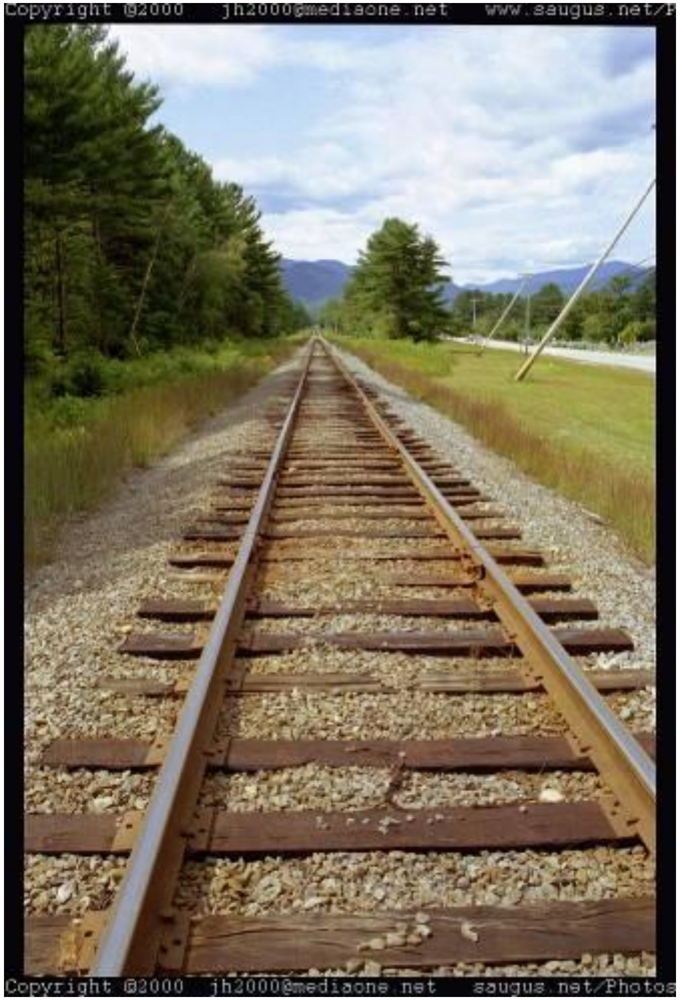




$$P(X,Y,Z) \longrightarrow p(x,y)$$

$$x = f\,\frac{X}{Z} \qquad y = f\,\frac{Y}{Z}$$

Funny things happen…



Parallel lines aren't…

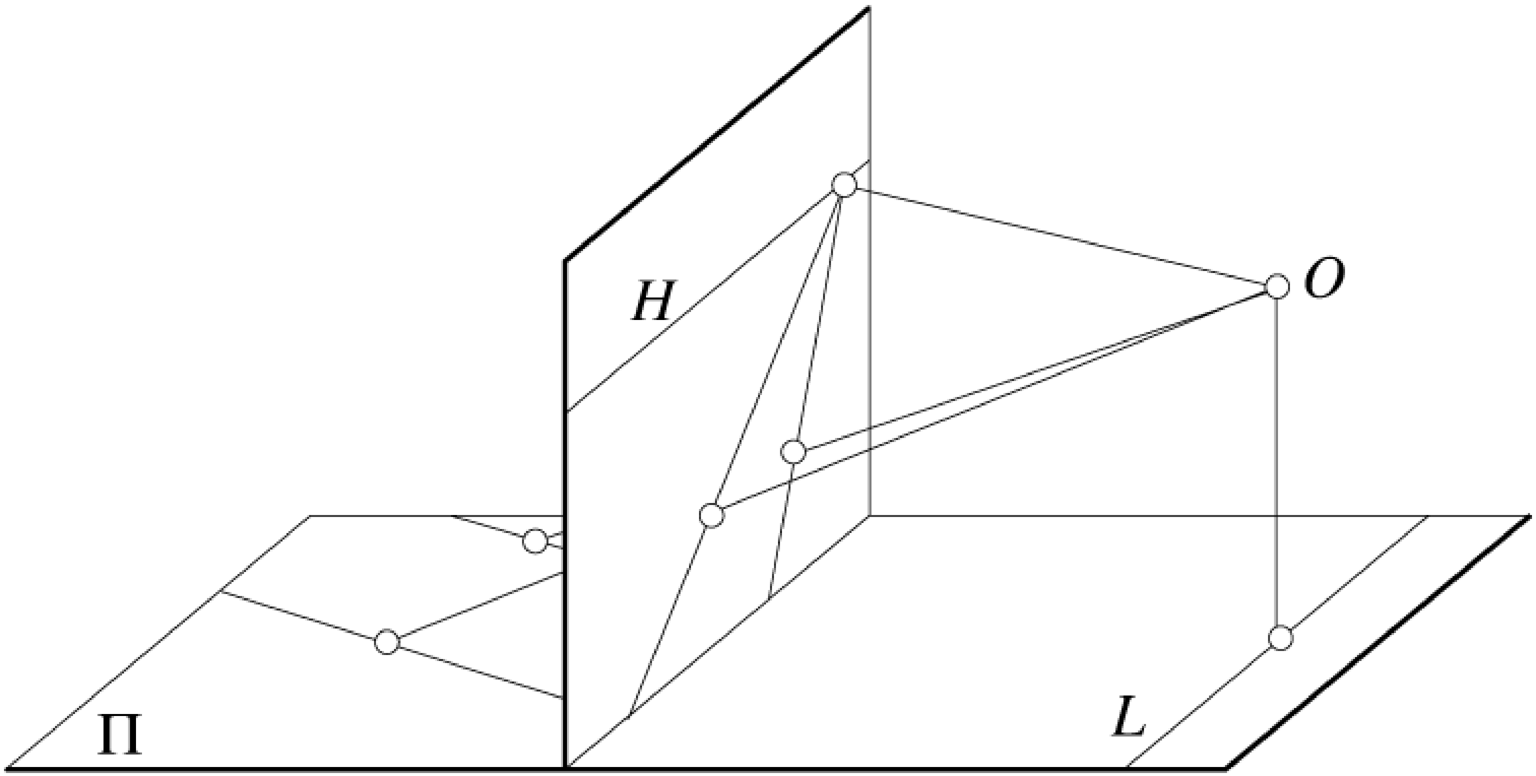


Figure by David Forsyth

Lengths can't be trusted...

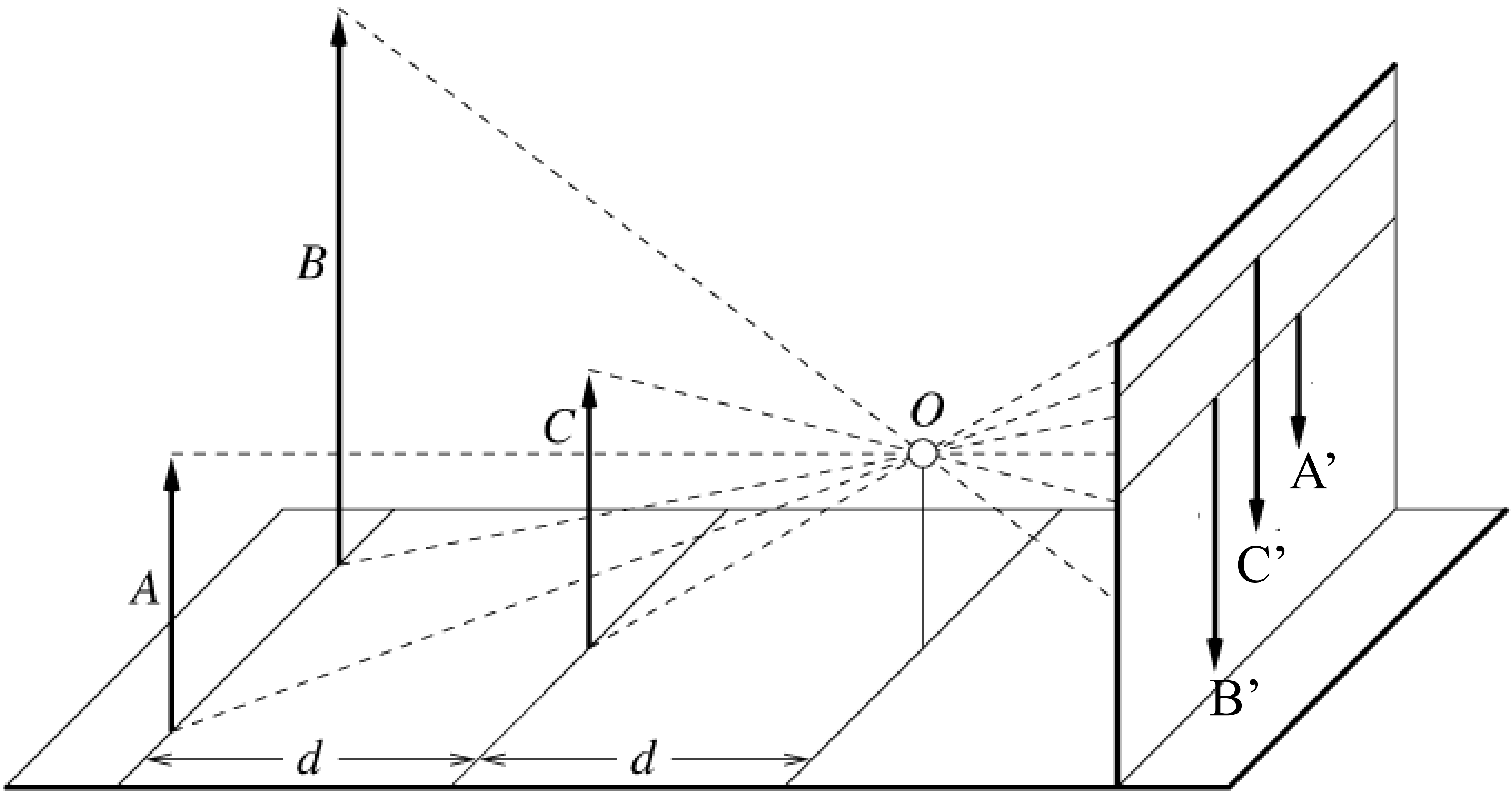


Figure by David Forsyth