Lecture 2: CS677

Aug 24, 2017

Review

- Previous class
  - Course requirements
  - Assignments, grading
  - Adding more students to the class
  - Topics to be studied in class
  - Some problems of vision
- **TODAY ONLY: office hours 1-2PM**
- Today's objective
  - Some example state-of-art apps
  - Human visual system (very briefly)
  - Image formation

Current state of the art

- The following slides show some examples of what current vision systems can do
  - Many taken from class page of Prof. Seitz/Szeliski

Driving Scene

Sensing the Driving Scene

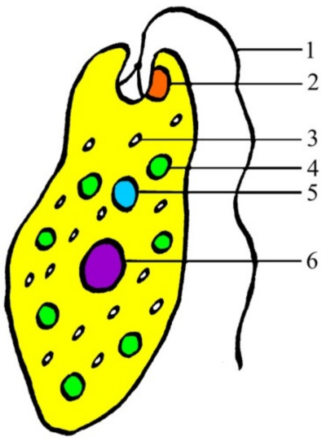
Note the vast amount of information the system can provide – free space (green carpet), vehicle and pedestrian detection, traffic sign recognition, lane markings – for the vehicle to understand and negotiate the driving scene.

From Mobileye

Self-Driving Cars

- A short video showing some visual needs and capabilities
  - https://www.youtube.com/watch?v=42rmGs0Rvtw
- A long talk on status of self-driving cars (watch on your own)
  - https://www.youtube.com/watch?v=GJ82mk99Agw
- A business analysis of participants in self-driving technology
  - http://www.businessinsider.com/the-companies-most-likely-to-get-driverless-cars-on-the-road-first-2017-4/#1-ford-18

Simple Eyes



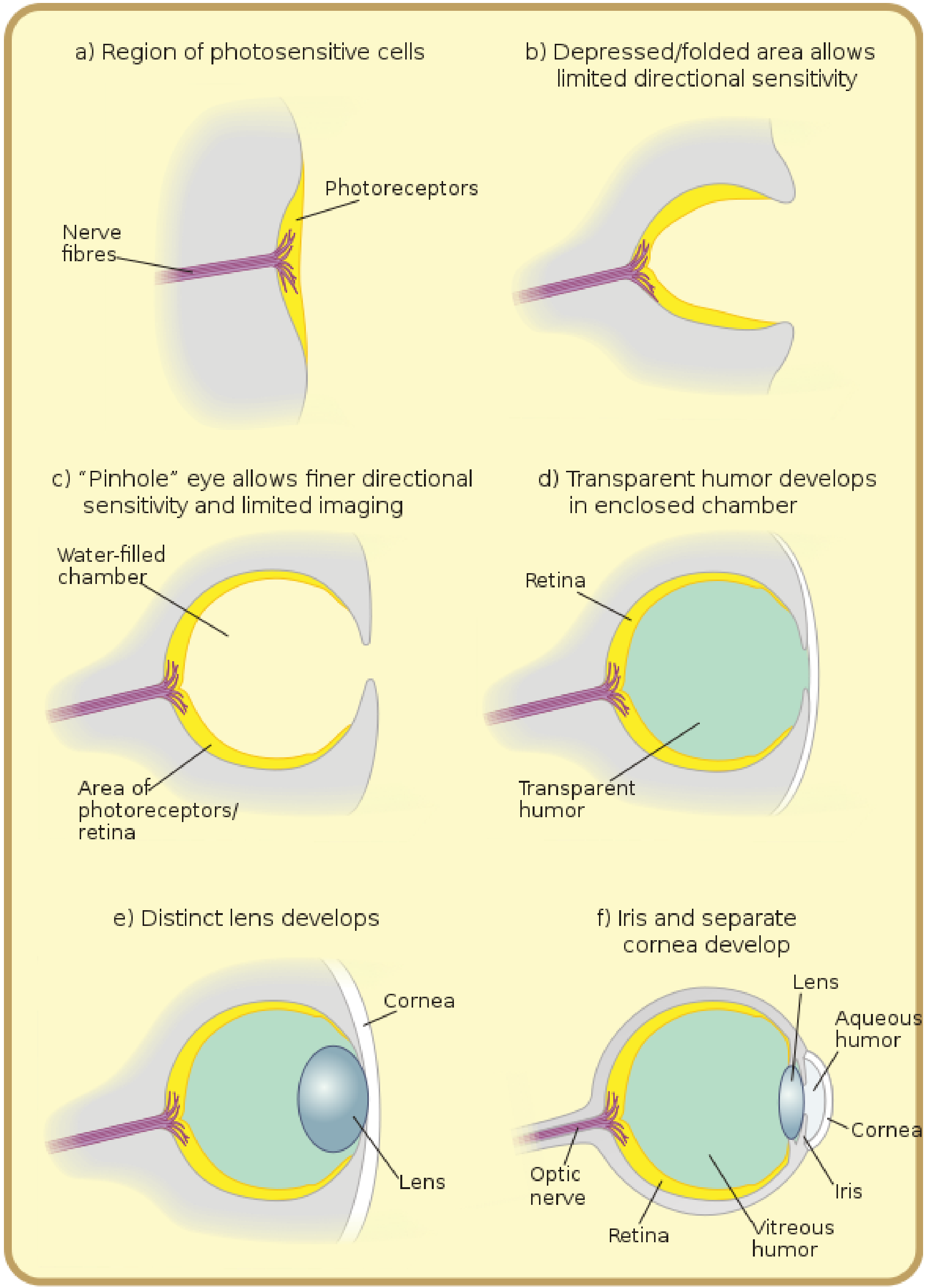
Single cell organism, can sense presence/absence of light only

http://www.wikiwand.com/en/Evolution_of_the_eye

Holes provide some directional sensitivity.
From Alessandro: wikipedia

Nautilus Eye: like a pin hole camera
From Hillewaert: wikipedia

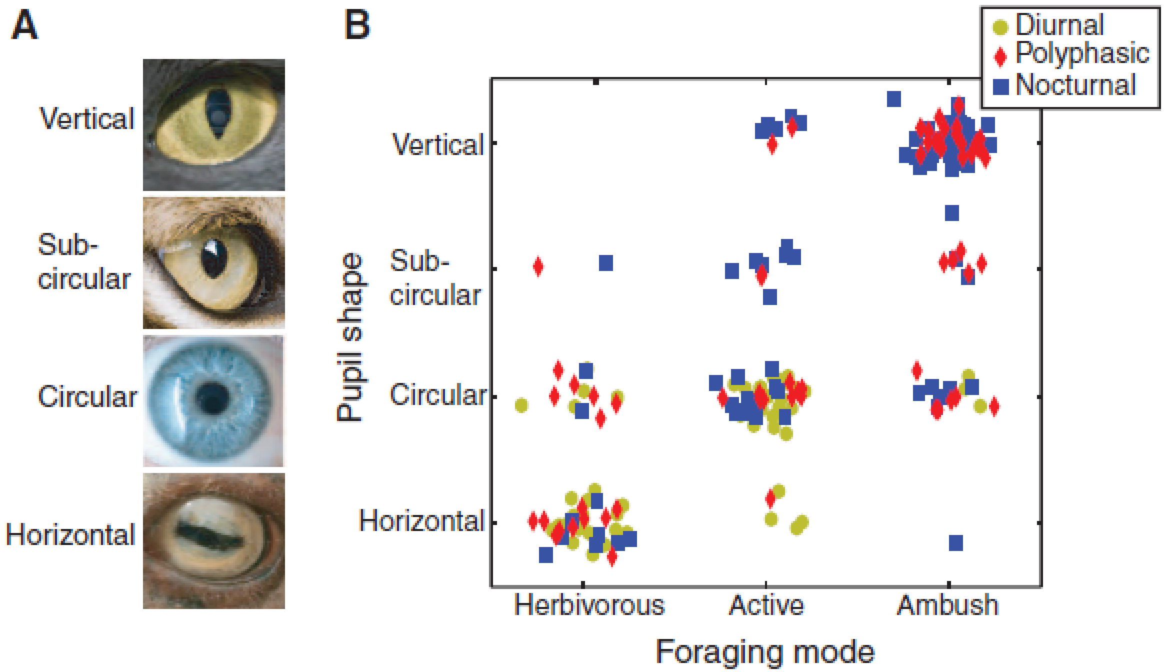
Evolution of Eyes



From Matticus: Wikipedia

Also, http://www.wikiwand.com/en/Evolution_of_the_eye

Pupil Shape

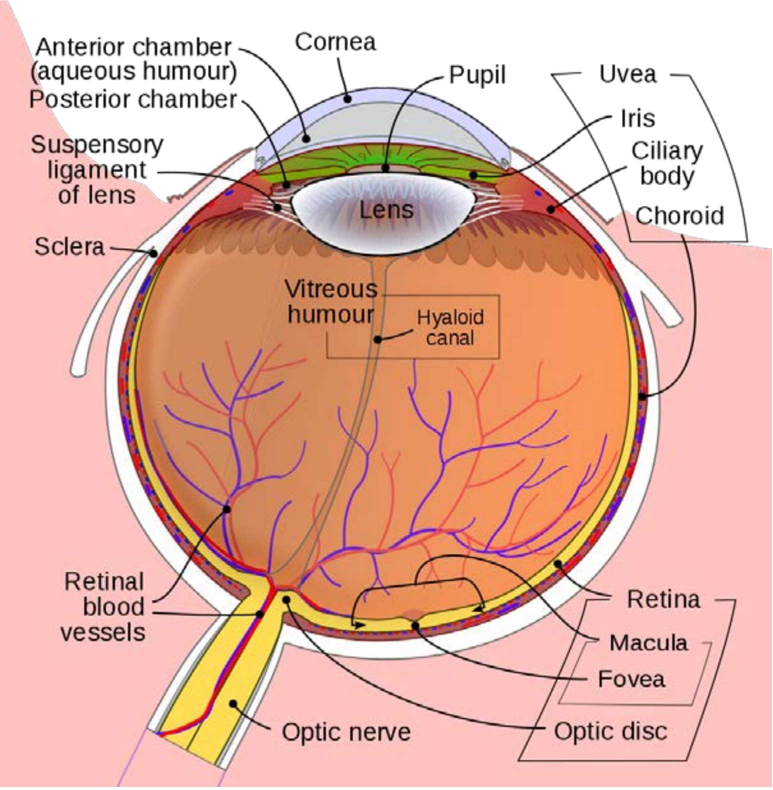


From Banks *et al*: “Why do animal eyes have pupils of different shapes?”, in Science Advances, August 2015

Human Eye

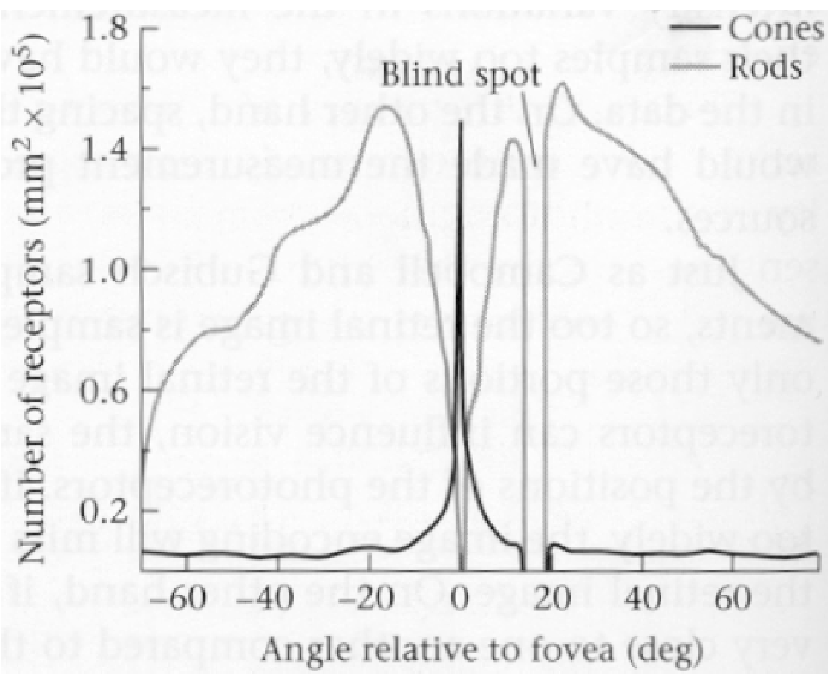
- Like a camera
  - Lens, pupil (iris), focus by *accommodation*
- Image formed on back of eye (retina)
- Optic nerve sends *data* to brain (cortex)
  - Blind spot (where optic nerve comes out)

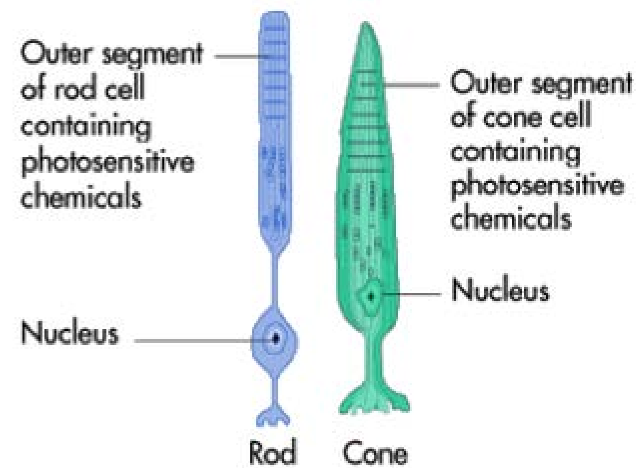
From Wikipedia



Retina

- Two types of photoreceptors
  - Rods: highly sensitive to light, not used for color vision, ~ 100M rods
  - Cones: 3 different types with different spectral sensitivities, less sensitive to light, ~ 5M cones
    - Explains why *color* is not seen at night
- Distribution is not uniform
  - High concentration of cones in fovea (0.5 minute visual angle)
  - Fixation (*foveation*) to get high resolution everywhere

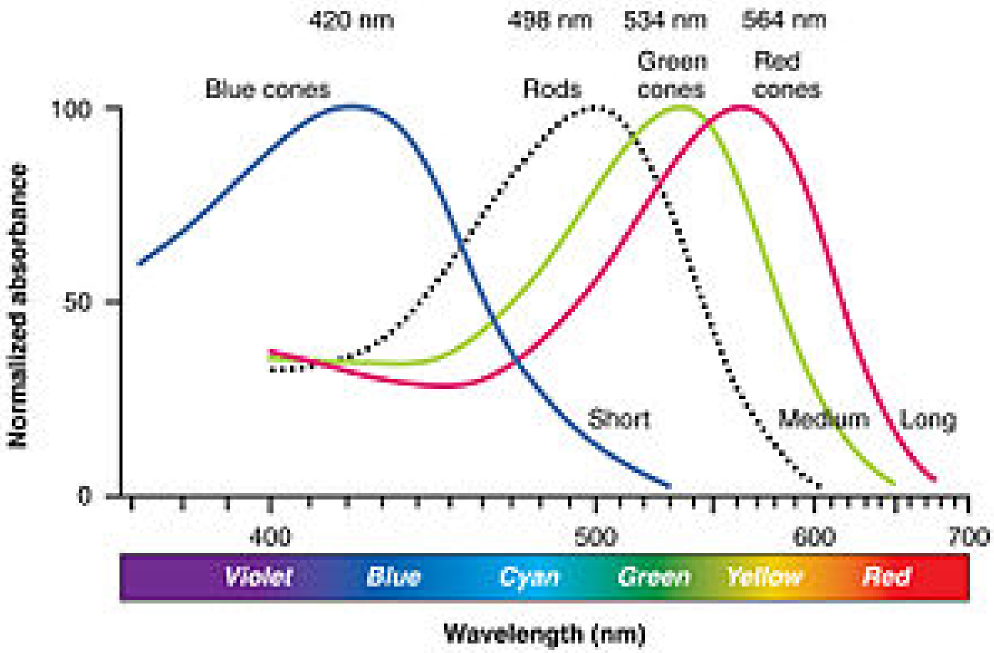




http://ionabio.weebly.com/

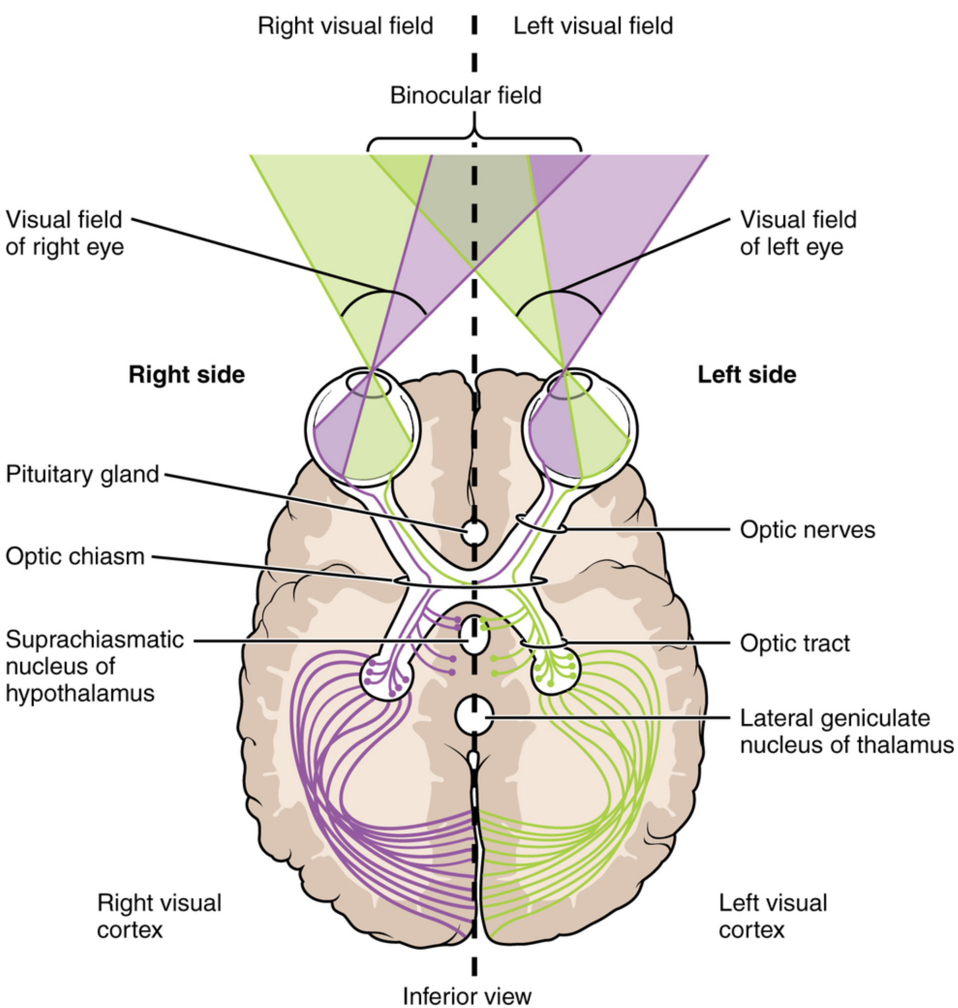
Color Sensor Response

- Eyes do not have built in color spectrometer
- Rather, we have 3 sensors with different responses to lights of different color
- Perceived color depends on relative responses of three sensors



https://en.wikipedia.org/wiki/Photoreceptor_cell

Cortex schematic



From lindsayoptometric.com

Optical nerve carries signals from retina to cortex

- ~100:1 ratio of nerve fibers to receptors: some processing performed at this level

- Optical *chiasma*: optic nerve fibers split to two halves of the brain

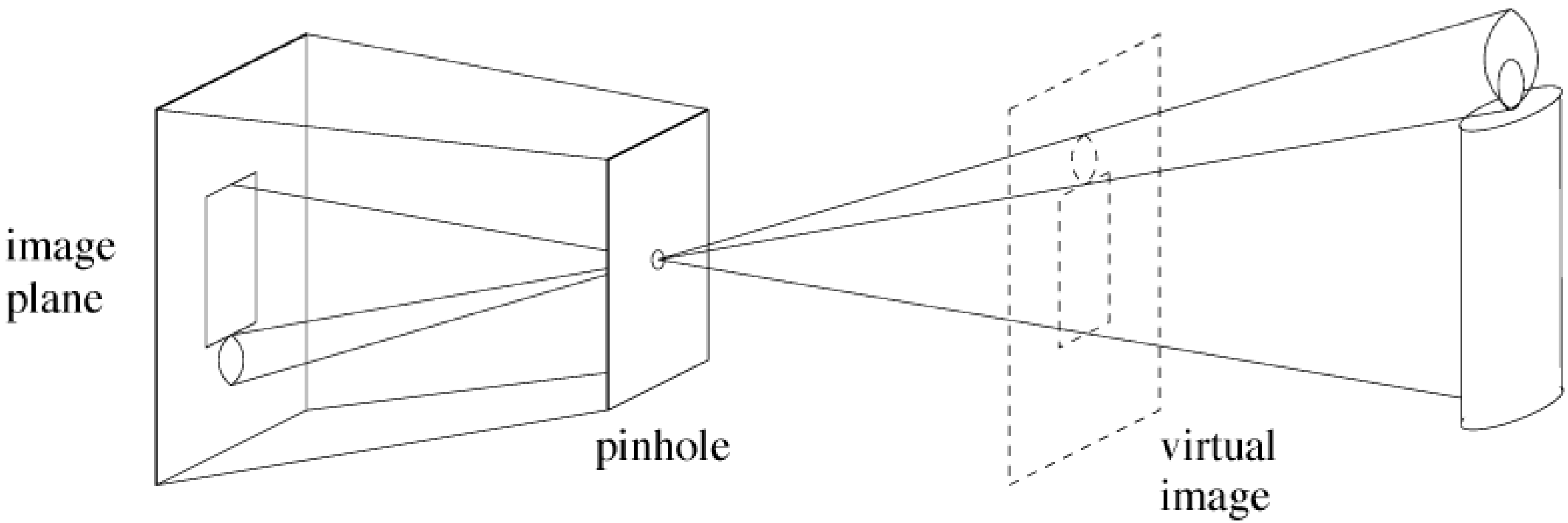
- Many functional areas (V1, V2,….): knowledge about them is limited

Image Formation

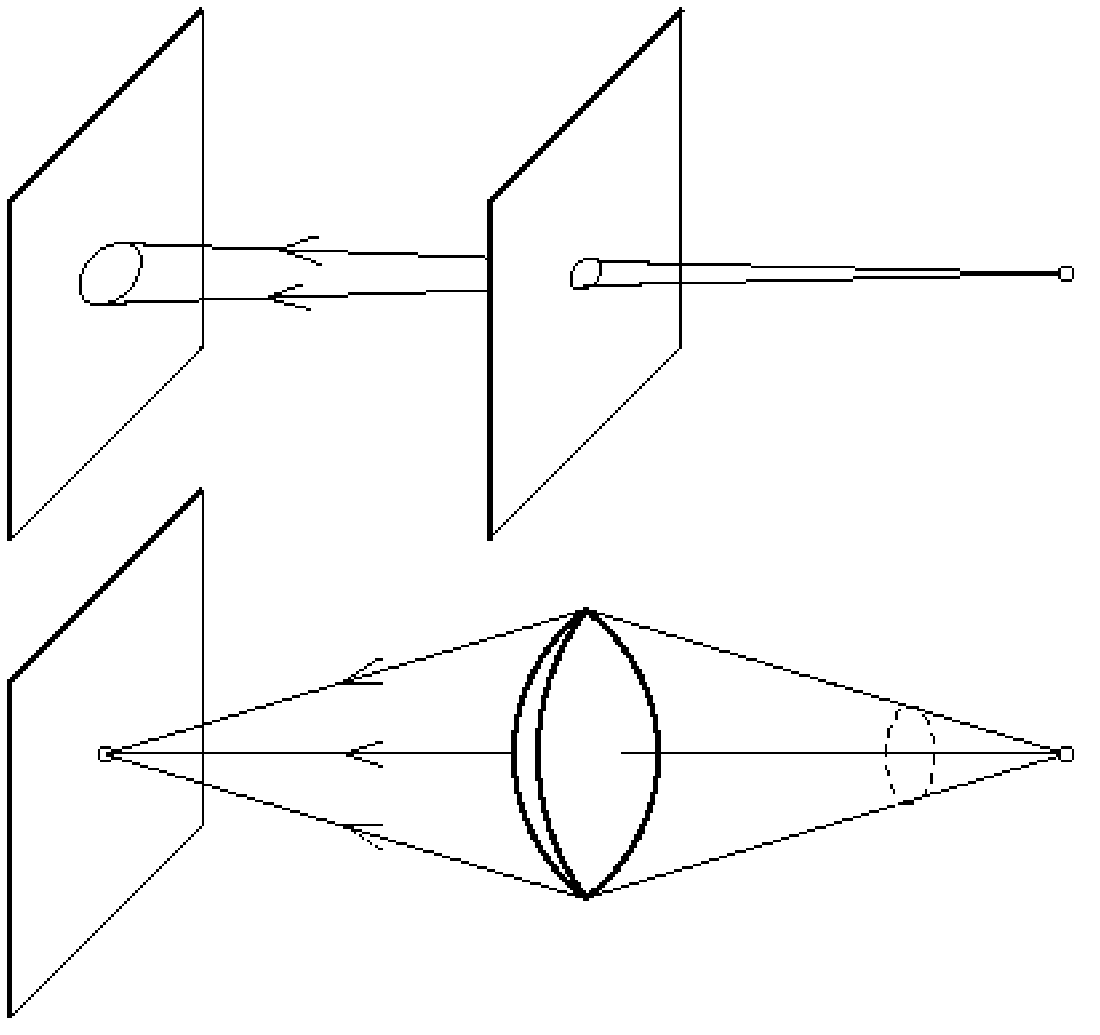
- Geometry
  - Where is the image of a point formed?
- Photometry/Colorimetry
  - How bright is the point?
  - What is its *color*?
- Ideal camera models
- Real lenses

Pinhole cameras

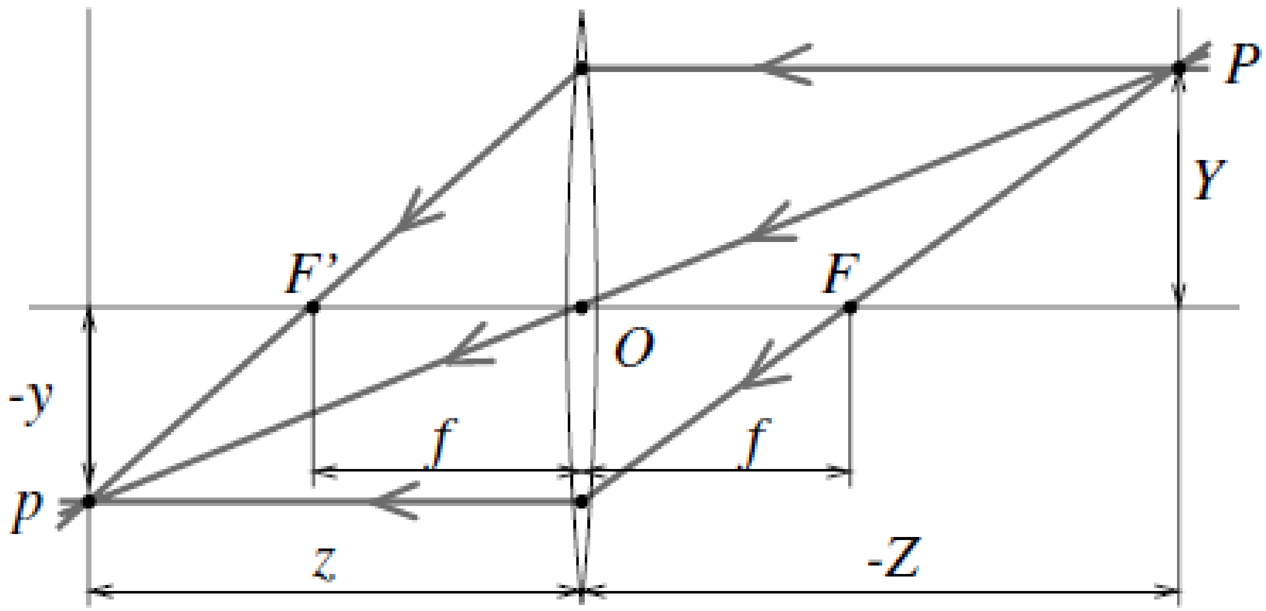
- Abstract camera model - box with a small hole in it
- Note inverted image
- Pinhole cameras work in practice, ignoring diffraction



The reason for lenses



The thin lens



$$\frac{1}{z} - \frac{1}{Z} = \frac{1}{f}$$

Thin Lens Properties

- Points at different depth focus at different positions of the image plane
  - With a fixed image plane, not all points will be in focus
  - “Depth of field”, *i.e.* distance over which focus is acceptable depends on the *aperture* size
  - Defocus property can be used to infer depth
    - Limited accuracy
- Field of view: depends on imaging surface size

Field of View (FoV)

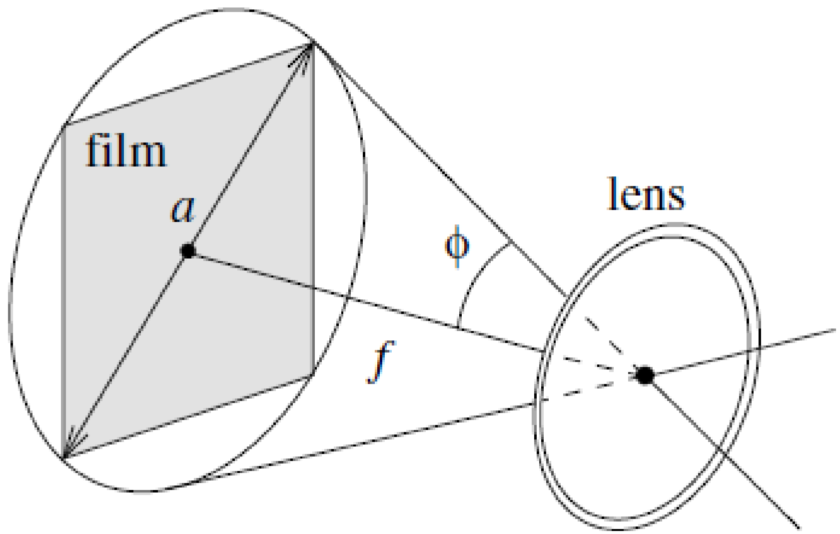
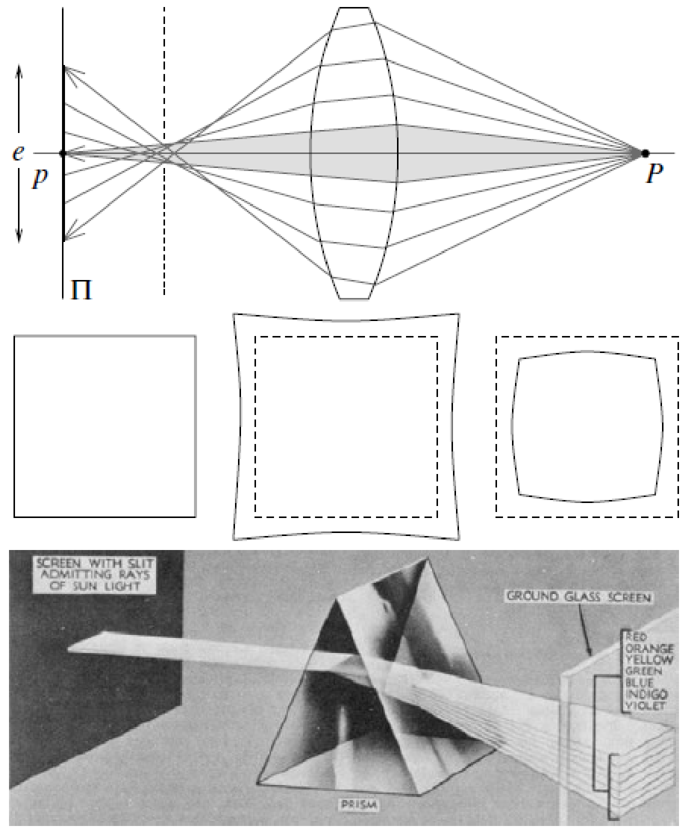


FIGURE 1.9: The field of view of a camera. It can be defined as 2ϕ, where $\phi \stackrel{\text{def}}{=} \arctan \frac{a}{2f}$, a is the diameter of the sensor (film, CCD, or CMOS chip), and f is the focal length of the camera.

Lens Distortions

- Real lenses suffer from various errors/distortions
- Chromatic aberration (not all wavelengths focus at the same point)
- Geometric distortions: complex lens systems used to reduce distortion
- Usually we will assume that complex lenses behave as ideal pinhole models but without the negative effects
  - No diffraction effects, sufficient light collection, all points in focus

Distortion Illustrations



(a)

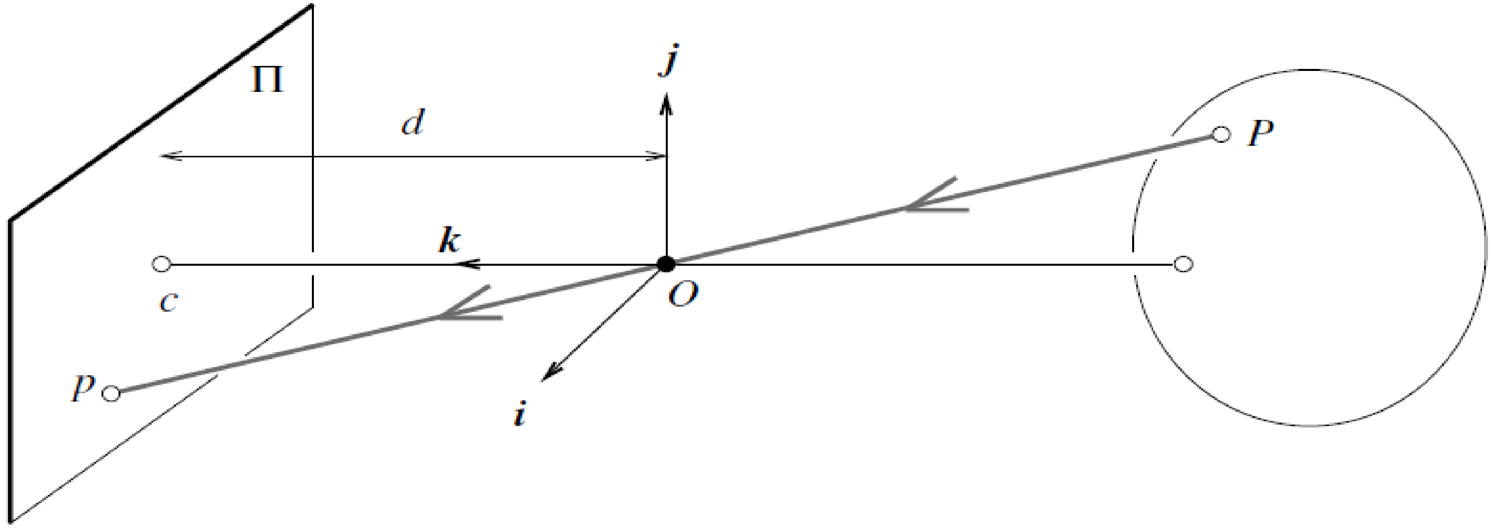
(b)

(c)

FIGURE 1.11: Aberrations. (a) Spherical aberration: The gray region is the paraxial zone where the rays issued from P intersect at its paraxial image p. If an image plane π were erected in p, the image of p in that plane would form a circle of confusion of diameter e. The focus plane yielding the circle of least confusion is indicated by a dashed line. (b) Distortion: From left to right, the nominal image of a fronto-parallel square, pincushion distortion, and barrel distortion. (c) Chromatic aberration: The index of refraction of a transparent medium depends on the wavelength (or color) of the incident light rays. Here, a prism decomposes white light into a palette of colors. *Figure from US NAVY MANUAL OF BASIC OPTICS AND OPTICAL INSTRUMENTS, prepared by the Bureau of Naval Personnel, reprinted by Dover Publications, Inc. (1969).*

The equation of projection

- Note: *k*-axis *towards* the camera (right handed coordinate system $\boldsymbol{k} = \boldsymbol{i} \times j$).



Let P = (X,Y,Z), p = (x, y, z)

- We know that z= d, find values of x and y
- Op = λ.OP for some λ, λ = d/Z

hence:

$$\begin{cases} x = d\dfrac{X}{Z}, \\ y = d\dfrac{Y}{Z}. \end{cases}$$