Announcements

- Read LaValle, Chapter 4,5.
- MP3 due tonight @11:59pm
Imaging Properties of a Lens

$f$ depends on: lens shape, material

\[ D = \frac{1}{f} \]
Structure of the Human Eye

- Cornea
- Anterior chamber (aqueous humor)
- Ciliary muscle
- Suspensory ligament
- Vitreous humor
- Hyaloid canal
- Fovea
- Retinal blood vessels
- Optic nerve
- Optic disc
- Choroid
- Sclera
- Retina
- Zonular fibres
- Iris
- Pupil
- Posterior chamber

Eye: 59D
Structure of the Human Eye

Figure 4.24: A simplified view of the human eye as an optical system.
Optical Power of the Human Eye

Figure 4.25: A ray of light travels through five media before hitting the retina. The indices of refraction are indicated. Considering Snell’s law, the greatest bending occurs due to the transition from air to the cornea. Note that once the ray enters the eye, it passes through only liquid or solid materials.

\[ D_{\text{eye}} = 59.52 + 10 \]
Imaging Properties of a Lens

How far should a point be from the lens to produce parallel rays?
Object is at distance $S_1 > f$, its "real image" is in focus at distance $S_2 < f$. 

\[ \frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f} \]
Imaging Properties of a Lens

\[ \frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f} \]

Object is at distance \( s_1 < f \), its "real image" is not in focus.

The "virtual image" is formed at distance \( -s_2 \) before lens.
Imaging Properties of a Lens

Does the formula still work for parallel rays?

\[ \frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f} \]
Examples of Use Cases

Projection
Examples of Use Cases

Magnification
Structure of the Human Eye

The diopter of the human eye is about $\approx 58 \text{ D}$

Eye lens is not spherical. Retina (and retinal image) is not flat.

Ciliary muscle has the ability to increase the diopter by $\leq 10 \text{ D}$ ($\leq 40\%$).

Optic nerve forms a blind spot on the retina.
Imaging System Inside of a Human Eye

**CASE 1**

The eye muscle is **relaxed**

Object is at **∞** Rays are **parallel**

The rays **do** get converged **on** retina. The image is **sharp**
The eye muscle is relaxed.

Object is at some distance. Rays are diverging.

The rays do not get converged on retina. The image is blurred.
Imagine Properties of the Human Eye

58 - 68D

\[
\frac{1}{58} \approx 17\text{cm}
\]

\[
\frac{1}{68} \approx 14\text{cm}
\]

How strong are your eye muscles?

How far can an object be so you can focus on it?

\( X > 30\text{cm} \)

\( X = 20 - 30\text{cm} \)

\( X = 10 - 20\text{cm} \)

\( X = 5 - 10\text{cm} \)

\( X = X < 5\text{cm} \)
CASE 3

The eye muscle is **not relaxed**

Object is at \( \text{distance} < \frac{1}{x} \) Rays are **divergent**

The rays **do** get converged **on** retina. The image is **sharp**
Vision Defects of a Human Eye

- too strong
- too weak

A Short Sighted Eye
Not self-corrected

A Long Sighted Eye
Hard to diagnose
Imaging System Inside of a Human Eye

CASE 4

Reading glasses

The eye muscle is _relaxed_.

Object is at _reading distance_. Rays are _divergent/parallel_.

The rays _do_ get converged _on_ retina. The image is _sharp_.

No vision defects
Imaging System Inside of a Human Eye

CASE 2

Diplopia:

Relaxed

Vergence:

Accommodation: the process of "zooming in", focusing on a nearby object.

Accommodation is normally coupled with vergence.
The eye muscle is **relaxed**.

Object is at **distance** $f$. Rays are **parallel**.

The rays **do** get converged. "Virtual images" are sharp on the retina.
Lens Aberrations

Focal Length and Angle of View
The illustration and sequence of photographs below, which are all taken from the same viewpoint, show that as camera lens focal length increases so the angle of view decreases.

Trade offs:
- Size
- Weight
- Focal length
- Field of view
- Distortion
- Cost
- Ease of manufacturing

Fisheye lens
Extreme wide-angle lenses of 6–8mm are known as fisheyes. They record a circular image of at least 180°, with some lenses even looking behind the camera with a 220° angle of view. The resulting image is very distorted, with vertical and horizontal lines bowed.

Wide-angle lens
Wide-angle lenses of 18–35mm have more general applications than fisheye lenses. Angles of view are generous and depth of field at all apertures is extensive. Poor-quality wide-angle lenses may sometimes show some distortion toward the edges of the image.

Standard lens
A standard 50mm lens is fitted on most 35mm SLRs. Useful for most types of subject, it often has a wide maximum aperture, making it good in low light. It does not show the same distortion as a wide or long lens, and its angle of view is similar to that of the human eye.

Long-focus lens
Angles of view of long-focus lenses of 80–400mm start to diminish rapidly. With so little of the scene filling the frame, the subject is shown very large, making a long lens ideal for distant subjects or detailed close-ups. Depth of field decreases as the lens gets longer.

Extreme long-focus lens
Focal lengths above 400mm are specialized and are not usually found on standard zooms. The use of a tripod to support the lens is essential because of its relatively heavy weight. A long lens has a shallow depth of field and a small maximum aperture.
Optical Distortion

Spherical lens

Aspheric lens
Put the Oculus Rift lens 40 mm away from the paper. Look through the lens and see which grid "appears" to be least distorted. Mark your result!
Spherical Aberrations

https://www.youtube.com/watch?v=EL9J3Km6wxI&app=desktop
Astigmatism
Coma
One More Issue
Electromagnetic vs Visible Spectrum

\[ f = \frac{c}{\lambda} \]
Spectral Power of a Light Source

is like a histogram of ____________________
Spectral Power of a Light Source

is like a histogram of ________________
Spectral Reflectance of Material

Reflectance (%)

400 600 800 1000 1200
Perceiving Color of an Object

In white light, the object appears red.

In red light, the object appears black.

In green light, the object appears black.
Chromatic Aberration

https://www.youtube.com/watch?t=6&v=-bcRYQKY4jc
Chromatic Aberration Correction

- Find and use material with a high Abbe number

https://www.youtube.com/watch?v=-bcRYSKvY4jc
Reducing Weight and Cost: Fresnel Lens
2001: The detailed optical structure of the lens is still unknown, although we know that the surfaces are aspheric and the refractive index has a gradient form. Both of these have possibly a strong influence on the aberrations of the lens and hence eye as a whole. A knowledge of the ocular aberrations arising at the lens is important in understanding the effect of corneal aberrations on visual performance.

2009: Cornea, lens and eye models are analyzed and compared to experimental findings to assess properties and eventually unveil optical design principles involved in the structure and function of the optical system of the eye. Models and data often show good match but also some paradoxes.