Demonstration of the shape of the contrast sensitivity function for luminance gratings. Spatial frequency increases continuously from left to right, and contrast increases from top to bottom.
Aqueous Humor
Vitreous Humor

Lens
Iris
Cornea
Ciliary muscles
Sclera
Extraocular muscles
Optic nerve
Sources of Retinal Image Blur

Diffraction
Aberrations
Light Scatter

Geometrical Optics and Physical Optics
Retinal Structure
Primate Peripheral Retina

Rods

Cone
outer segment
inner segment
nucleus
rods synaptic terminal
cone

×1000

after Young, 1969
Stiles-Crawford Effect (1933)
Housefly \( \sim 0.5 \text{ c/deg} \)

Cat \( \sim 5 \text{ c/deg} \)

Human \( \sim 60 \text{ c/deg} \)

Eagle \( \sim 150 \text{ c/deg} \)
FOV 0.8° of Visual Angle or 243.7 µ° eccentricity
The Sampling Theorem:

To avoid aliasing, you need a sample (a photoreceptor) for each bright and each dark bar of the highest spatial frequency component in the retinal image.
Ganglion Cell Axons
Section Through Primary Visual Cortex
Also called Striate Cortex or V1
* A. Roorda & D. R. Williams, *Nature* 1999
Achromatic channel

Red-green channel

Yellow-blue channel
LENS INCREASES its focusing power by becoming more sharply curved. When the initially unaccommodated, or flattened, lens is viewed from the side (a), it looks fairly thin from front to back. It thickens as it accommodates (b); the front surface moves closer to the cornea but the back surface remains in place. The change in shape is effected primarily by the contraction of the ciliary muscle. A front view shows that the lens adopts the unaccommodated state (c) when the muscle expands so that its diameter is at a maximum. The expansion of the muscle pulls the zonules taut, and they pull on the lens and flatten it. When the muscle contracts (d), the zonules relax, and the lens rebounds into a rounded state, much as a foam-rubber ball rebounds after compression. The illustrations of accommodation are exaggerated for clarity.
Radiometry
Photometry
Colorimetry
Methods to correct the eye’s refractive errors:
Glasses and Spectacles

Paintings also show these early types of “glasses”

Detail of *Hugh of St. Cher*, painted in 1352 by Crivelli

Detail of *Death of the Virgin* painted between 1400 and 1410 by the Master of Heiligenkreuz
Perfect Eye

Planar wavefront

Spherical wavefront

Aberrated wavefront

Aberrated Eye
Zernike Modes

radial order
2nd

astigmatism defocus astigmatism
$Z_2^2$ $Z_2^0$ $Z_2^2$

trefoil coma coma trefoil

3rd
trefoil coma coma trefoil
$Z_3^3$ $Z_3^{-1}$ $Z_3^3$

4th
quadrafoil secondary astigmatism spherical secondary astigmatism quadrafoil
$Z_4^4$ $Z_4^{-2}$ $Z_4^0$ $Z_4^{-2}$ $Z_4^4$

5th
pentafoil secondary trefoil secondary coma secondary coma secondary trefoil pentafoil
$Z_5^5$ $Z_5^{-2}$ $Z_5^{-1}$ $Z_5^1$ $Z_5^{-2}$ $Z_5^5$
Hartmann-Shack Wavefront Sensor Results

Aberration-free

\[ \begin{align*}
\text{DL} & \quad \text{YY} & \quad \text{GYY}
\end{align*} \]

Wave Aberrations

Point Spread Functions

5 arcmin
University of Rochester Library viewed from half a mile away in broadband light with a large (6.8mm) pupil.
LASIK

Laser Beam

Corneal flap

Excimer laser removes (ablates) underlying corneal tissue
Customized Contact Lenses

Closed Loop Ablation of Contact Lens In Place on the Patient’s Eye
Fundus Imaging
1. Retinitis Pigmentosa
Can we track photoreceptor cell rescue in gene therapy?
Rochester, UC, Berkeley, Cornell University
2. Can We Track Ganglion Cell Bodies In Glaucoma?

Adaptive Optics, Confocal imaging, Ellipsometry, Nomarski, OCT, Two-Photon Microscopy, ...

Beth Peterson and Dennis Dacey, UW
Adaptive optics allows telescopes to see through the turbulent atmosphere.
Weather on Neptune Resolved With AO

Without AO

With AO
Adaptive Optics Provides Highest Resolution Images of the Living Retina

Without Adaptive Optics

With Adaptive Optics
High Stroke MEMS Mirrors

Boston Micromachines
Iris AO
Lucent

Actuator Array  Mirror Segment
The Goal:
Recovering Cell-Sized Structure
In Living Human Retina
Optical Sectioning in the AOSLO

RS left eye, 4.5 deg superior