Cvision – 1
Introduction; Camera Geometry

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Outline

- 'Computer Vision'?
- Cameras & Cameras Geometry
- The Human Visual System

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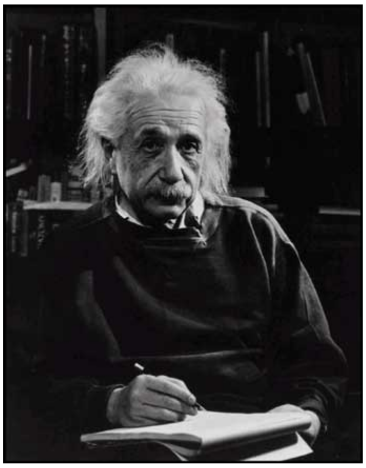
Topic: Computer Vision?

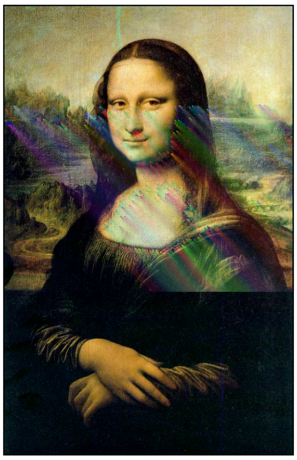
- ‘Computer Vision’?
- Camera and Camera Geometry
- The Human Visual System

A Picture is Worth 1000 Words

A Picture is Worth 100.000 Words

A Picture is Worth a Million Words

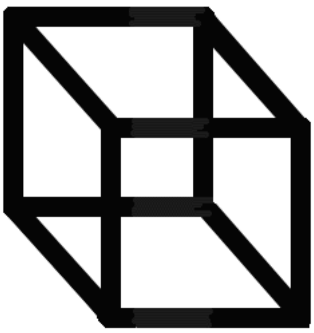




Human Vision

- Can do amazing things like:
  - Recognize people and objects
  - Navigate through obstacles
  - Understand mood in the scene
  - Imagine stories
- But:
  - Suffers from Illusions
  - Ignores many details
  - Ambiguous description of the world
  - Doesn't care about accuracy of world

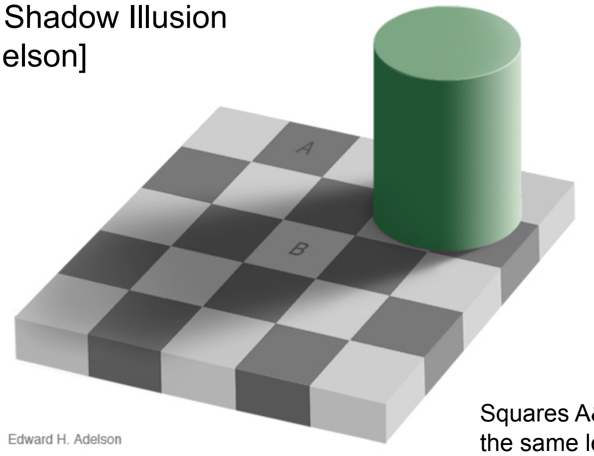
A Picture is Worth a ...?



Necker's Cube Reversal

A Picture is Worth a ...?

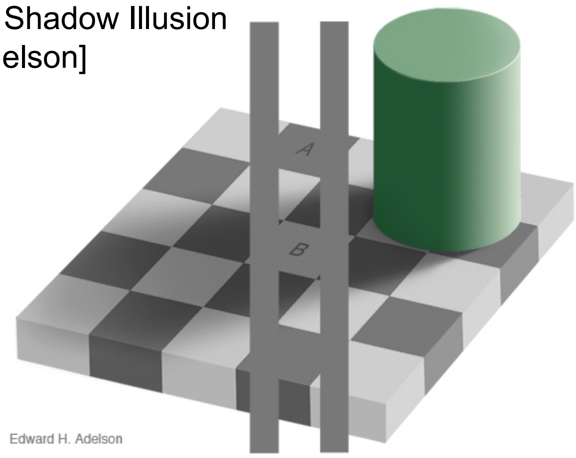
Checker Shadow Illusion
[E. H. Adelson]



Squares A&B are at
the same level of grey

A Picture is Worth a ...?

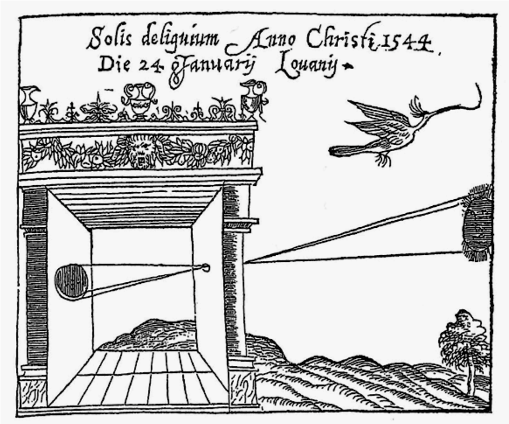
Checker Shadow Illusion
[E. H. Adelson]



Topic: Camera Geometry

- ‘Computer Vision’?
- Camera and Camera Geometry
- The Human Visual System

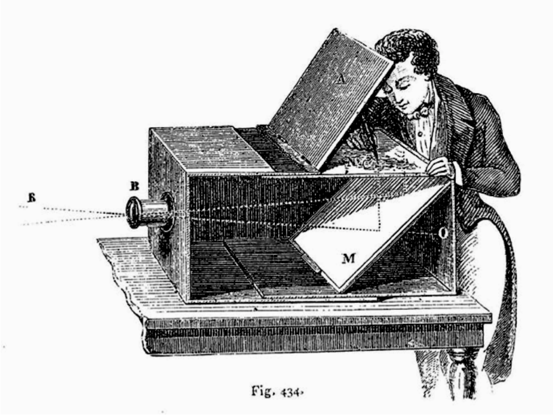
A Brief History Cameras



Camera Obscura, Gemma Frisius, 1544

1544

A Brief History of Cameras



Lens Based Camera Obscura, 1568

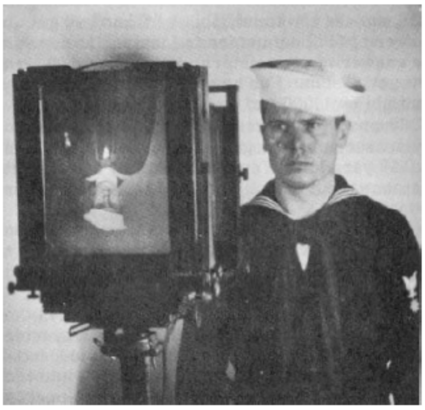
1544
1568

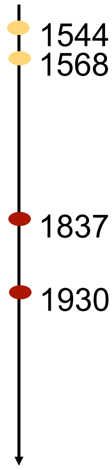
A Brief History of Cameras

Still Life, Louis Jaques Mande Daguerre, 1837

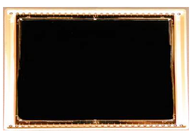
1544
1568
1837

A Brief History of Cameras

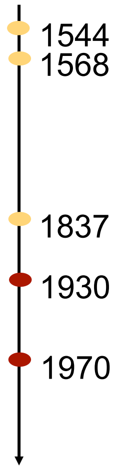




A Brief History of Cameras



Silicon Image Detector, 1970



A Brief History of Cameras

Digital Cameras

1544
1568
1837
1930
1970
1995

Pinhole Camera Model

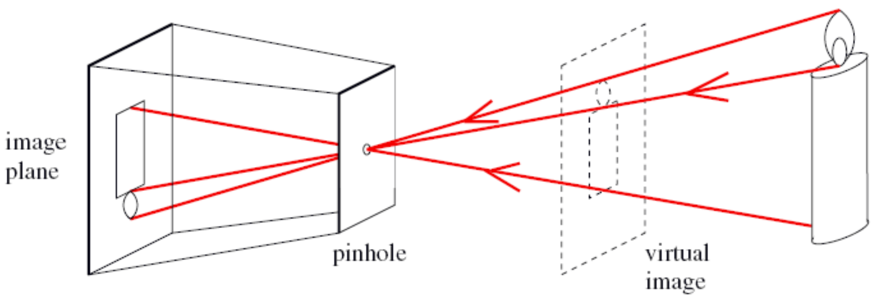


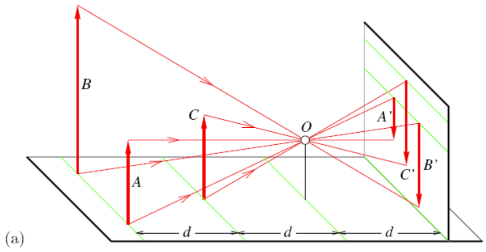
Figure 1.2. The pinhole imaging model.

Pinhole or central perspective, Bruneleschi, XV century

Basic Camera Geometry

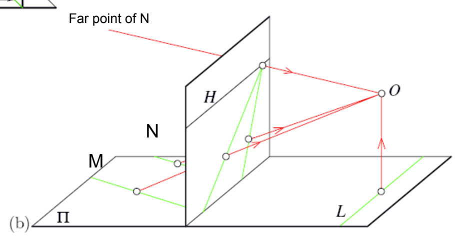
- Far objects appear smaller
- Lines project to lines
- Projection of paralell lines meet at a single "vanishing point"(VP)
- VPs of coplanar sets of lines are colinear: form the single vanishing line of the plane (Horizon)

Basic Camera Geometry



H_A=H_C=0.5 H_B

M,N paralell; L has no image



(Strong)Perspective projection

- These geometric properties are “common sense”
- Other properties can be inferred if we formalize the model using….
- …. Mathematics, of course…

(Strong)Perspective projection

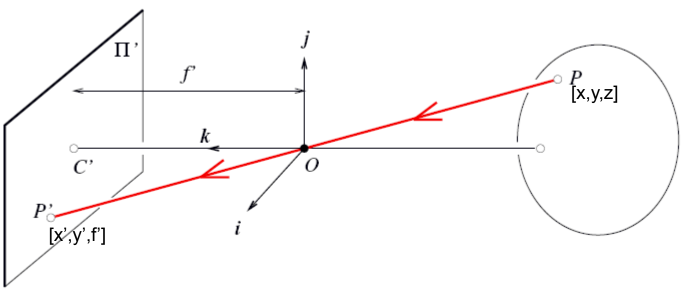


Figure 1.4. The perspective projection equations are derived in this section from the colinearity of the point P, its image P' and the pinhole O.

$$\begin{cases} x' = \lambda x \\ y' = \lambda y \\ f' = \lambda z \end{cases} \iff \lambda = \frac{x'}{x} = \frac{y'}{y} = \frac{f'}{z}, \qquad \begin{cases} x' = f'\frac{x}{z}, \\ y' = f'\frac{y}{z}. \end{cases}$$

Special case: Weak perspective (affine projection)

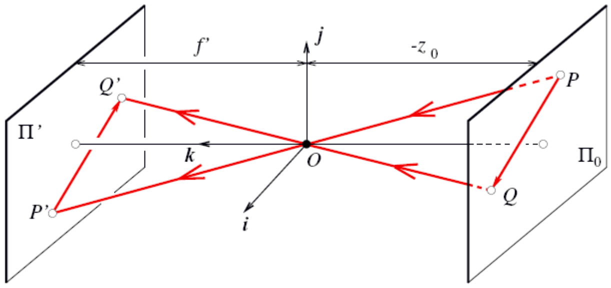
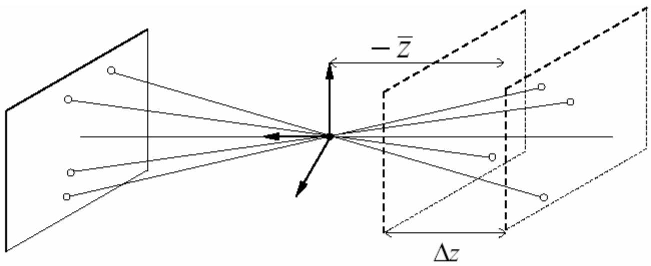


Figure 1.5. Weak-perspective projection: all line segments in the plane Π_0 are projected with the same magnification.

$$\begin{cases} x' = -mx \\ y' = -my \end{cases} \quad \text{where} \quad m = -\frac{f'}{z_0}.$$

If scene points are in a plane, projections are simply magnified by m

Special case: Weak perspective (affine projection)



If $\Delta z << -\bar{z}$: $\begin{matrix} x' \approx -mx \\ y' \approx -my \end{matrix}$ $\quad m = -\frac{f}{\bar{z}}$

Justified if scene depth is small relative to average distance from camera

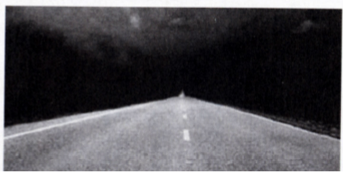
Pinhole Photography

©Charlotte Murray Untitled, 4" x 5" pinhole photograph, 1992

Image Size inversely proportional to Distance

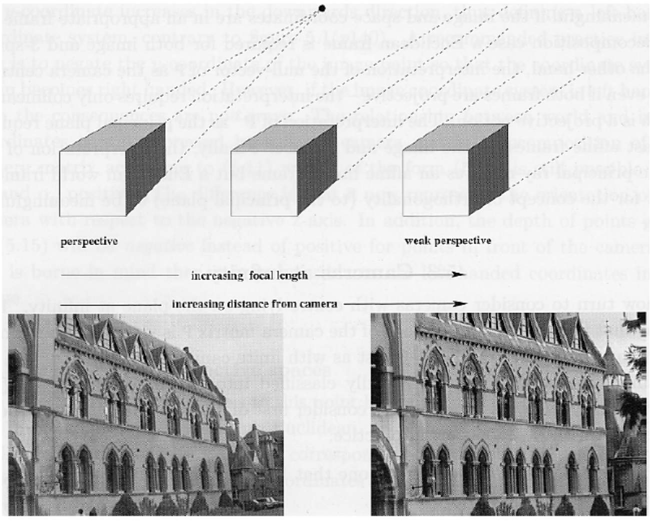
Reading: http://www.pinholeresource.com/

Perspective models photos



Strong perspective:
Angles are not preserved
The projections of parallel lines intersect at one point

Perspective models photos



From Zisserman & Hartley

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Perspective models photos

Strong perspective:
Angles are not preserved
The projections of parallel
lines intersect at one point

Weak perspective:
Angles are better preserved
The projections of parallel
lines are (almost) parallel

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Problems with Pinholes

- Pinhole size (aperture) must be "very small" to obtain a clear image.
- However, as pinhole size is made smaller, less light is received by image plane.
- If pinhole is comparable to wavelength λ of incoming light, DIFFRACTION blurs the image!
- Sharpest image is obtained when:

  pinhole diameter $d = 2\sqrt{f'\lambda}$

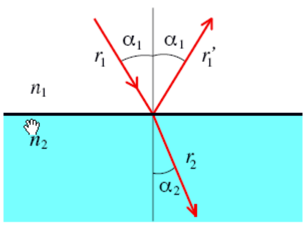
  Example: If *f'* = *50mm*,

  = *600nm* (red),

  d = *0.36mm*

Fig. 5.96 The pinhole camera. Note the variation in image clarity as the hole diameter decreases. [Photos courtesy Dr. N. Joel, UNESCO.]

Optics: Simple Lenses



Reflection and refraction – Snell's law

$$n_1 \sin\alpha_1 = n_2 \sin\alpha_2.$$

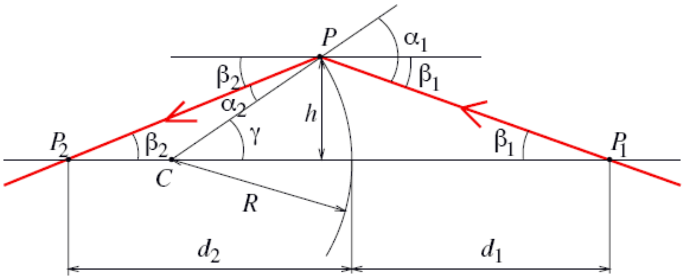
First order or paraxial optics: for small angles

$$n_1\alpha_1 \approx n_2\alpha_2$$

Higher order optics: for real cases, use Taylor series

$$\sin\alpha = \alpha - \frac{\alpha^3}{3!} + \frac{\alpha^5}{5!} - \frac{\alpha^7}{7!} + \ldots$$

Paraxial refraction



$$\alpha_1 = \gamma + \beta_1 \approx h(\frac{1}{R} + \frac{1}{d_1}) \quad \text{and} \quad \alpha_2 = \gamma - \beta_2 \approx h(\frac{1}{R} - \frac{1}{d_2}).$$

Paraxial refraction equation

$$n_1\alpha_1 \approx n_2\alpha_2 \Longleftrightarrow \frac{n_1}{d_1} + \frac{n_2}{d_2} = \frac{n_2 - n_1}{R}.$$

Thin lenses model (paraxial optics)

•Lenses are used to avoid the problems of pinhole imaging

•They are based on the refraction optics laws

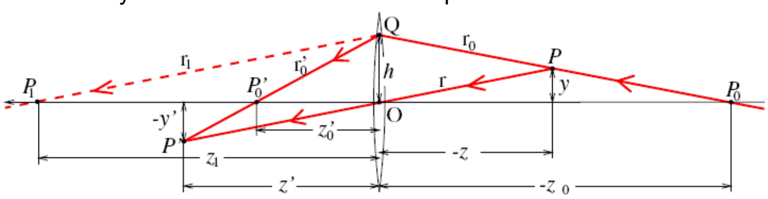
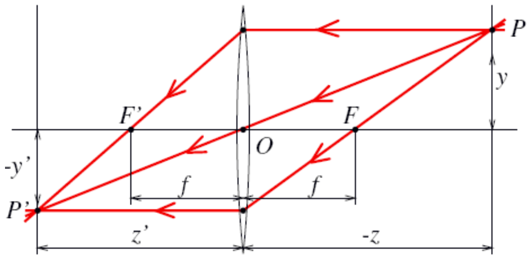


Figure 1.11. Image formation in the case of a thin lens. The ray r_1 is dashed to indicate that it will never actually reach the point P_1 since it will be refracted by the left boundary of the lens before that. Note that the z axis is oriented from right to left to ensure consistency with the previous figures, thus P and P_0 have negative depths z and z_0.

Thin lenses model (paraxial optics)



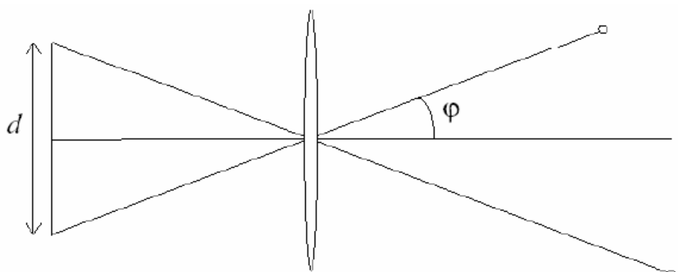
All rays emanating from **P** converge to a single point **P'**

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

Points at infinity are focused on plane $z' = f$

Ideal because: infinite aperture
infinite field of view
infinitely small distance between surfaces

Finite Field of View



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

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

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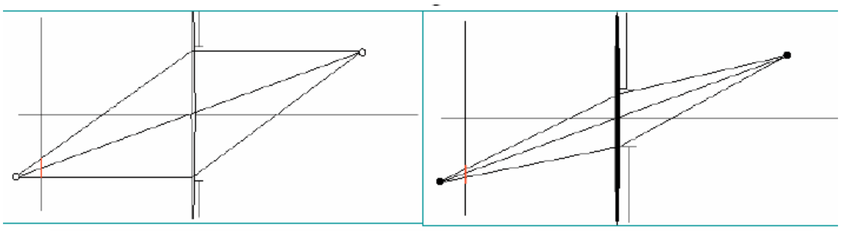
Finite Aperture



Ideal case: Only the points on one plane are in perfect focus
Finite aperture: points within a region of depth D (depth of field) are in focus.
For a given f, the larger the aperture, the smaller D
Depth of field controlled by f/a

Depth of Field

- Range of object distances over which image is sufficiently well focused.
- Range for which *blur circle* is less than the resolution of the sensor.

http://images.dpchallenge.com/images_portfolio/27920/print_preview/116336.jpg

Real Lenses

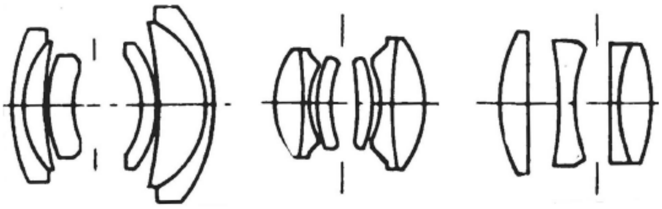
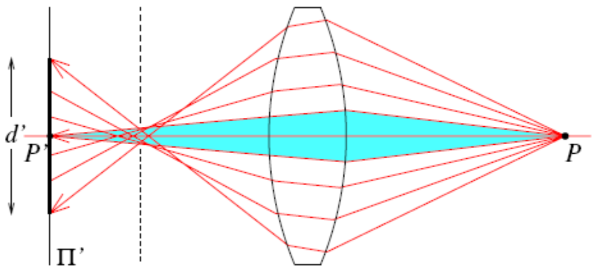


Figure 1.17. Photographics lenses. Reprinted from [Montel, 1972], p. 54.

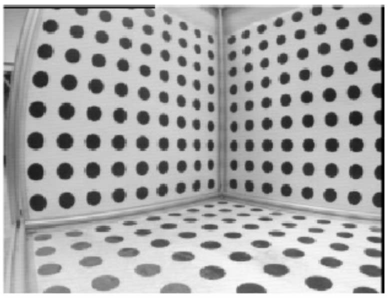
- Previous approximation is incorrect
  - → Aberrations and distortions
  - → Blurring and incorrect shape in the image

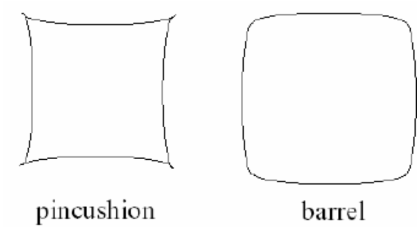
Spherical aberrations



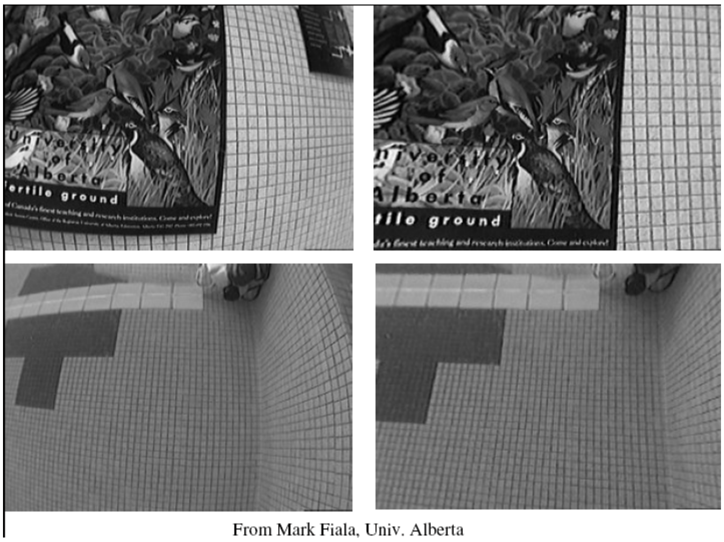
Rays further from the optical axis are focused closer to the lens

Geometric distortion



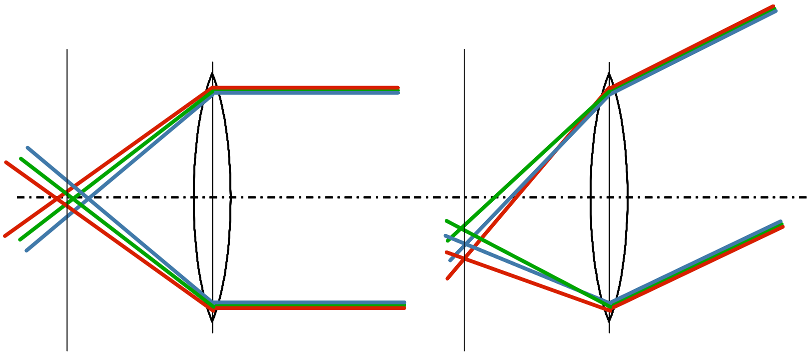


Geometric distortion



From Mark Fiala, Univ. Alberta

Chromatic Aberration



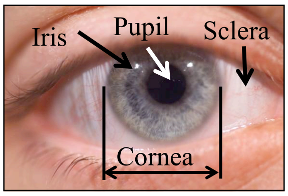
longitudinal chromatic aberration (axial)

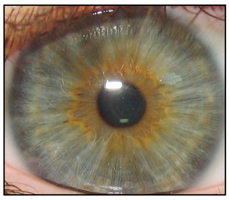
transverse chromatic aberration (lateral)

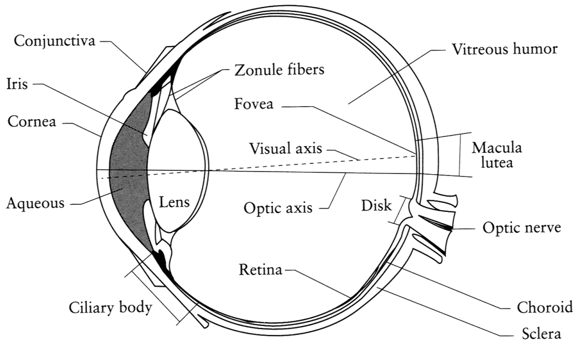
Topic: The Human Visual System

- ‘Computer Vision’?
- Camera and Camera Geometry
- The Human Visual System

Our Eyes



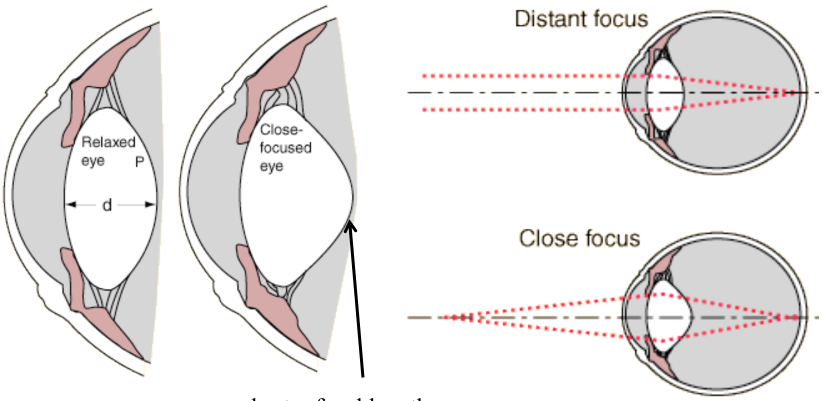




-Iris is the diaphragm that changes the aperture (pupil)

-Retina is the sensor where the fovea has the highest resolution

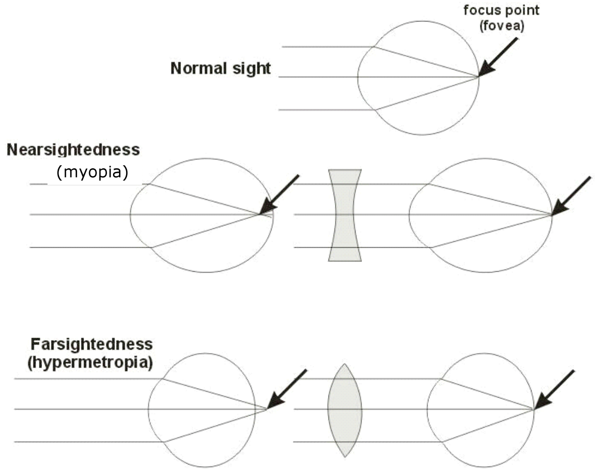
Focusing



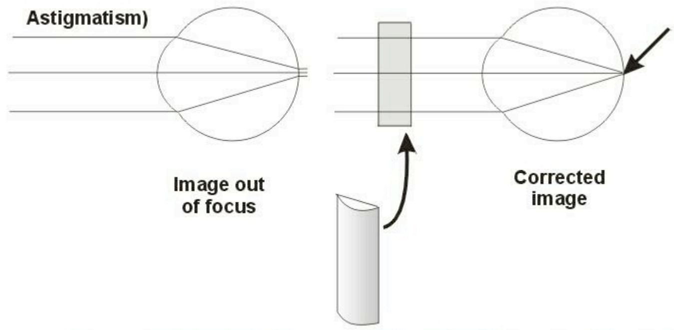
shorter focal length

Changes the focal length of the lens

Myopia and Hyperopia



Astigmatism



The cornea is distorted causing images to be un-focused on the retina.

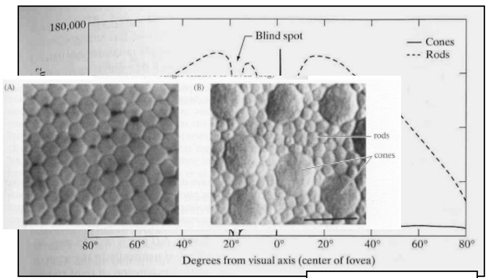
Blind Spot in the Eye

●　　　　　　　　　　　　+

Close your right eye and look directly at the "+"

Colour

- Our retina has:
  - **Cones** – Measure the frequency of light (colour)
    - 6 to 7 millions
    - High-definition
    - Need high luminosity
  - **Rods** – Measure the intensity of light (luminance)
    - 75 to 150 millions
    - Low-definition
    - Function with low luminosity



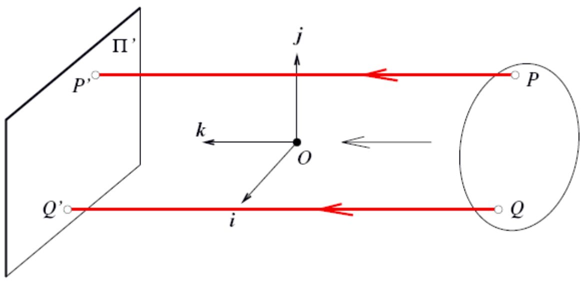
Gonzalez & Woods

We only see colour in the center of our retina!

Resources

- J.C. Russ – Chapters 1 and 2
- Gonzalez & Woods – Chapter 1
- L. Shapiro, and G. Stockman – Chapter 1
- "Color Vision: One of Nature's Wonders" in http://www.diycalculator.com/sp-cvision.shtml

Orthographic projection



Justified if scene depth is small compared
to distance from camera *and*
camera remains at approximately constant distance