Vision

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Straight Photography
Image Formation in a Single Lens
What is Light?

• Some useful ways to think of light:
  • Rays of light
  • Waves of light
  • Electromagnetic radiation that has both wavelike and particle-like properties, containing quanta of light: photons
What can happen to light?

- Refraction
- Reflection
- Diffraction
- Scattering
- Absorption
- ...

Image Formation in the Eye
Anatomy of the Eye
Phototransduction
Bipolar Cells

Ganglion cell

Message is transmitted to ganglion cell

Message is sent to the brain

Bipolar cell

Message is transmitted to bipolar cell

Photoreceptor

Photopigment splits, chemical reactions produce message

Photon strikes photopigment
SEM of rods and cones
The Optic Nerves

- Optic Disc
- Chiasm
- Optic Nerve
- Optic Tract
- Optic Radiations
- Primary Visual Cortex
Photographic Camera
Camera objectives contain many different lenses that act together as a single next-to-perfect lens. This is necessary to correct for optical aberrations.
The Stereo Image
Optical Aberrations

- Aberrations deteriorate image quality. Lens systems are designed to mimic a single, ideal, infinitely thin lens.
Refraction in a single Lens
Fermat’s Principle

Light travels between two points along the path that requires the least time, as compared to other nearby paths.

(Fermat = French mathematician, 1600s)
Law of Reflection

$\theta_1 = \theta_2$
Snell’s Law (Refraction)

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
Total Internal Reflection

\[ n_1 \sin \theta_C = n_2 \]

Critical Angle
Geometrical Ray Optics

Three Principal Rays:
“4f system”
Magnification

\[ M = \frac{f}{(f-v)} \]
Imaging at different focal positions

a. Object is at infinite distance

The image is a point at the principal focus.
Imaging at different focal positions

b. Object is beyond twice the focal length (2F)

Image is real, inverted, diminished and located between F' and 2F'.

Imaging at different focal positions

c. Object is at twice the focal length (2F)

Image is real, inverted, of the same size and located at 2F'.
Imaging at different focal positions

d. Object is between 2F and F

Image is real, inverted, bigger and located beyond 2F'.
Imaging at different focal positions

e. Object is at the focus (F)

Reflected rays are parallel. No image is formed.
Imaging at different focal positions

f. Object is between the focus and the optical center

Image is virtual, erect, bigger and located between 2F and F.
Magnifying glass and loupe
IT’S BREAK TIME
Lens-Maker’s Equation

\[
\frac{1}{F} = (n - 1) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)
\]

- **F** = focal length \((1/2\ C)\)
- **n** = refractive index
- **R** = radius of curvature

**Positive (Converging) Lens**

- **R_1** = positive
- **R_2** = negative
- **F** = positive

**Negative (Diverging) Lens**

- **R_1** = negative
- **R_2** = positive
- **F** = negative
Spherical Aberration

cross-section

the caustic curve
Spherical Aberration

Legend:
- Red: Light Rays
- Black: Optical Axis
- Green: Best Focus Point

Lens with Spherical Aberration

Aspherical Lens
Aspherical Lenses

Earliest preserved optical quality lenses (~10th century Visby, Sweden)
Spherical mirror
Caustic Curve

Spherical aberration in a cup of tea
Parabolic Reflector
The Fresnel Lens
Fresnel Lenses

John Ford using a 24” Fresnel lens shooting John Wayne

Fresnel lens in lighthouse
Refraction in a Prism
Visible Light Wavelength Spectrum

Energy

Wavelength [m]

10^6 10^0 10^-3 10^-8 10^-11 10^-13

Radio waves  Microwaves  IR  UV  X-rays  Gamma-rays

750 700 600 500 400 [nm]
Refractive index $\sim$ wavelength

Chromatic aberration
Chromatic Aberration

Longitudinal / Axial Chromatic Aberration

Lateral / Transverse Chromatic Aberration

Legend
- RGB Color Rays
- Optical Axis
- Best Focus Point
Achromatic Doublet

First lens: Crown glass    Second lens: Flint glass
Not perfect

(Mirrors don’t have chromatic dispersion)
Field Curvature

Curvature of field:
Correcting Coma

- Light from the middle of the lens concentrated here.
- Light from outer region of lens spreads out here.
- Replace with lens of this shape.
Simple Lenses

Biconvex

Plano-convex

Positive meniscus

Negative meniscus

Plano-concave

Biconcave

Single Element Spherical Lenses
Depth of Field/Focus

Large depth of field  Small depth of field
Circle of Confusion
Small aperture = more DOF
Large aperture = less DOF
Did I use a small or large aperture here?

Monarch butterfly (*Danaus plexippus*) on its favorite food, the milkweed plant.
“Bokeh” 暈け

Say’s Phoebe (*Sayornis saya* named after the American naturalist Thomas Say) in Moore Creek Preserve shot at F# 2.8
Extremely small aperture

Ansel Adams shooting in the High Sierra
F# ("F-number") = \frac{f}{D}

Determined by ratio of lens focal length \( f \) and lens aperture Diameter \( D \)

\[ f/1 = f/\left(\sqrt{2}\right)^0, \quad f/1.4 = f/\left(\sqrt{2}\right)^1, \quad f/2 = f/\left(\sqrt{2}\right)^2, \quad f/2.8 = f/\left(\sqrt{2}\right)^3, \ldots \]
Again...
F# also affects resolution (we will talk about this next time)
Next time, we will also talk about two-lens imaging systems

- Modern microscopes use this layout
- Possible to control both field and aperture stop
First Homework is due Thursday!

- Homework is due at the beginning of class
- If you cannot attend class on Thursday, please email me the homework (same deadline)

(Straight photography vegetables, shot by Edward Weston, F64 group)