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# Image Formation

Dr. Gerhard Roth

COMP 4102A

Winter 2014

Version 1

# Image Formation

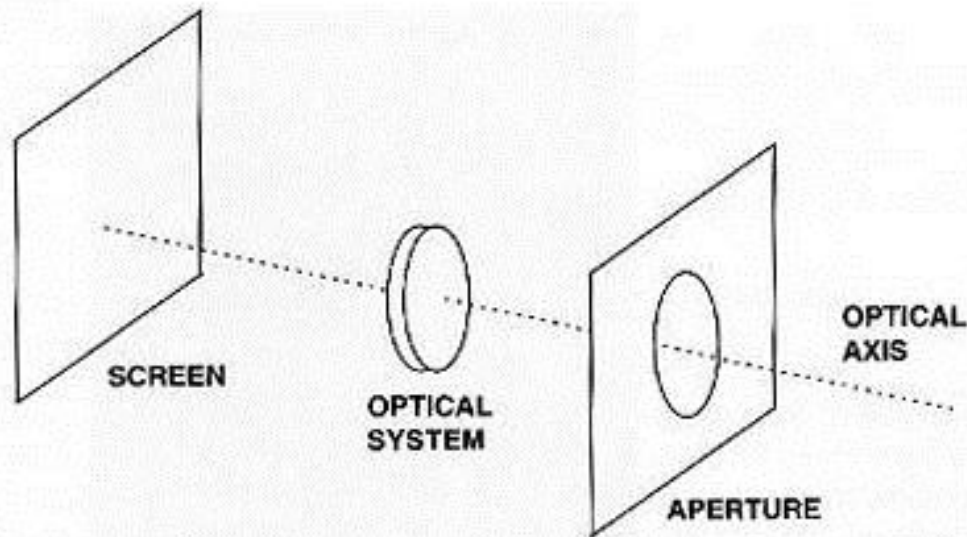
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- Two type of images
  - Intensity– image encodes light intensities (passive sensor)
  - Range (depth)– image encodes shape and distance
    - Created from processing passive images or by an active sensor
- Intensity image is a function of three things
- 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

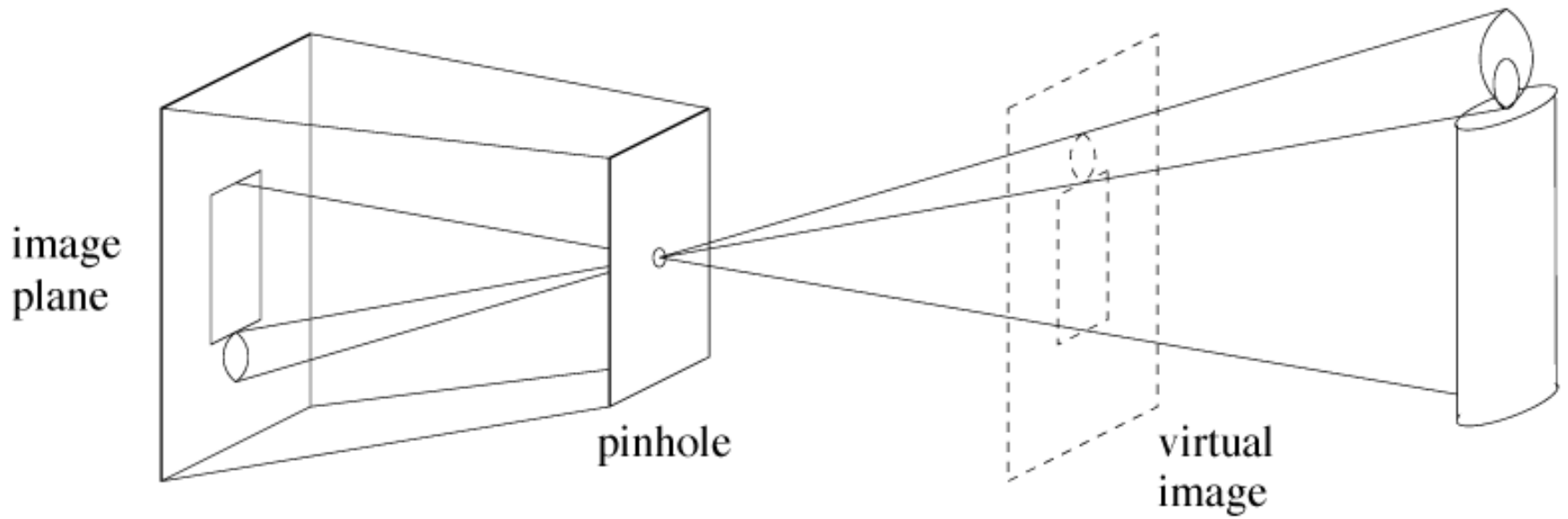
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Light rays coming from outside world and falling on the photoreceptors in the retina.



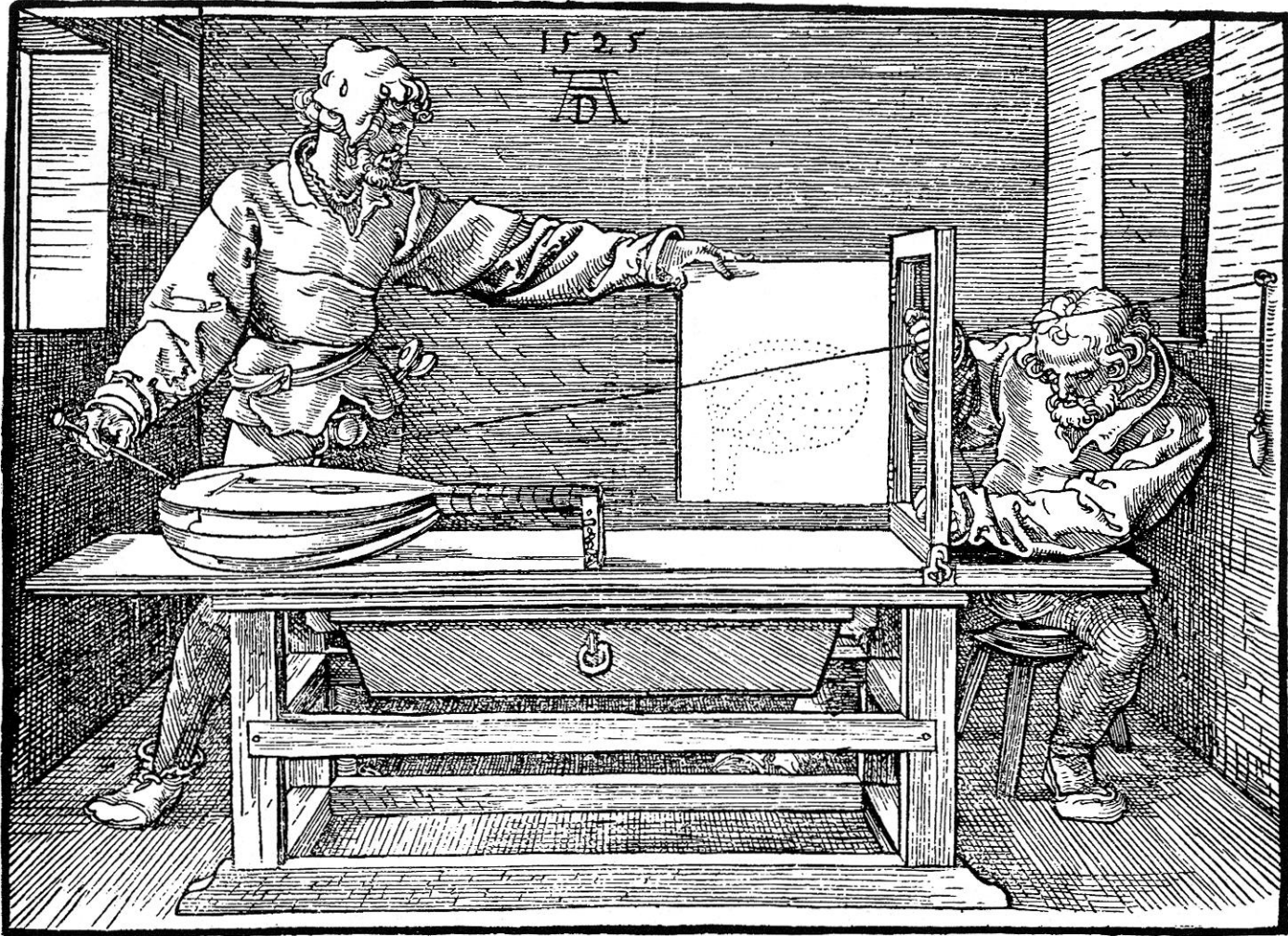
# Pinhole Camera

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# Perspective Projection

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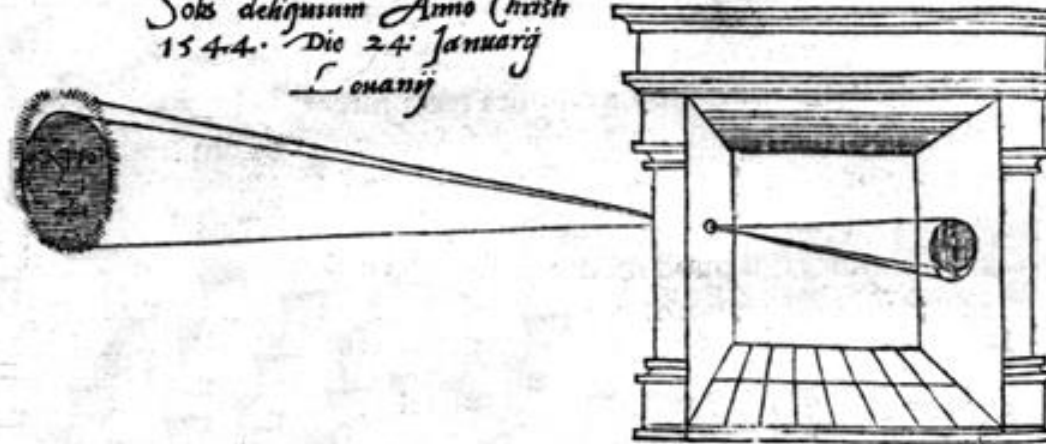
*Draughtsman Drawing a Lute, Albrecht Dürer, 1525*

# Camera Obscura

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

*Solis deliquium Anno Christi  
1544. Die 24. Januarij  
Louanij*



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

**Camera Obscura, Reinerus Gemma Frisius, 1544**

Camera Obscura: Latin ‘dark chamber’

# Camera Obscura

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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

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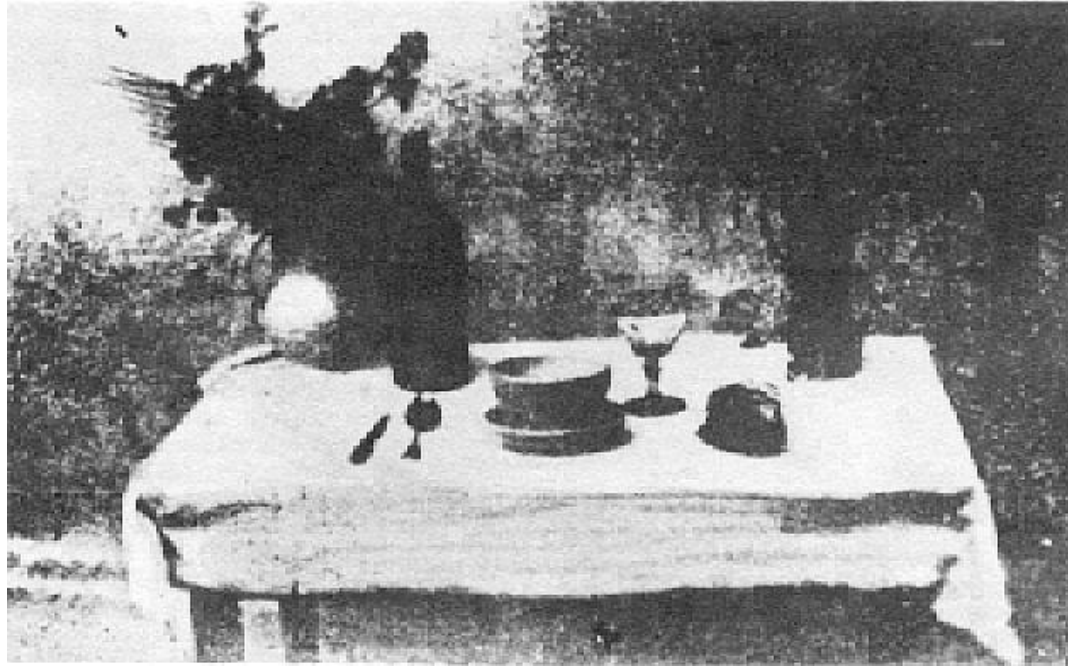


Photographic camera: Joseph Nicéphore Niepce, 1816



# First Photograph

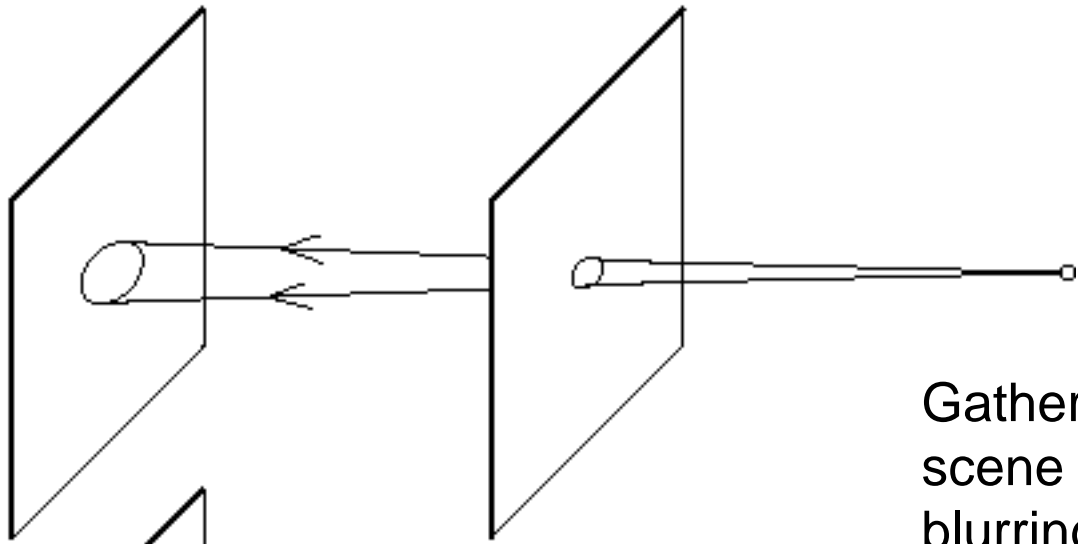
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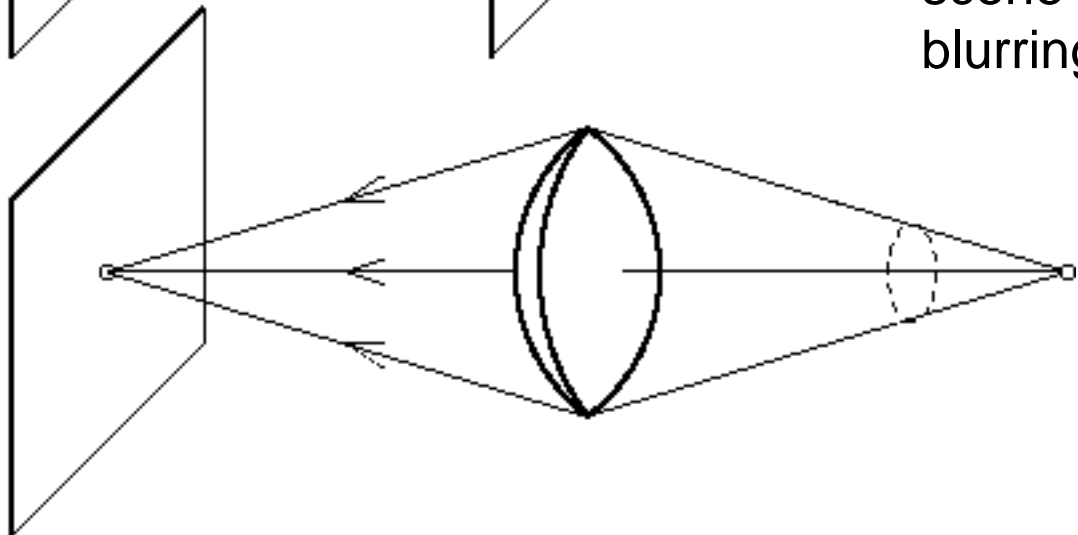
First photograph on record, *la table servie*,  
obtained by Niepce in 1822.

# Why Lenses?

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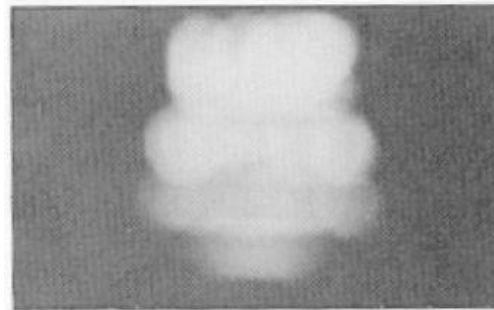
Gather more light from each scene point and also reduce blurring



# Why Lenses?

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



2 mm



1 mm

- Pinhole too small - diffraction effects blur the image



0.6mm



0.35 mm

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



0.15 mm

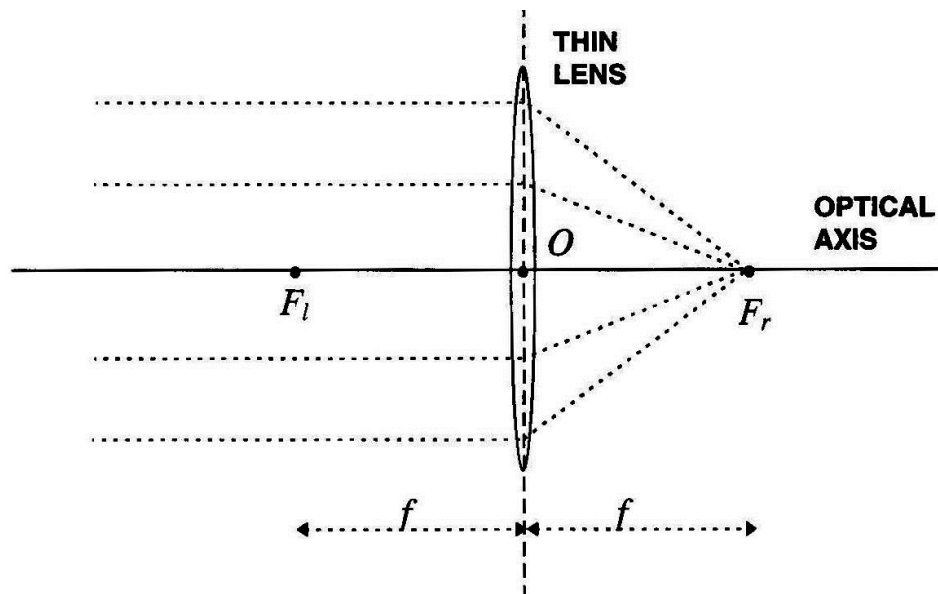


0.07 mm

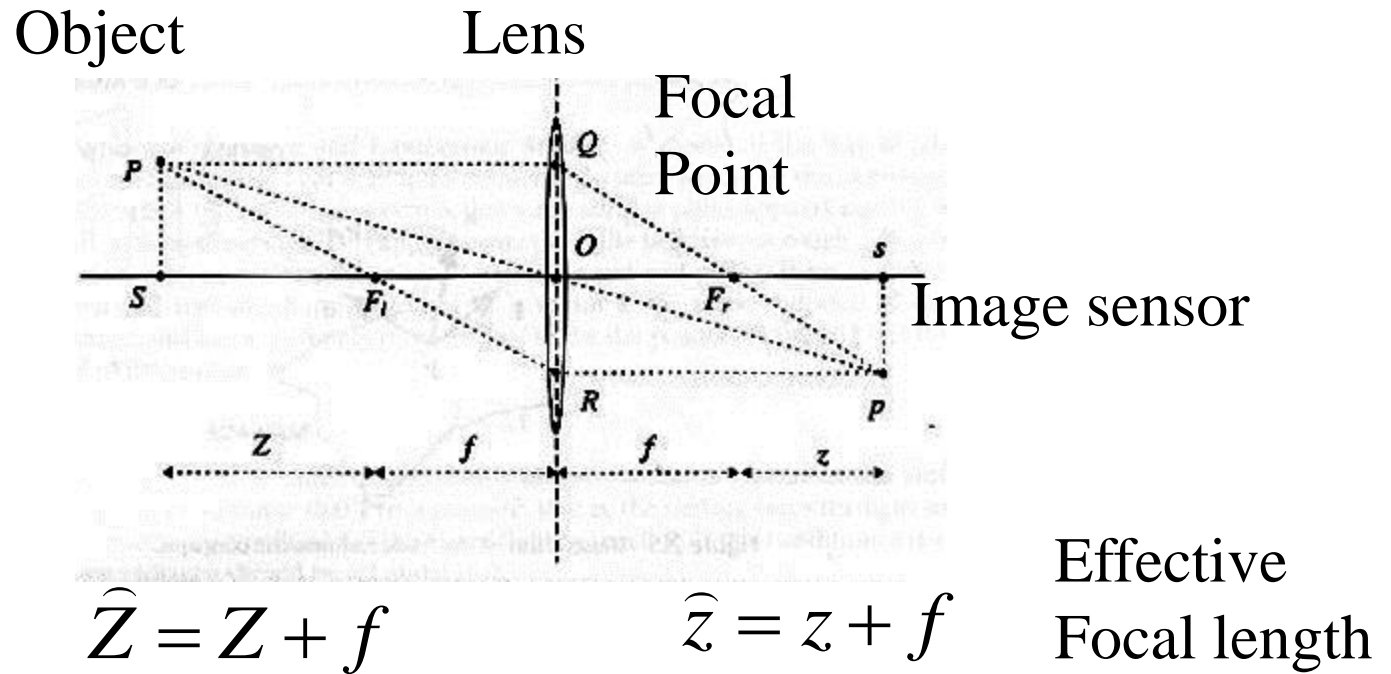
# Camera with Lens - Thin Lens Model

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- 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



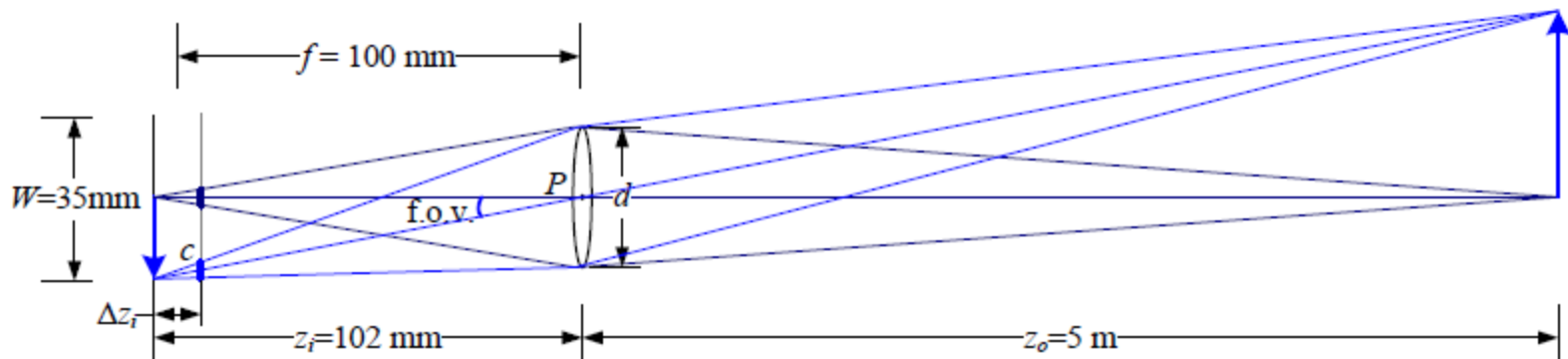
$$\frac{1}{\widehat{Z}} + \frac{1}{\widehat{z}} = \frac{1}{f}$$

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 point 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 (explained by model)



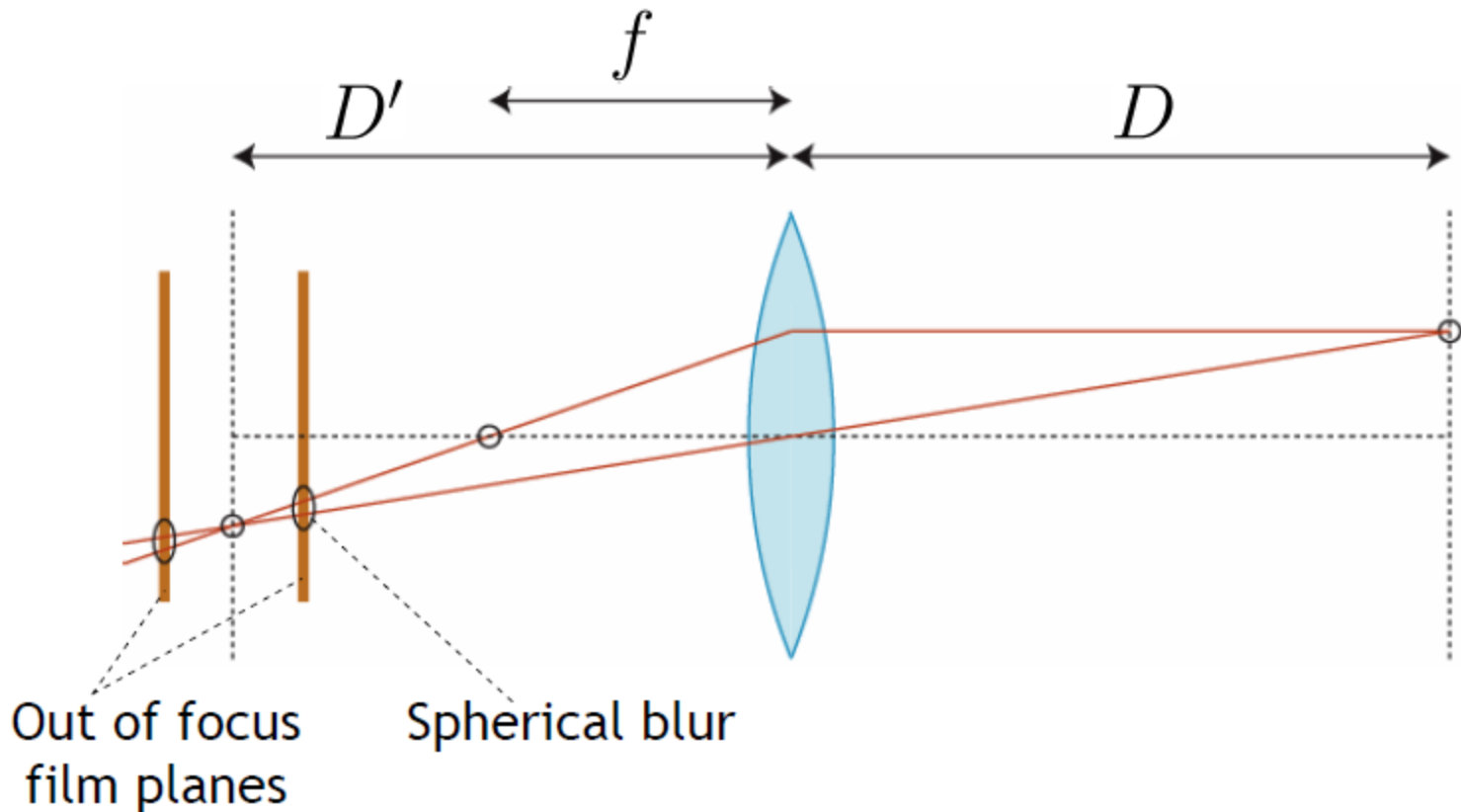
Thin lens applet:

[http://www.phy.ntnu.edu.tw/java/Lens/lens\\_e.html](http://www.phy.ntnu.edu.tw/java/Lens/lens_e.html)

# Depth of field

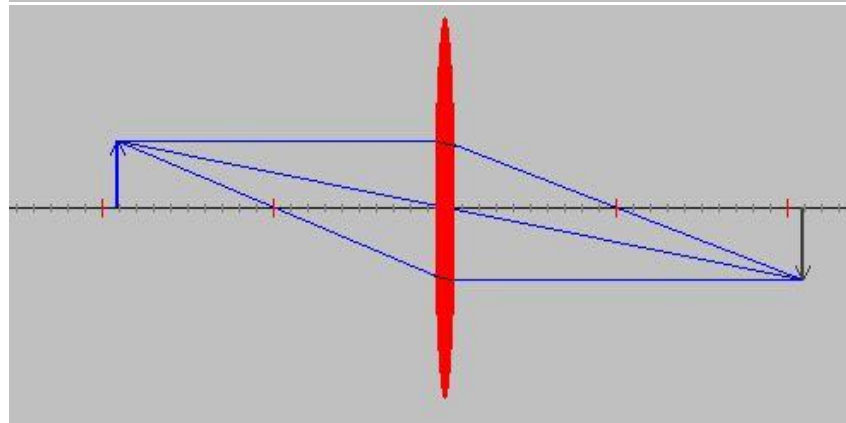
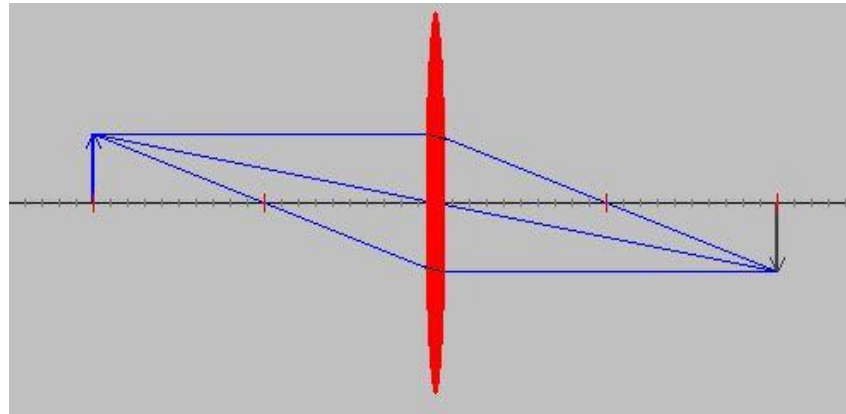
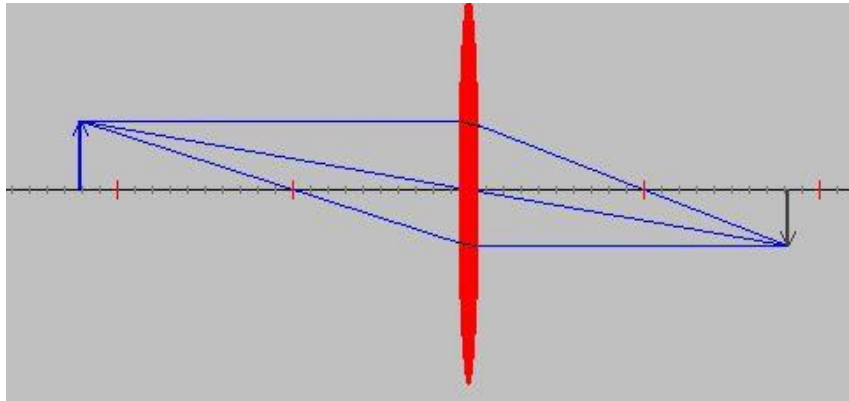
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- Point is in focus over a given distance which is the depth of field which changes with  $f$
- In focus region has less than one pixel of blur



# Depth of field

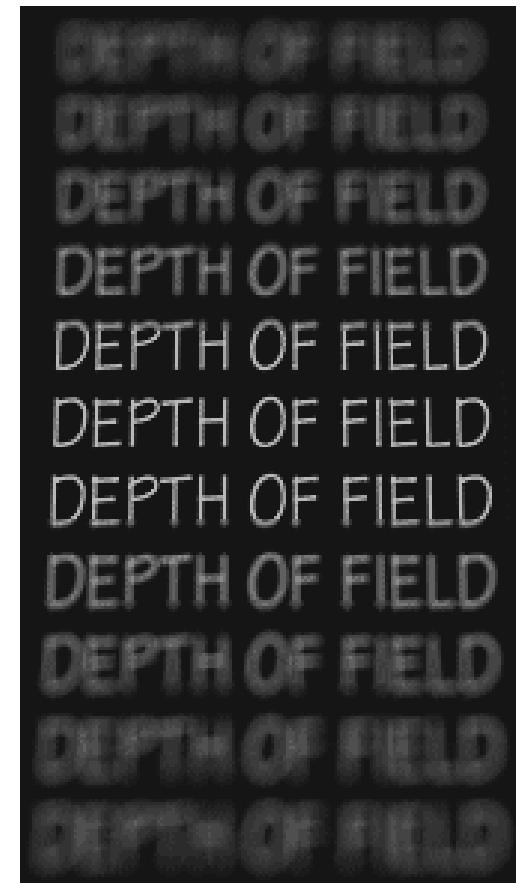
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# Depth of field

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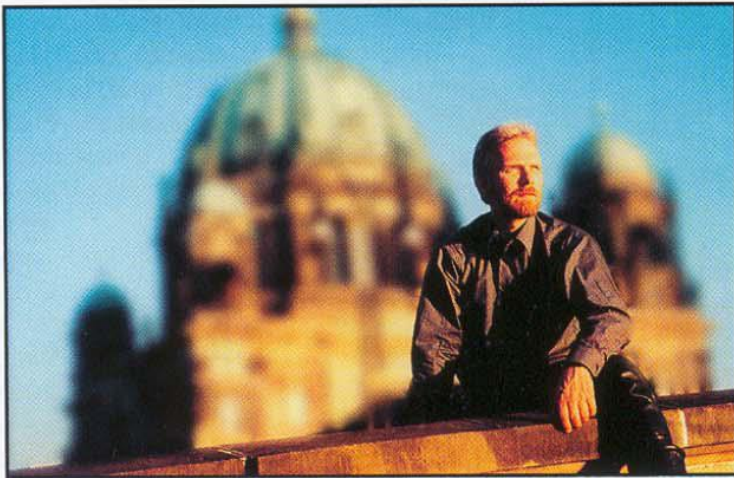


# Aperture size

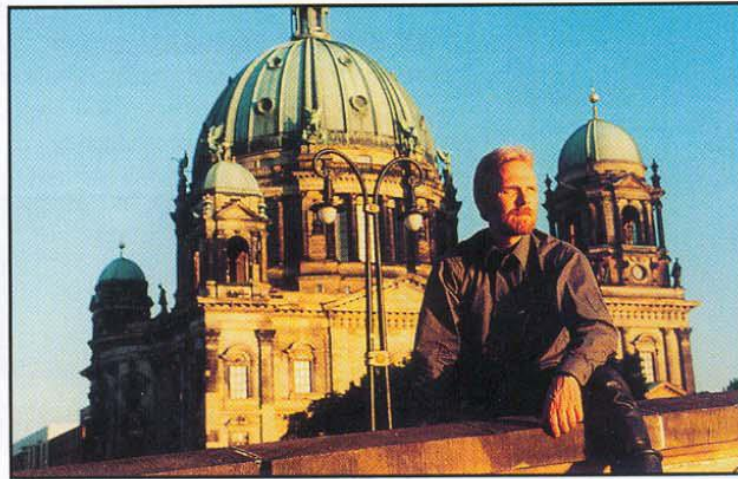
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- Blurriness of out of focus objects depends on the aperture size
- Larger aperture means smaller depth of field but it also lets in more light

Large aperture opening



Small aperture opening



# Varying the aperture



Large aperture = small DOF



Small aperture = large DOF

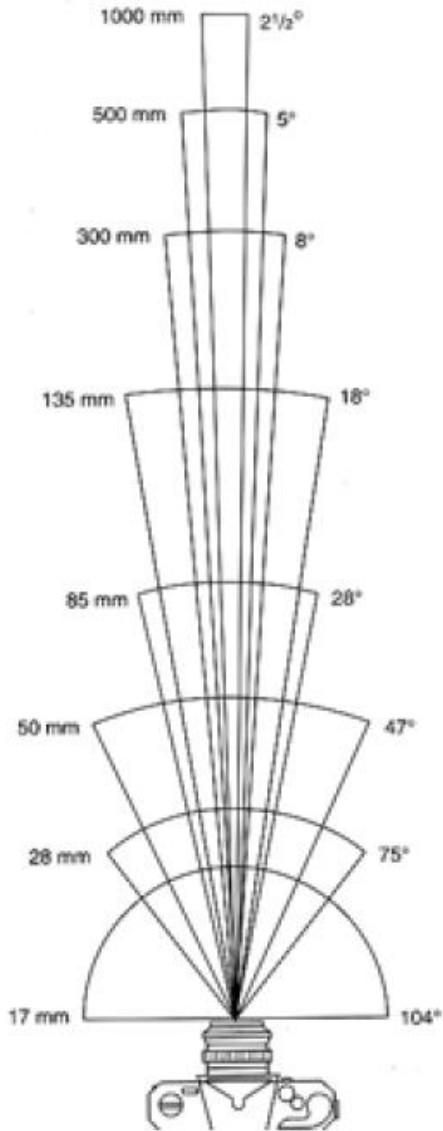


# Nice Depth of Field effect

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# Field of View (Zoom)



17mm



28mm



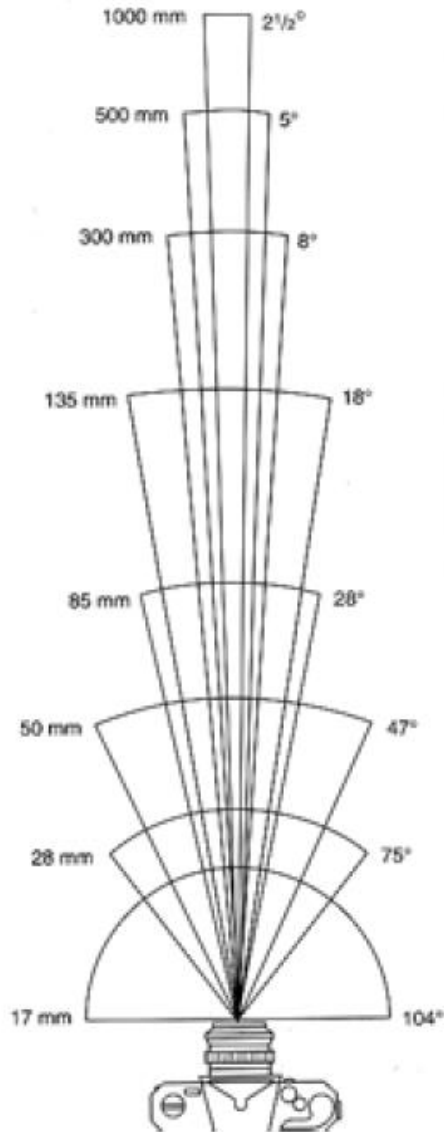
50mm



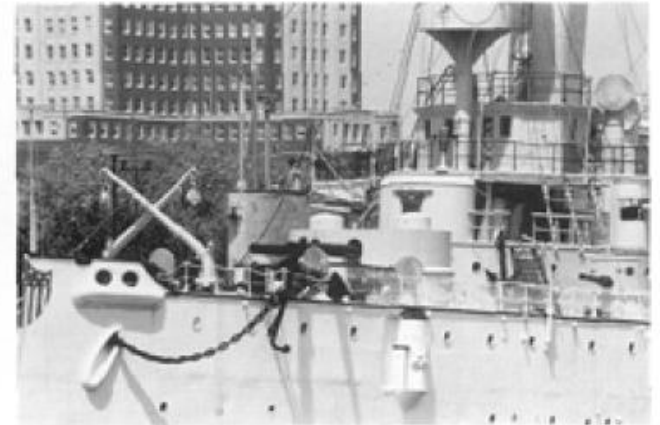
85mm

**From London and Upton**

# Field of View (Zoom)



135mm



300mm



500mm

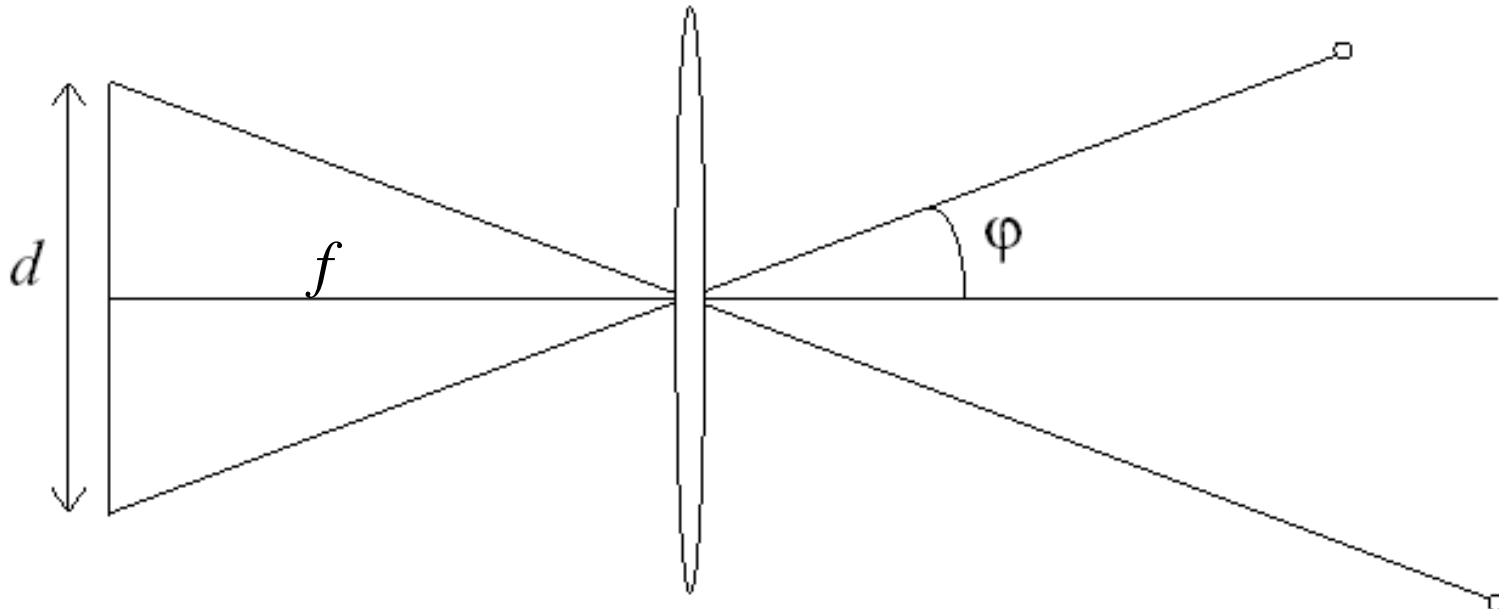


1000mm

**From London and Upton**

# FOV depends of Focal Length

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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

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Large FOV, small  $f$   
Camera close to car



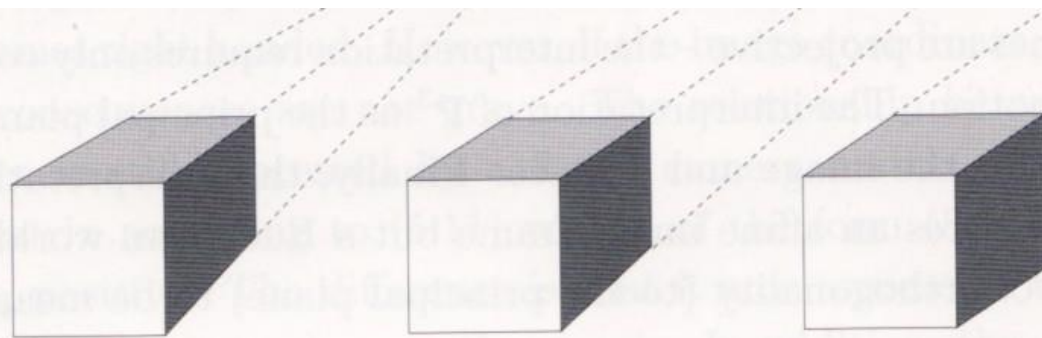
Small FOV, large  $f$   
Camera far from the car

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



# Effect of change in focal length

Small  $f$  is wide angle, large  $f$  is telescopic

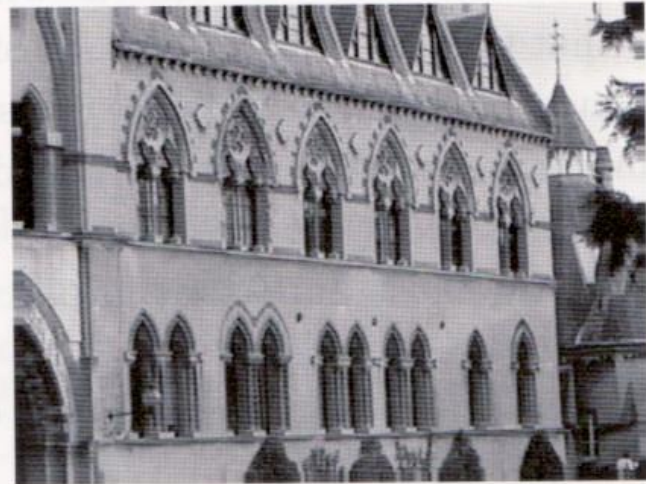
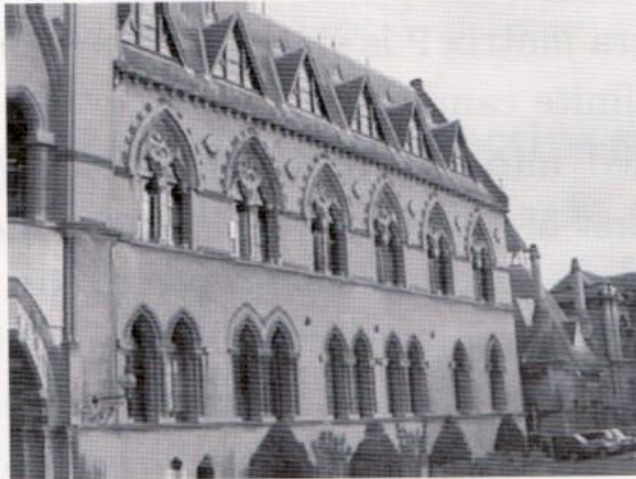


perspective

weak perspective

increasing focal length

increasing distance from camera



# Autofocus

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- Uses sensor, control system and motor to focus on a selected point or area
  - Can get sharp images over large depth variation
- Intelligently adjust camera lens to maintain focus on an object (another definition)
- Two approaches, passive and active
- **Active**
  - Triangulation using an active sensor such as laser, ultrasound, or infrared light
- **Passive**
  - Phase detection (similar to stereo) to find depth
  - Contrast detection uses blur or lack of it to find depth

# Autofocus

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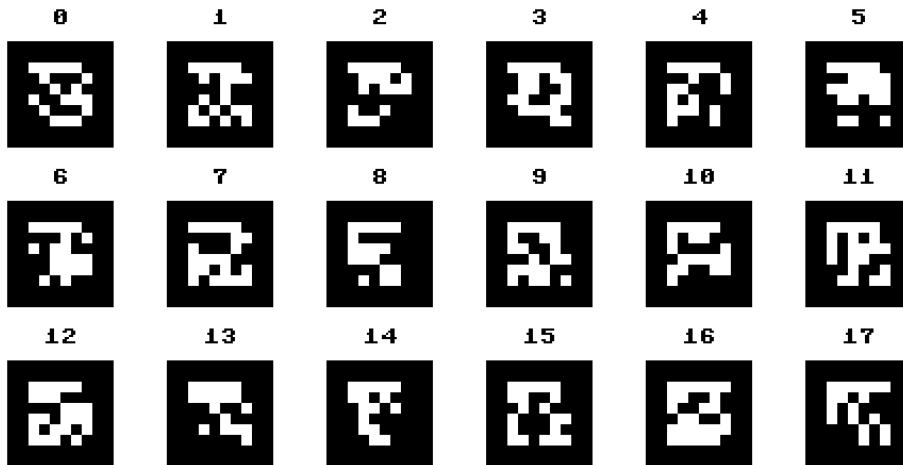
- On all high end cameras, and now on many low end cameras (webcams) and phones
- In Android have fixed focus, autofocus (it does it once), or continuous autofocus
- Most sophisticated image processing applications require an in-focus image
- Requires autofocus
  - QRTag and OCR (including my chess application)
- Not require autofocus
  - ARTag, a tag system with much less information
  - Such applications work on wider variety of devices

# QRTag versus ARTag

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- QRTag
  - Lot of info, small regions
  - Can encode entire URL



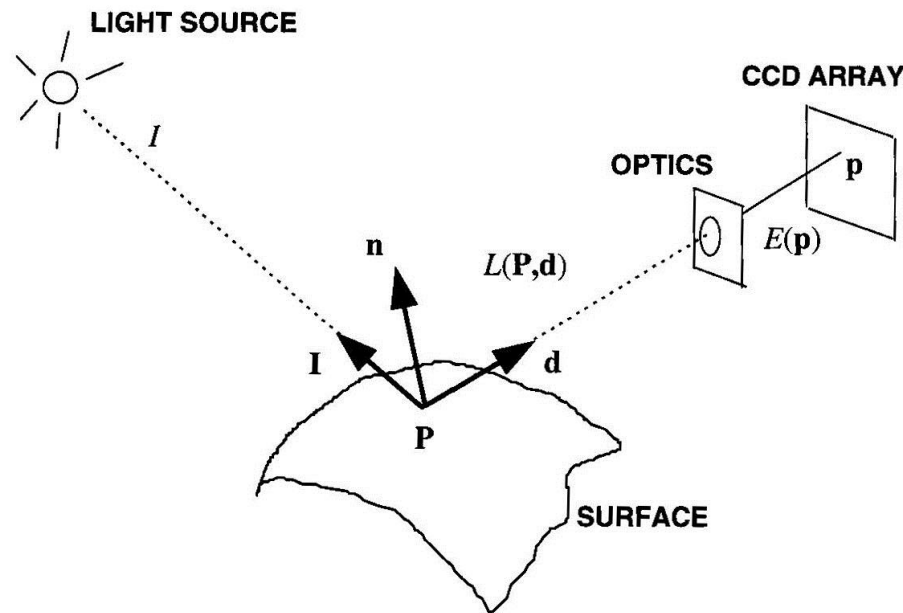
- ARTag
  - Less info, large regions
  - Only 10 bits of encoding

# Basic radiometry

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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 Model

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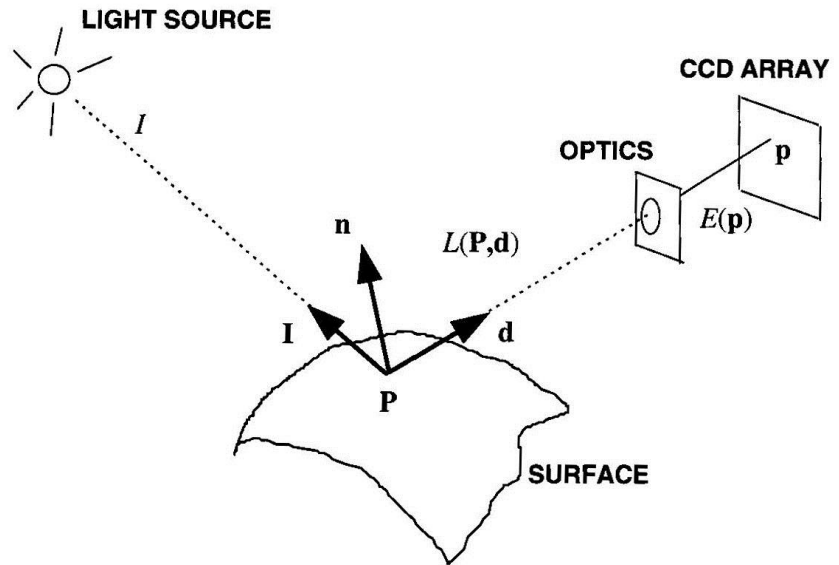
- A model of the way in which the surface reflects incident light is called a surface reflectance model
- There are a number of different types of surface reflectance models
  - Fix the lighting, and the object and then move the camera while looking a single surface point
- The changes in appearance of that surface point defines the specularity
  - Plain sheet of paper is non-specular (no change)
  - Desktop is semi-specular (some change)
  - Mirror is very specular (a great deal of change)

# Surface Reflectance for Lambertian

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

$\rho$  is called surface albedo and it depends on the surface material

And  $L$  is scene irradiance (no  $d$  vector term)

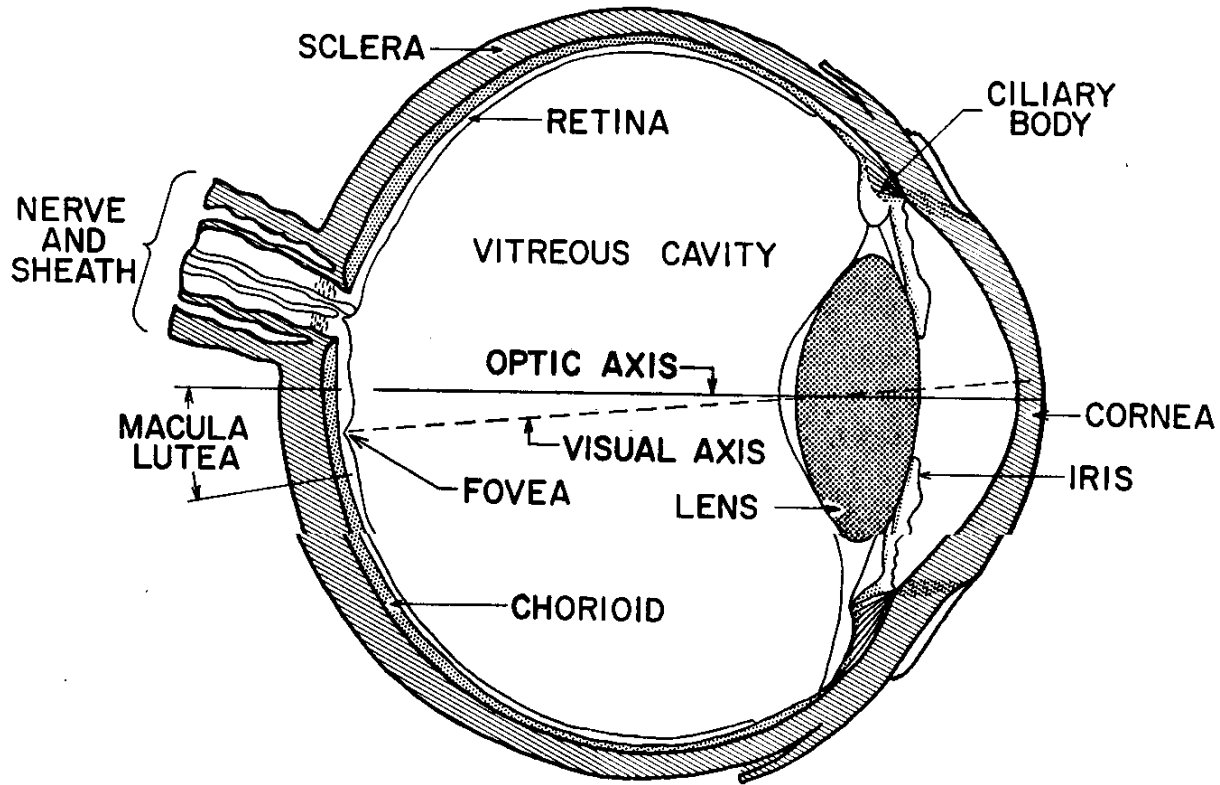


**Lambertian model:** each surface point appears equally bright from all viewing directions (no term with  $d$ ). Non specular surface.

**Specular model:** this is not true, looks brighter from some viewing directions (mirrors are very specular). These models are much more complex than the lambertain model (more parameters)

# Human Eye

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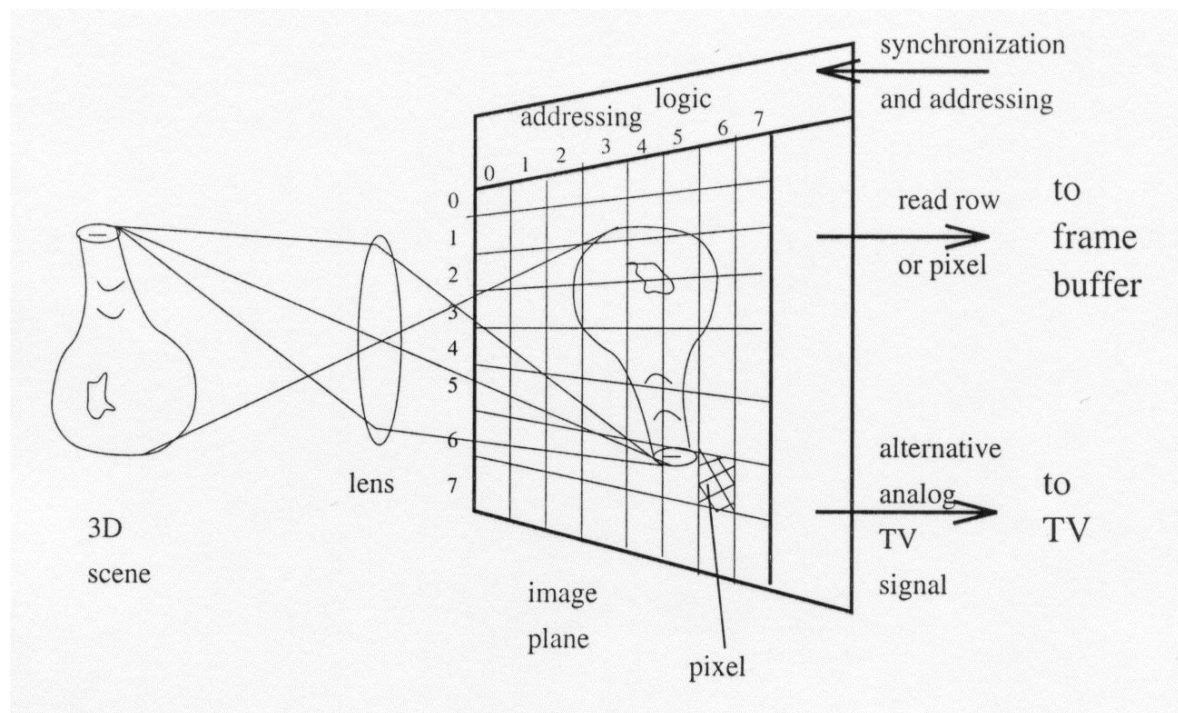




# CCD (Charge-Coupled Device) Cameras

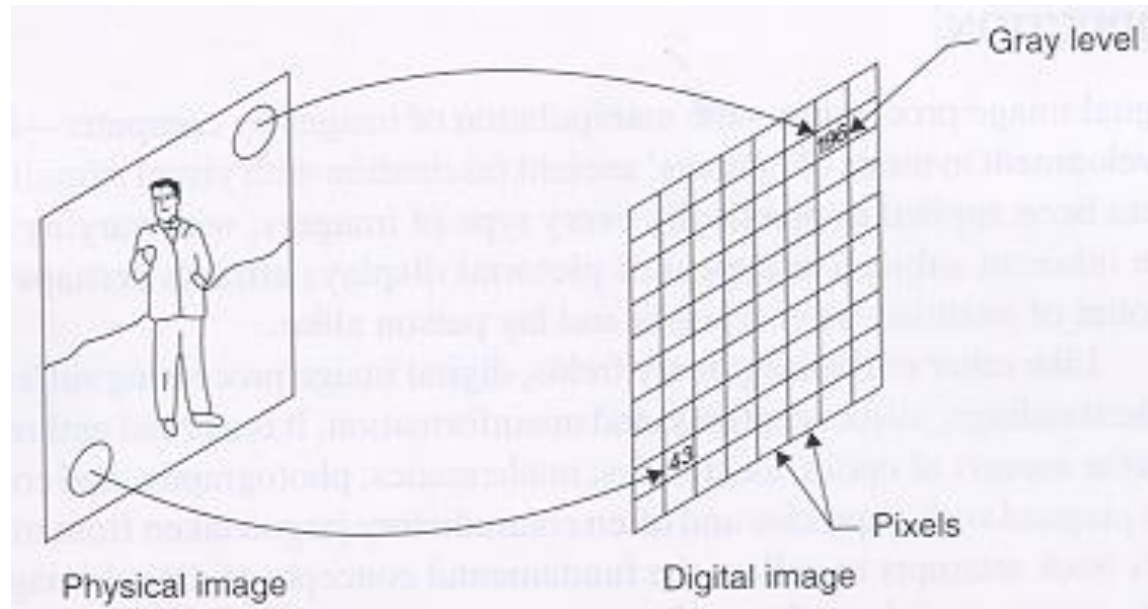
Small solid state cells convert light energy into electrical charge (sensing elements always rectangles and are usually square)

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



# Image Digitization

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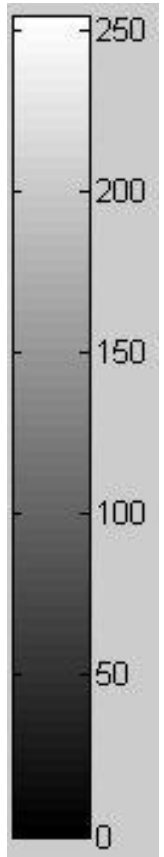
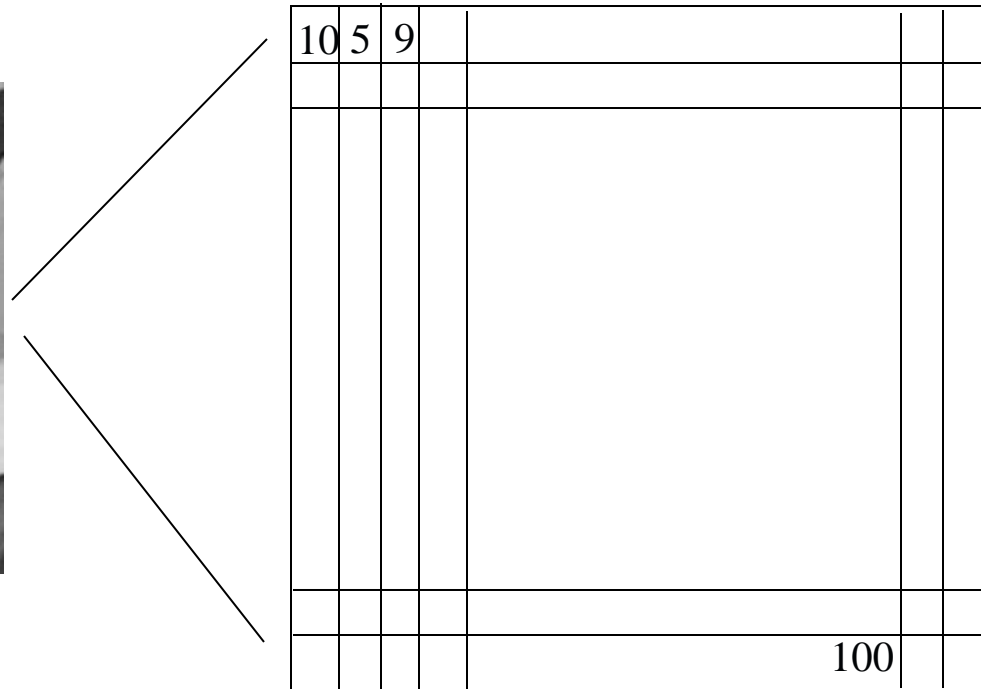
Sampling – measuring the value of an image at a finite number of points.

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

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

# Grayscale Image

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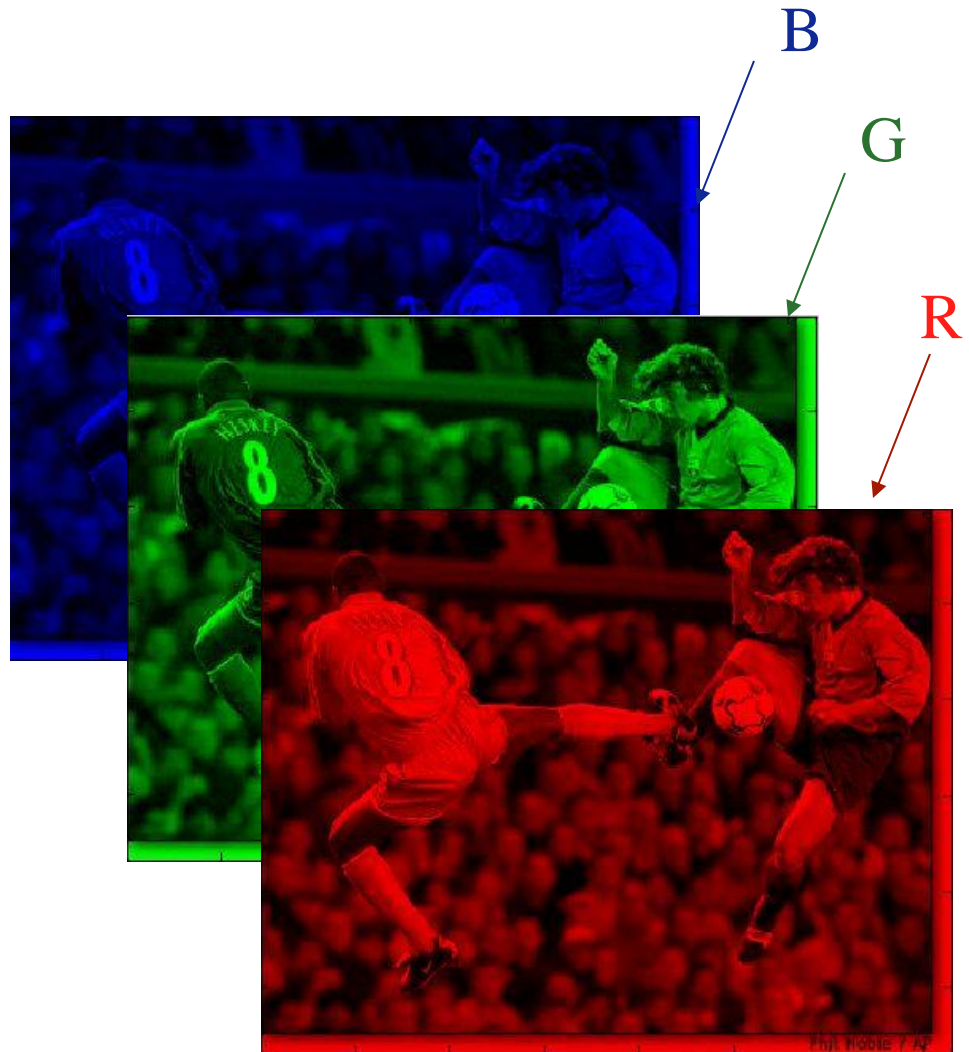
A digital image is represented by an integer array  $E$  of  $m$ -by- $n$ .  
 $E(i,j)$ , a pixel, is an integer in the range  $[0, 255]$ .

# Color Image

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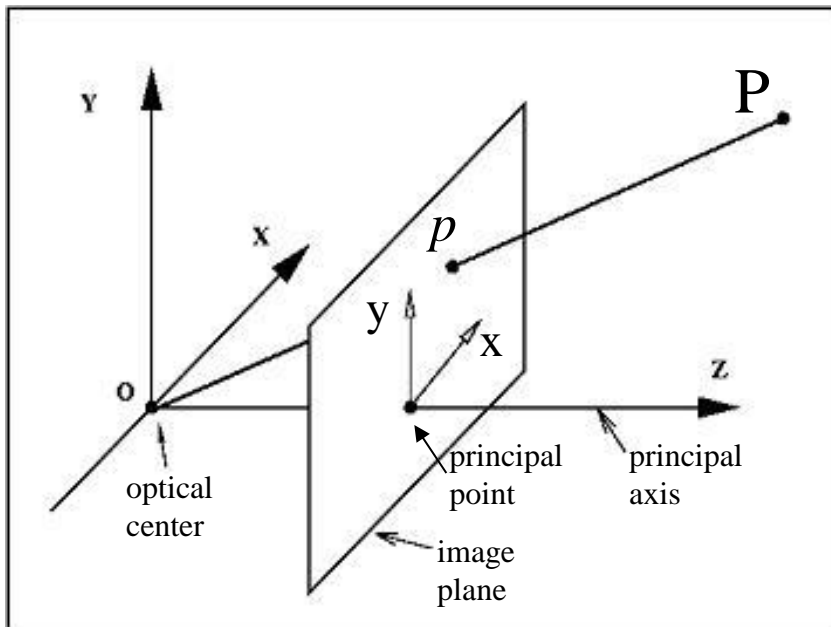
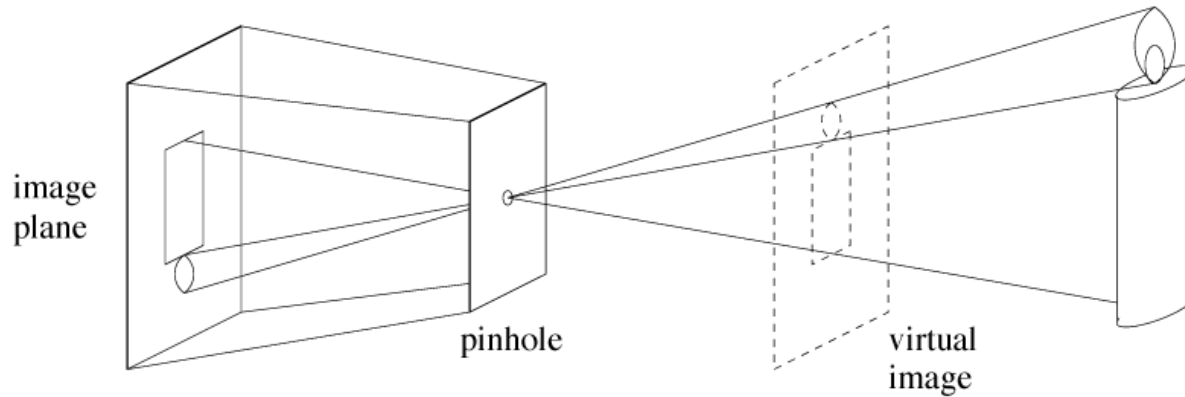


Phil Noble / AP



# Geometric Model of Camera

## Perspective projection

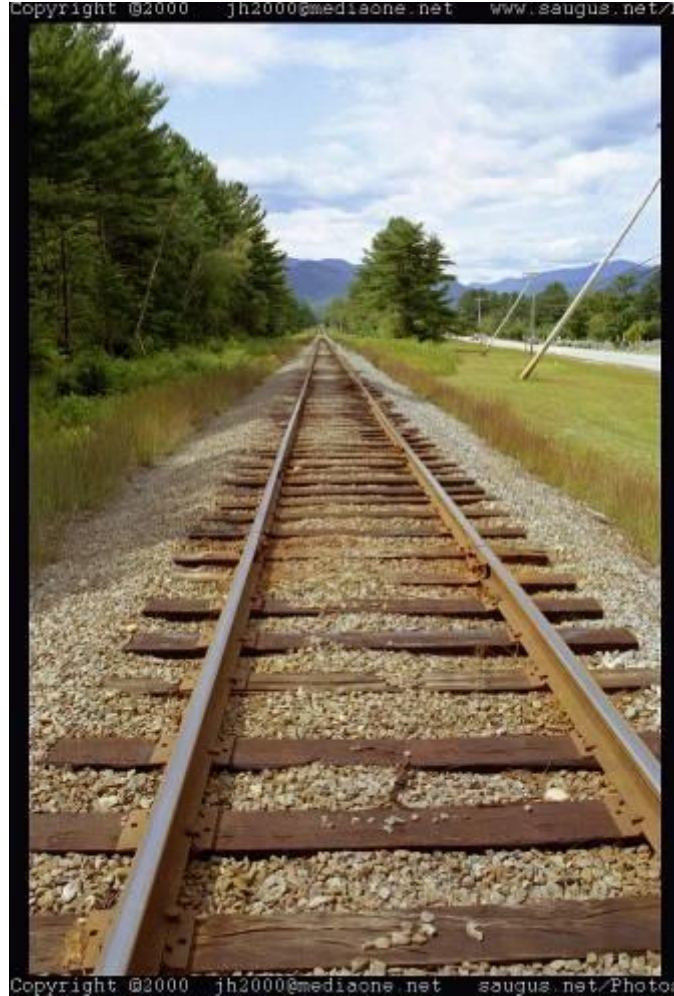


$$P(X, Y, Z) \rightarrow p(x, y)$$

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

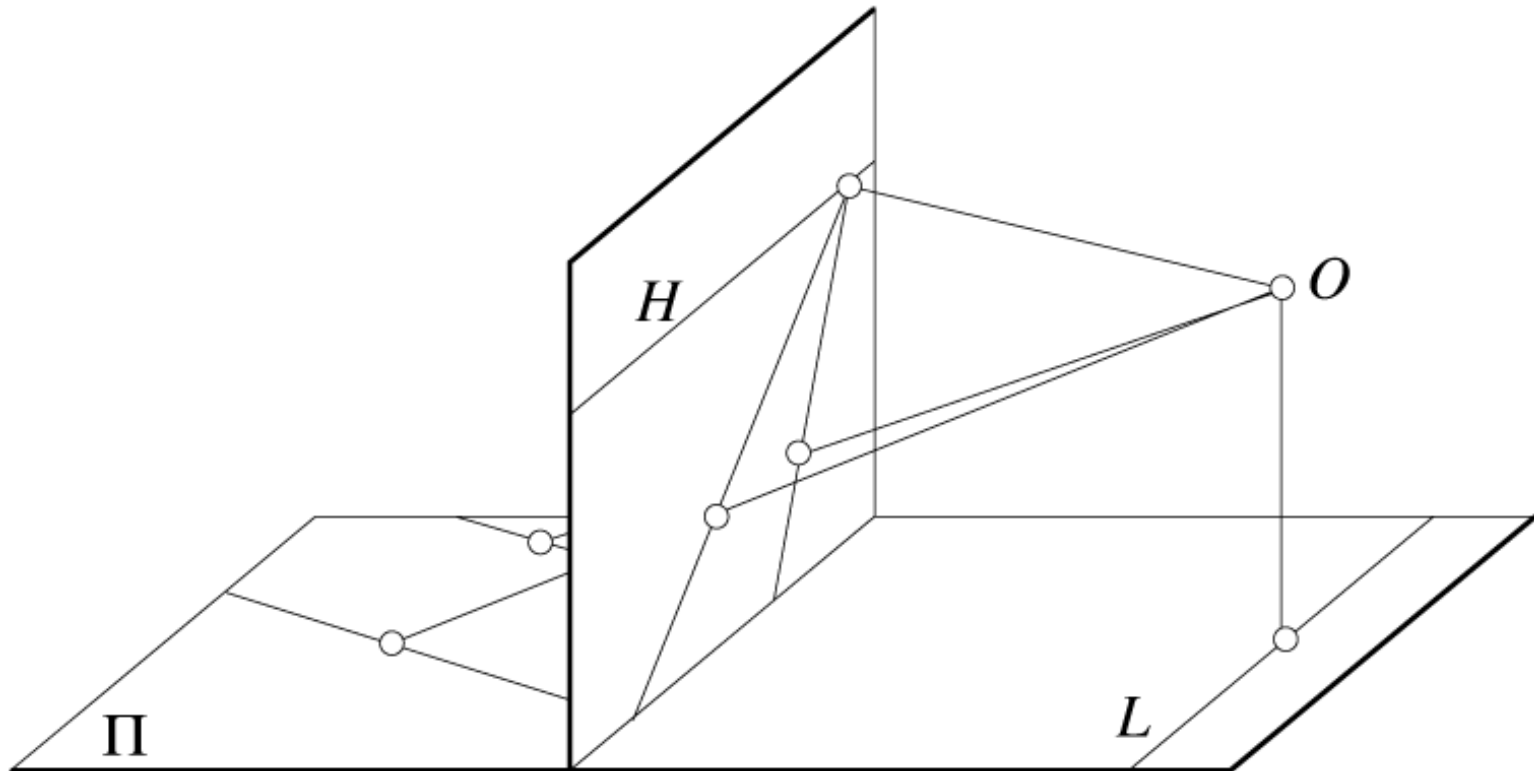
# Funny things happen...

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# Parallel lines aren't...

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# Lengths can't be trusted...

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