Chapter 1

How Eyes Work

Dr. Craig Blackwell has made a great video on the mechanics of the eye. You should watch it: https://youtu.be/Z8asc2SfFHM

Mechanically, your eye works a lot like a camera. The eye is a sphere with two lenses on the front: The outer lens is called the *cornea*, while the second lens is simply called "the lens." Between the two lenses is an aperture that opens wide when there is very little light, and closes very small when there is bright light. The opening is called the *pupil* and the tissue that forms the pupil is called the *iris*. When people talk about the color of your eyes, they are talking about the color of your iris. The blackness at the center of your iris is your pupil.

There are two types of photoreceptor cells in your retina: rods and cones. The rods are more sensitive; in very dark conditions, most of our vision is provided by the rods. The cones are used when there is plenty of light, and they let us see colors.

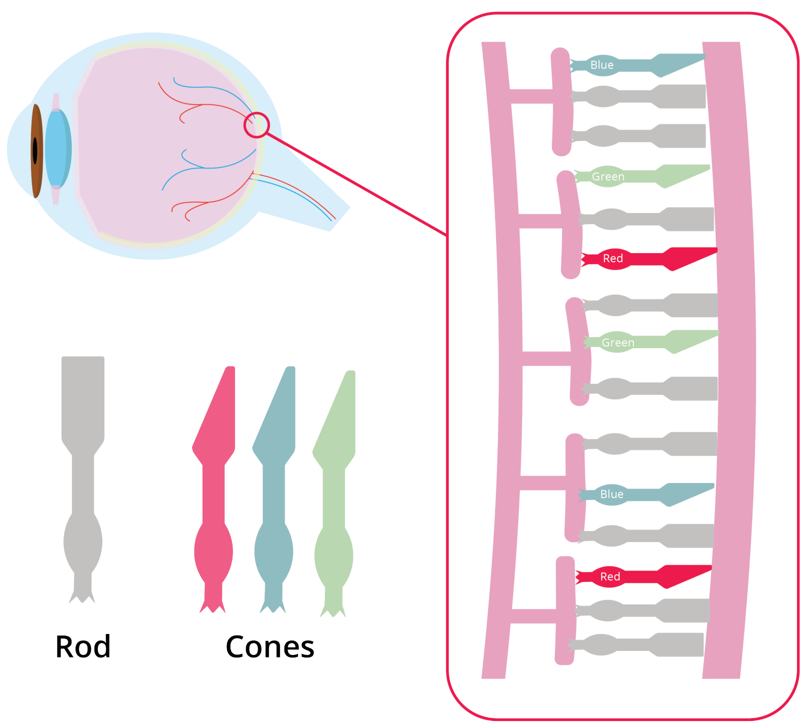

Figure 1.1: The cones and rods of the eye act as sensors and cognitive vision.

The white part around the outside of the eyeball? That is called the *sclera*.

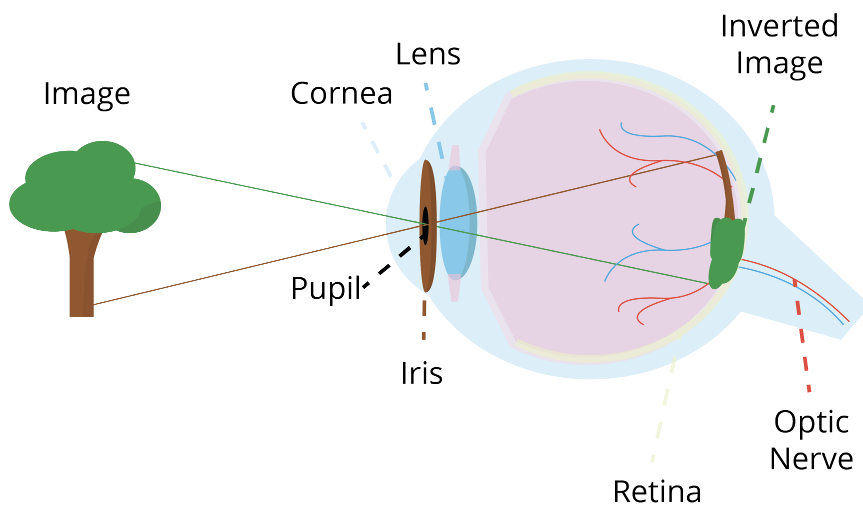

Figure 1.2: The eye works just like a camera's lens.

The walls of the eye are lined inside with the *retina*, which has sensors that pick up the light and send impulses down the optic nerve to your brain.

Just like a camera, the images are flipped when they get projected on the back of the eye (see Figure 1.2).

1.1 Eye problems

Now that you know the mechanics of the eye, let's go over a few things that commonly go wrong with the eye.

1.1.1 Glaucoma

The space between your cornea and lens is filled with a fluid called *aqueous humor*. To feed the cells of the cornea and lens, the aqueous humor carries oxygen and nutrients like blood would, but unlike blood, it is transparent so you can see. Aqueous humor is constantly being pumped into and out of that chamber. If aqueous humor has trouble exiting, the pressure builds up and can damage the eye. This is known as *glaucoma*. See Figure 1.3.

1.1.2 Cataracts

The lens should be clear. As a person ages, the proteins in the lens break down and clump together, becoming opaque. This can also be accelerated by diabetes, too much exposure to sunlight, obesity, and high blood pressure. From the outside, the eye will look cloudy. This is called a *cataract*, and it makes it difficult for the person to see.

This problem can be corrected, however. The person's cloudy lens is removed and replaced with a clear, manufactured lens.

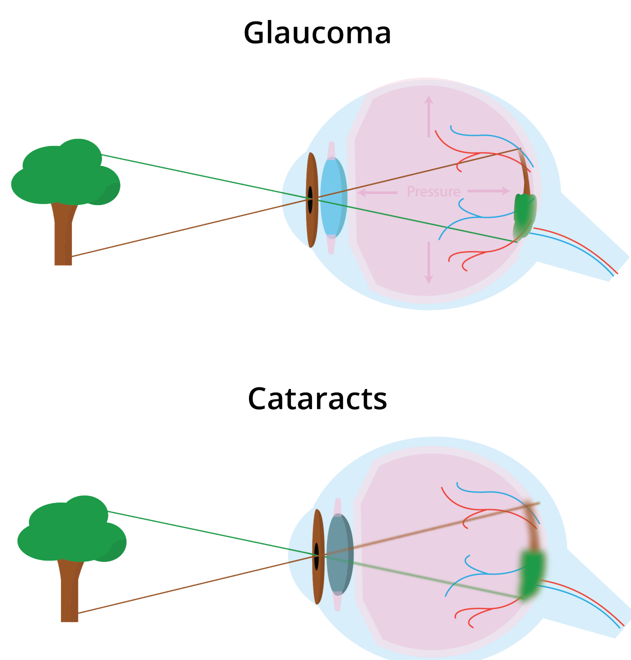

Figure 1.3: Cataracts and Glaucoma represented in the eye cross section.

1.1.3 Nearsightedness, farsightedness, and astigmatism

If you are in a dark room and a tiny LED is turned on, the photons from that LED can pass through your cornea in many different places. If your eye is focusing on that light correctly, all the photons should meet up at the same place on the retina.

FIXME: Diagram here

If the lenses are bending the light too much, the photons meet up before they hit the retina and get smeared a bit across it. To the person, the LED would appear blurry. The eye is said to be *nearsighted* or *myopic*. This signals that near objects appear blurry, but farther objects appear correctly.

If the lenses are not bending it enough, the photons would meet up behind the retina. Once again, they get smeared a bit across the retina and the LED looks blurry to the person. The eye is said to be *farsighted* or *hyperoptic*. The objects which are distant can appear clearly, while closer objects are heavily blurred.

Your lenses are supposed to bend the photons the same amount vertically and horizontally. If one dimension is focused, but the other is myopic or hyperoptic, the eye is said to have *astigmatism*.

Myopia, hyperoptia, and astigmatism can be corrected with glasses or contact lenses. Doctors can also do surgical corrections, usually by changing the shape of the cornea.

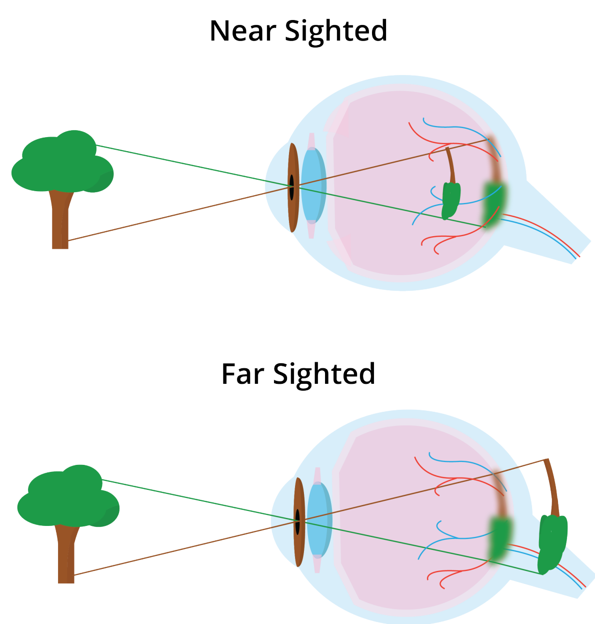

Figure 1.4: Nearsightedness versus farsightedness.

1.2 Seeing colors

TED-Ed has made a good video on how we see color. Watch it here: https://youtu.be/l8_fZPHasdo

When a rainbow forms, you are seeing different wavelengths separating from each other. In the rainbow:

- Red is about 650 nm.
- Orange is about 600 nm.
- Yellow is about 580 nm.
- Green is about 550 nm.
- Cyan is about 500 nm.
- Blue is about 450 nm.
- Violet is about 400 nm.

If you shine a light with a wavelength of 580 nm on a white piece of paper, you will see yellow.

However, if you shine two lights with wavelengths of 650 nm (red) and 550 nm (green), you will also see yellow.

Why? Our ears can hear two different frequencies at the same time. Why can't our eyes see two colors in the same place?

As mentioned above, the cone photoreceptors in our eyes let us see colors. There are three kinds of cones:

- Red: Cones that let us see the frequencies up to about 700nm.
- Green: Cones that are most sensitive to frequencies near 550nm.
- Blue: Cones that are most sensitive to frequencies near 450nm.

When a wavelength of 580 nm hits your retina, it excites the red and green receptors, and your brain interprets that mix as yellow.

Similarly, when light that contains both 650 nm and 550 nm waves hits your retina, it excites the red and green receptors, and your brain interprets that mix as yellow.

You can't tell the difference!

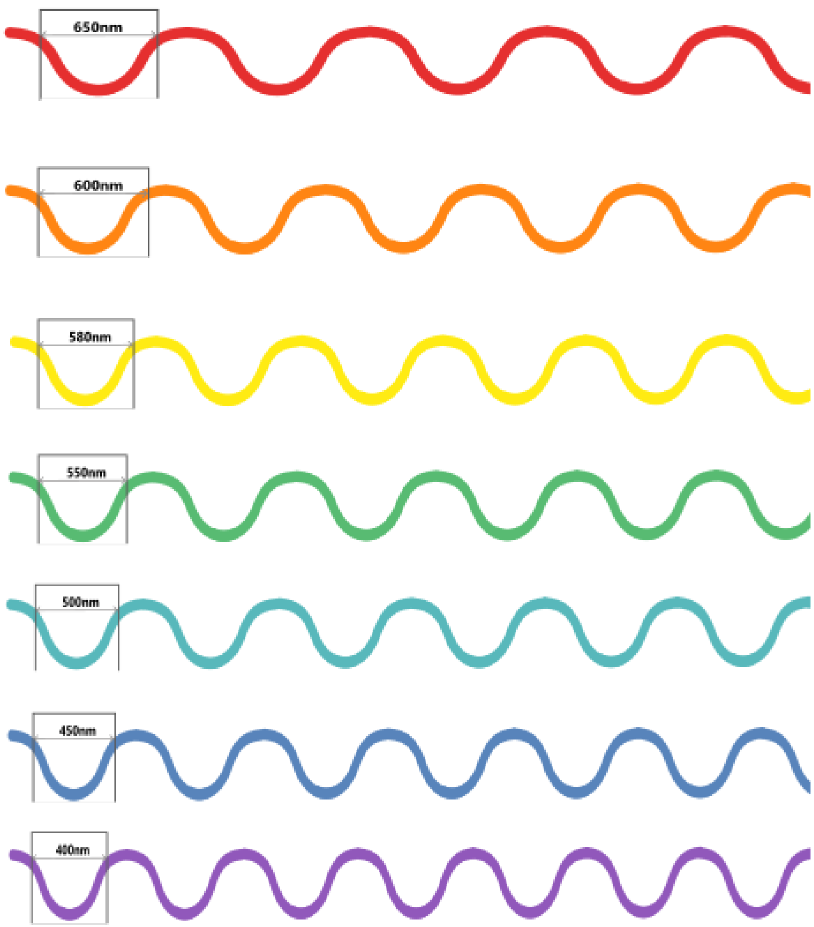

Figure 1.5: All colors have different wavelengths.

Now we know why the sensors on the camera are RGB. The camera is recording the scene as closely as necessary to fool your eye.

A TV or a color computer monitor only has three colors of pixels: red, green, and blue. By controlling the mix of them, it creates the sensation of thousands of colors to your eye.

1.3 Pigments

A color printer works in the opposite fashion. Instead of radiating colors, it puts pigments on the paper that absorb certain frequencies. A pigment that absorbs only frequencies near 650 nm (red) will appear to your eye as cyan. This makes sense, because the sensation of cyan is created when your blue and green receptors are activated.

Thus, pigment colors come in:

- Cyan: absorbs frequencies around red
- Magenta: absorbs freqencies around green
- Yellow: absorbs frequencies around blue

If you buy ink for a color printer, you know there is typically a fourth ink: black. If you put cyan, magenta, and yellow pigments on paper, the mix won't absorb all the visible spectrum in a consistent manner. Our eyes are pretty sensitive to this, so we would see brown. This is why we add black ink to get pretty grays and blacks.

We call this approach to color CMYK (as opposed to RGB). If an artist is creating an image to be viewed on a screen, they will typically make an RGB image. If they are creating an image to be printed using pigments, they typically create a CMYK image. (Most of us don't care so much — we just let the computer do conversions between the two color spaces for us.)

This is a draft chapter from the Kontinua Project. Please see our website (`https://kontinua.org/`) for more details.

Appendix A

Answers to Exercises

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