Silicon vision: Retinas (biological and silicon), silicon phototransduction, retinal prosthetics

In this part of the block course, you will learn about retinas, both biological and silicon. The tutorial part will cover the structure and function of biological retinas and how image sensors (electronic digital cameras) and silicon retina vision sensors are built. The practical work will consist of experiments on neuromorphic chips. One of the possible presentation topics is to report on the state of retinal prosthetics.

Reading

For reading, we have two articles. We will provide you these papers.

1. *"The Silicon Retina," M. A. Mahowald and C. Mead, Scientific American, vol. 264, pp. 76-82, 1991* – This paper discusses retina functionality from an engineer's perspective.
2. *A silicon visual system as a model animal. T. Delbruck, S.C. Liu. (2004). Vision Research, vol. 44, issue 17, pp. 2083-2089.* – This paper shows you exactly how the physiologist's friend chip works.

Projects

The following projects are possible subjects of your block course presentation report

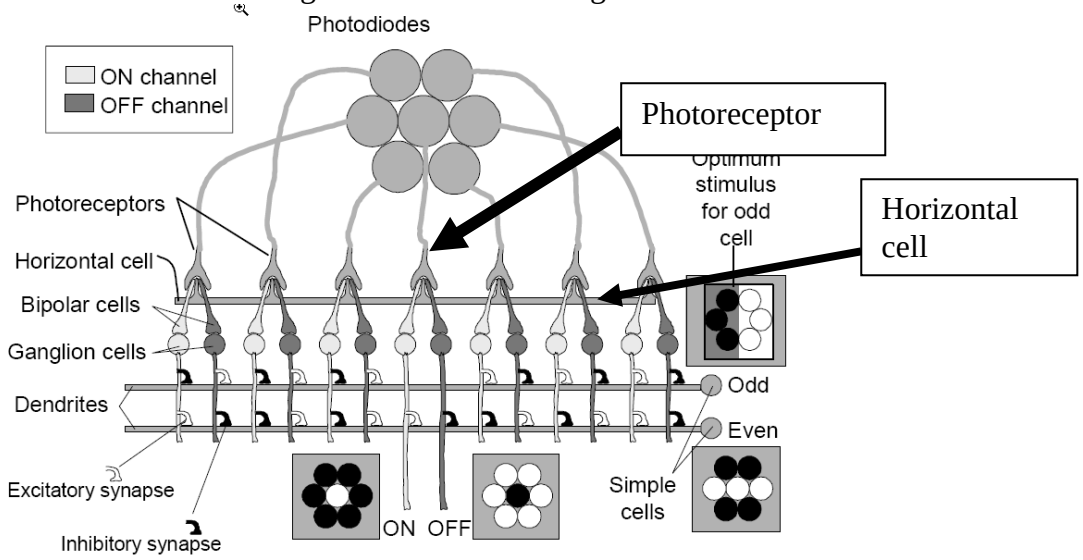
1. Measurements of an electronic photoreceptor circuit
2. Measurements of a spiking silicon retina
3. Report on state of retinal prosthetics

Practical work

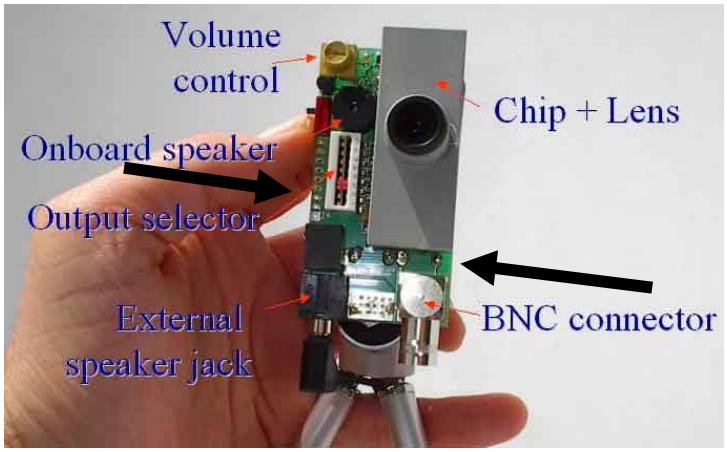
The two exercises are practical work and we will have 5 setups in total, 3 for the first exercise and 2 for the second so there will be space for everyone to do experiments at the same time.

Practical work 1. Measuring photoreceptors to compare measured and designed gain

In this experiment, you will use the oscilloscope to measure the responses of two cells on the PhysioFriend chip, an adaptive photoreceptor and a horizontal cell. You will compare these measurements with the gain that has been designed into the circuits.



These outputs are available on the chip at the output #1 and the pin on the right side right above the coax BNC connector as shown below. You can ground the oscilloscope on the BNC connector.



The aim of this experiment is to measure the gain for transient (changing or AC) signals and the gain for static (non-changing or DC) signals, and to compare them with what was designed on the chip to be the ratio of transient to static gain.

Your stimulus to the chip will be a black and white edge printed on a piece of paper, like this one:

You will connect the output from the PhysioFriend chip to the oscilloscope and record the response while you wave this stimulus back and forth in front of the chip.

You will measure the true contrast of the stimulus by using the Tektronix photometer we provide. You can then relate the true measured contrast of the stimulus to the measured voltage responses recorded on the oscilloscope.

The photoreceptor is designed to have a static gain of about 40 mV/e-fold. An “e-fold” is a factor of e=2.71 in intensity. The horizontal cell is the average photoreceptor output. Therefore, if you hold the stimulus constant, the horizontal cell should approach the DC value of the photoreceptor, and the change in the horizontal cell output voltage between when you show it the dark and light part of the stimulus should be related to the contrast by

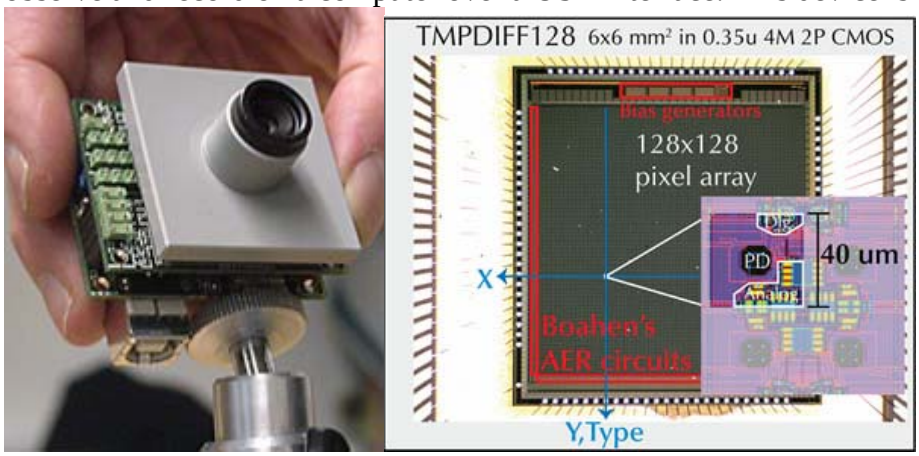
$$\Delta V = 40\text{mV} \times \ln\left(R_{\text{white}}/R_{\text{dark}}\right) \qquad (1.1)$$

where R_{white} is the reflectance (proportional to luminance) of the white stimulus paper and R_{dark} is the reflectance of the gray part of the paper. Paper with a reflectance ratio (contrast) of 2.71 between white and dark should cause a 40mV output difference.

The adaptive photoreceptor has higher gain for transient (changing) stimuli. The gain is designed on the chip to be a factor of about 10 higher for transient than for sustained stimuli. Is this true according to your measurements?

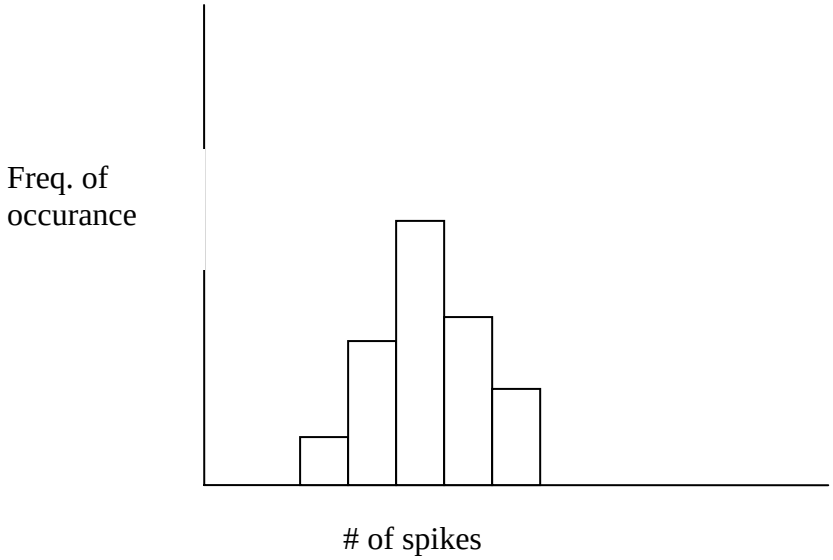
Practical work 2. Measuring the spiking silicon retina by characterizing pixel variability

In this experiment we have set up two stations with spiking silicon retinas that you can observe and record on a computer over a USB interface. This device is shown here:



Each retina has 128x128 pixels and the spike output addresses are captured by a computer and displayed for you. This chip is an Address-Event Representation (AER) chip. The pixels respond to movement, or more specifically, to *temporal contrast*. Each spike means that the log intensity has changed by a threshold amount *T* since the last event from that pixel.
In this experiment, you will play with the silicon retina to understand its properties. You will also do the following quantitative measurement.

1. Using the same black and white edge stimulus as in experiment 1 above, but now you will record the response of the whole retina to this moving edge as you move the edge back and forth 10 times. After recording the response, you will probe 10 random cells that have seen the edge moving back and forth. Each cell (pixel) may respond differently to the edge (like real retina cells). These differences are due to differences in the pixel and transistor properties and to optics, stimulus, lighting, and other variations. Plot the histograms of the number of spikes you obtain from each pixel.
2. From each pixel you will record both ON-type and OFF-type spikes. Each spike means that the log intensity changed by a certain threshold amount since the last spike from that pixel.
3. Using the matlab scripts provided to you, load your recorded data file and select a block of cells to analyze. Produce a combined histogram of all the cell responses.
4. Interpret this data to quantify the number of spikes per edge and the fractional variability in this number. From the measured contrast of the stimulus, compute the threshold in ln(intensity) for each spike.



Presentation topic

For your presentation, you could choose to discuss one of the practical exercises above, or you could choose to report on the following subject.

3. **Report on state of retinal prosthetics**

This work is not experimental, but rather is a research topic on which you will report on the present-day state of the development of retinal prosthetics. Various companies (like Retina Implant AG, Second Sight and Optobionics) and large government-funded consortiums (at MIT, Frauenhofer, Reutlingen, Japan) have begun trying to develop prosthetics for vision that are meant to help blind people with some retinal diseases regain some sight. But all of these efforts lag far behind the immense progress made in auditory prosthetics.
In this project, you will research this topic and prepare a presentation covering some of the following topics.

1. What kinds of vision deficits (blindness) can be helped by a future prosthetic? E.g. macular degeneration, retinitis pigmentosa, retinal detachment, developmental problems?
2. Who are the consortiums or companies working on prosthetics?
3. What are the various approaches to stimulating the optic nerve or cortex? E.g. sub-retinal, supra-retinal, optic nerve cuff, cortical stimulation.
4. What are the components of present-day prosthetics?
5. What are the leading breakthroughs so far reported?
6. What are the challenges? E.g. in biocompatibility, in electrode design, in stimulation protocol, in realistic perception rather than phosphenes.