AcrylicVision: A Model of the Eye

Addeson Lehv, Nicholas Bustamante, and Luis Perez-Cuesta

ABSTRACT

The objective of this project was to study the optics of the human eye and develop an educational tool to better understand it. For this purpose we created a model eye in a scale 10:1, that would also enable us to mimic various vision pathologies affecting different eye's components.

BIOLOGY of the HUMAN EYE

We focused on the following components of the eye: the cornea, the iris, the crystalline lens, and the retina. The cornea is a convex lens which, in our scenario, shrinks the image to fit the retina. The iris is the colored part of the eye, a muscle that controls the diameter of the pupil. The pupil dilates or contracts depending on how much light is needed. By changing its shape, the crystalline lens is able to focus on objects at different distances from the eye. In the back of the eye is the retina, which is made up of photoreceptor cells that react with light. This is where an upside down version of the image forms on the eye.

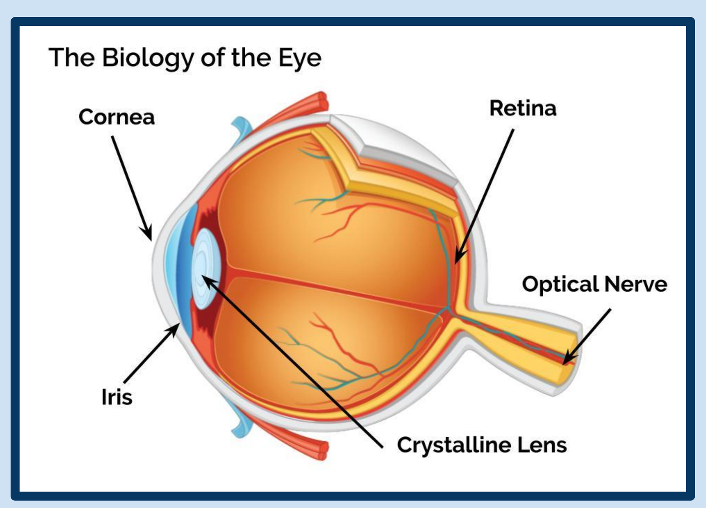


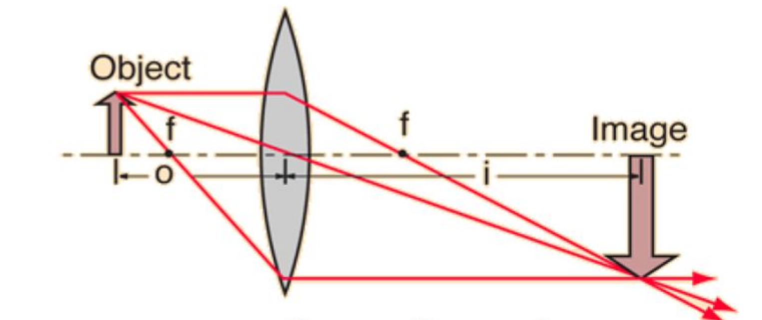
Fig. 1: Diagram of the human eye showing the different optical components

MIMICKING the EYE

We were able to mimic the eyeball and the retina using a white acrylic globe, the white color resembling the external aspect of the eye and at the same time serving as a projection screen (retina) on the inside. Lenses and other components were laid out internally using Computer Aided Design (CAD) to custom design 3D printed parts. To preserve the alignment along the optical axis, from the object to the retina, we mounted all components on a rail, also using custom designed 3D printed parts. Finally we aimed to mimic vision pathologies such as cataracts, by replacing the crystalline lens with a blurred lens.

OPTICS of the HUMAN EYE

To mimic the cornea and the crystalline lens, we needed to familiarize ourselves with optics. Our work here was rooted in the following principle about convex lenses:



$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

let f = focal length
let o = distance between object and the lens
let i = distance between image and the lens

Fig. 2: Diagram of light rays bent by a convex lens and forming an image at the focal plane

We first scaled up the sizes and distances of the human eye in a ratio 10:1, and according to that we figured out the focal distances we needed for our lenses system in order to be able to form an image in the back of the eye.
For this we used the following equation:

$$\frac{1}{f} = \frac{1}{fc} + \frac{1}{fl} - \frac{d}{fc \cdot fl}$$

let f = total focal length
let fc = focal length of the cornea
let fl = focal length of the optic lens
let d = distance between cornea lens & optic lens

We did this for two cornea-crystalline configurations: one for far sight, with a long focal distance crystalline, and another one for near sight, with a short focal distance crystalline.

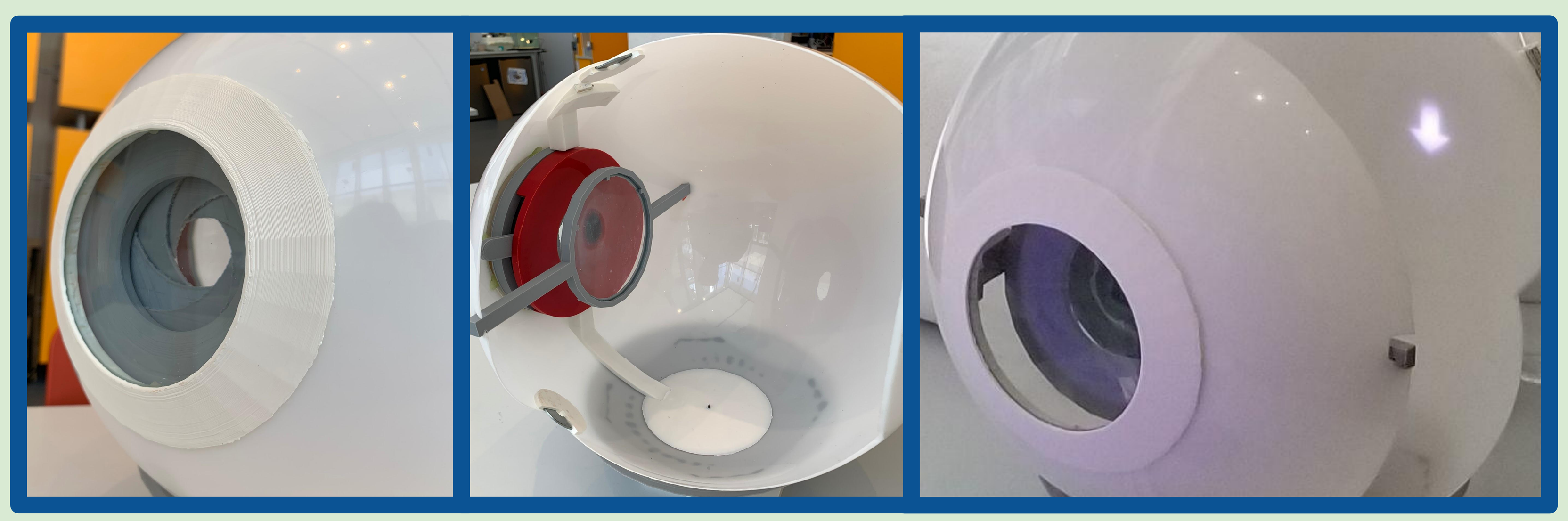


Fig. 3: Left, external view of the eye looking inwards, with cornea and iris. Middle, inside view with crystalline lens. Right: flipped image of an arrow pointing *upwards*, forming on the model eye's retina.

COMPUTER AIDED DESIGN (CAD) and 3D PRINTING

The uses of CAD and 3D printing was essential for mimicking the iris and also for the basic construction of the model eye. We created our cornea holder and several other custom made parts making our own unique designs in Tinkercad. Some of the CAD files for the iris were downloaded from a website*. We also designed and printed parts to keep the crystalline suspended in the globe and optically aligned. Lastly, we printed a concave shaped eye holder that is used to keep the eye stationary by attaching it to the rail, and other parts aiding structure and alignment.

Fig. 4: 3D printed iris in a dilated (left) and a constricted (right) pupil configuration.

*Internal diaphragm design: Wojciech Porcek's website at Thingiverse (https://www.thingiverse.com/wporcek/about)

CONCLUSION

How can we build a model eye which best mimics the functionality of a human eye? Through this project, we successfully created a model eye that has many functionalities of a real eye, is able to model different vision pathologies, and also serves as an educational tool. During this project we gained skills in computer aided design and optics. We also presented our model eye at Saturday Science, an outreach event hosted by BioBus and Columbia at the Zuckerman Institute. Currently, we are working in developing a robotic mechanism to have the iris automatically responding to light intensity, which will show how the image on the retina is affected. We are also working in mimicking other vision pathologies like short sightedness, astigmatism and macular degeneration.