CSE 252A: Human Visual System

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1 Different Ways to Study Biological Vision

1.1 Physiological

In which we examine physical structures, e.g. eyes, to understand biological vision.

1.2 Psychophysical

In which we examine input/output relationships of vision. *What do you see?* Present people with stimuli, have them report what they're perceiving, and understand as a system what's happening.

We can utilize optical illusions within this approach to studying vision.

1.3 Cellular Recordings, Functional MRI

In which we measure things directly, e.g.

- **as cellular recordings:** put probes inside of the brain and look at electrical signal response to stimuli, maybe from a particular neuron (*single cell recordings*).
- **as an fMRI scan:** for which we can look at a slice in the brain and see where the activity is.

1.4 Computational Modeling

In which we build systems to model the data that we have. We can then perform experiments such as ablation studies in order to determine the contributions of different components.

In this lecture we will mainly focus on the first two methods of study.

2 The Human Eye

The narrative. Light comes in, passes through the *cornea* (the front layer of the eye), then the *iris* (the colored part of the eye) which expands/contracts to control how much light gets in through the *pupil*; next light is refracted through the *lens*, then through a bunch of *vitreous humor* (jelly goo), and then finally the light hits the *retina* at the back of the eye.

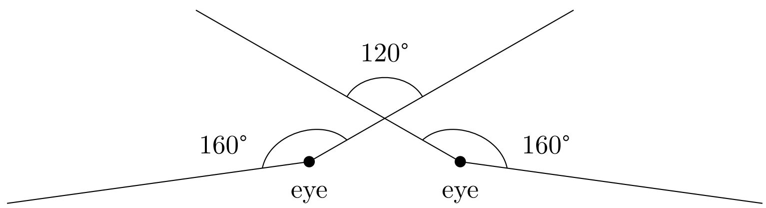
2.1 Focus

To focus on something, little muscles pull on the soft lens and the lens's shape changes.

2.2 Field of View

We have a pretty broad field of view (FOV). For one eye, the horizontal FOV is 160 degrees and the vertical FOV is 130 degrees. (It helps that the retina is rounded and not flat.)

For two eyes:



As shown, each eye has a 160° FOV pointing a little outward. On the whole there is 120° stereo vision and a peripheral 40° on each side which only one eye sees.

2.3 Lighting Range

The amount of light striking the eye varies tremendously based on factors such as the time of day, whether you're inside, etc. Direct sun gives an illuminance of 100,000 lux, home lighting gives an illuminance of 10 lux, and a cloudy moonless night gives an illuminance of 0.0001 lux. This is why you walk inside and suddenly can't see anything, or you go outside and it's so, *so* bright.

2.4 Retina

There are two types of light-sensitive cells in the retina: *rods* and *cones* (named for their shape).

- **Rods:** 10^8 of them (more). Mostly in the periphery.
- **Cones:** 5×10^6 of them (less). Mostly packed in a tight hexagonal grid in the fovea.
  - Cones see color and give high resolution.
  - Cones need more light to function, so are invoked during daytime.
  - Three types of cones: S, M, L (respond to short-, medium-, and long-wavelength light respectively, and therefore respond most to blue, green, and red respectively).

In fact there are many layers of cells in the retina. The rods and cones are in the back. In front of them are the optic nerve fiber layer, the ganglion cells, the bipolar cells, etc. (many layers). Notably, light has to pass through all of this wiring to reach the rods and cones. Evolutionarily, this is because the rods and cones need a lot of food/energy and must be close to the blood and the back (and I mean *everything* can't fit in the back).

The product of all of this retina business is a bunch of wiring which comes out toward the middle and is funneled out via the optic nerve. The optic nerve leaves the eye through an opening near the middle of the back, which creates a blind spot in the eye where this opening is.

2.4.1 Retinal Neurons

There are many different variations of retinal neurons. For example, the *bipolar cell* does a little bit of computation and aggregation and has two ends (input and output). Meanwhile, the *ganglion* is more complex and has lots of dendrites serving as inputs into the cell – and then processing occurs, and the output comes out as a single thick axon. (This output is part of the wires getting funneled out through the blind spot to the brain.)

There are 1.5×10^6 nerves (which correspond to retinal neurons) in the optic nerve bundle.

In the fovea (area of high resolution), the ratio of cones to nerves is 1:3 (i.e. one cone fans out to three nerves, 1+ wire per sensor!). In the periphery, the ratio of rods to nerves is 125:1 (i.e. 125 rods as inputs to one ganglion, all sort of averaged together – 125 sensors per wire).

- So each cone on average has much more impact (contributes to high resolution there).

2.5 Next Stop: The Brain

After leaving the eye through the optic nerve, most of the visual signal goes to the visual cortex at the back of the head, where processing happens.

Information from the left sides of both eyes flows to the left of the visual cortex; information from the right sides of both eyes flows to the right of the visual cortex. And so the information from both eyes comes together; this is probably where the stereo processing happens.

3 Other Eyes

Other animals have different eye structures. For example, insects have compound eyes: instead of a single lens with a bunch of rods and cones behind them, they have a bunch of tiny lenses with one sensor sitting behind each one. This dates back to the trilobite's visual system all those years ago.

- *A scallop* has 100 eyes. Light comes in through the lens, then reflects off of a reflector in the back and hits some light-sensitive pigment.
- *A stomatopod* has eyes on stalks, each with three components. This means that they can do stereo with one eye (see the same point with multiple parts of the eye, and combine information to determine depth). This might be because they're prone to getting into fights & losing eyes.
  - They also have 16 visual pigments (as opposed to our 3-4). This means they can see much more of the spectrum than us, including ultraviolet and infrared and polarized light – we are completely color blind compared to them.

According to a study of visual acuity in May 2018, mosquitos have almost no resolution, flies have a little more, cats have almost as much as humans, and wedge-tailed eagles beat humans by a good amount.

- One measure of acuity: how many alternating black/white strips we can distinguish in one visual degree without it turning into gray. Humans can do 60 cycles. Wedge-tailed eagles 140.