

Neuromorphic Engineering: Biological and silicon retinas

In this part of the block course, you will learn about biological and silicon retinas.

The tutorial part will use the structure and function of biological retinas as an example of how silicon retina vision sensors are built.

For its practical exercises, this part will use two neuromorphic chips, the *Physiologist's Friend Chip* (short name *PhysioFriend*), and the *Dynamic Vision Sensor Silicon Retina* (short name *DVS*). The practical work will consist of experiments using these sensors.

Your report on this part of the course should cover the practical experiments and answer the questions at the end of this document.

Reading

For reading we will provide 2 articles.

1. "[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 how the physiologist's friend chip works. You only need to carefully read sections 1,2, the start of 3, and 4.
2. "[Neuromorphic Sensory Systems](#)", T. Delbruck and S.C. Liu (2010) *Current Opinions on Neurobiology* — This paper is about silicon retinas and cochleas. You only need to understand the sections on the address-event representation and the part about the dynamic vision sensor (DVS), including the figure about it.

Final quiz

At the end of this block, you will have 30 minutes to answer questions on a quiz, without any notes or help from your friends.

Grade

Your grade in this block will be based on both the combined reports and your answers to the quiz.

Practical work

We will have setups for your practical work:

1. (Lecture room or INI Foyer) Physiologist's Friend Chips for determining the receptive fields by plotting them on a tangent screen, like you did with the simulation. You may also try to use the Physiologist's Friend Chip simulation program as a visual stimulus for the chip. See <http://www.ini.uzh.ch/~tobi/friend>.
2. (dungeon) DVS128 event-based silicon retinas. See <http://siliconretina.ini.uzh.ch>.

We will also supply you with a light meter that can measure incident illumination in lux. 1 lux of white light (with spectrum of sunlight) corresponds to about 10^4 photons/um²/second. Office lighting is about 500 lux, while full sun is 100 klux and moonlight is about 0.1 lux.

Schedule

Morning of first day: Lecture sessions and reading to prepare for practical sessions

Afternoon of first day: Some more lecture, Practical work, session 1

Morning of second day: Lecture and discussion session

Afternoon of second day: Practical work session 2, quiz.

Report

Please hand in a group report on your practical work, including answers to the questions in the practical works and at the end of this document. **Your report must be handed in before the next block course block.**

1. A group can have at most 2 people.
2. **Make sure all names of people involved are on the report**, in order of work. I.e. the person who did the most work on the report goes first.
3. **You must cite all sources and credit all illustrations, according to the ETH policy on plagiarism** http://www.ethz.ch/faculty/exams/plagiarism/index_EN

Your report

Please include the following sections in your report

1. Block course improvements

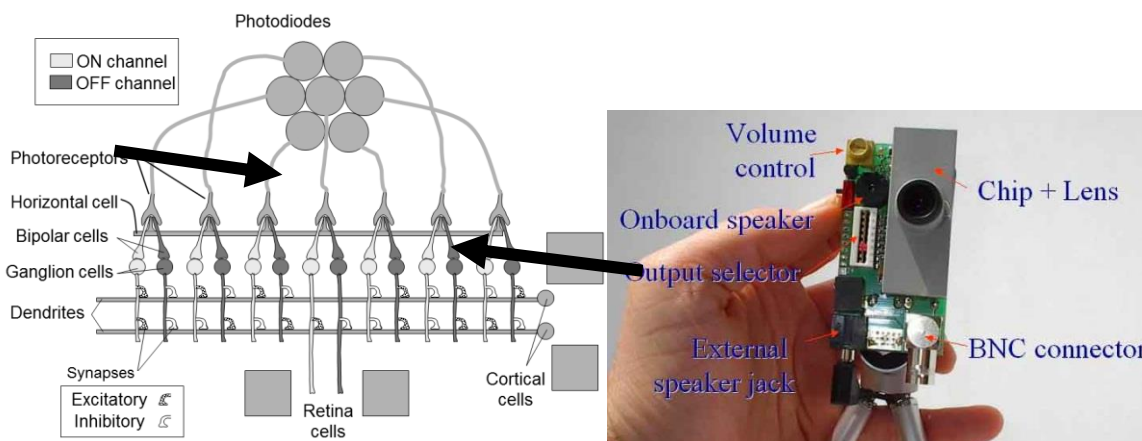
Provide concrete suggestions for improving this part of the block course on computational neuroscience.

1. Is the material too difficult or too easy?
2. What part did you enjoy the most? The least?
3. What part will be most useful to you? Least useful?
4. What words were unclear and need more definition?
5. What material needs more background to be presented?

2. Practical work 1: Characterizing physiologist friend chip cells

Your aim here will be to learn about the architecture of the Physiologist's Friend Chip and to determine the cell types and receptive fields of 4 spiking cells.

The illustrations below show the architecture of the chip and the controls and outputs on the board. See the paper about the chip for more information.



2.1. Report on Physiologist Friend Chip Receptive Fields

In your report, explain the receptive fields of the cells numbered **3,4,7,8**.

You should identify the ON and OFF regions of each receptive field and quantify how large they are in degrees. Please also provide an accurate sketch of the shape of the ON and OFF sub-regions of each receptive field.

To compute the size in angular degrees, measure the linear size S_{cm} in cm of the receptive field, the distance from the stimulus to the chip d_{cm} in cm, and compute

$$S_{\text{deg}} = \frac{180}{\pi} S_{\text{rad}} \approx \frac{180}{\pi} \frac{S_{\text{cm}}}{d_{\text{cm}}} \approx 57 \frac{S_{\text{cm}}}{d_{\text{cm}}} \quad (1.1)$$

Where S_{rad} is the angular size in radians and S_{deg} is the angular size in degrees.

From the size of the center of the receptive field, estimate the size of the sensitive area of a single photoreceptor on the chip (the photodiode size). The device is equipped with a lens with a focal length of 8mm. To compute the size of the photoreceptor on the chip, use geometric optics with the assumption that the angles are small. I.e. just compute

$$S_{\text{chip}} = 8\text{mm} \times S_{\text{rad}} \quad (1.2)$$

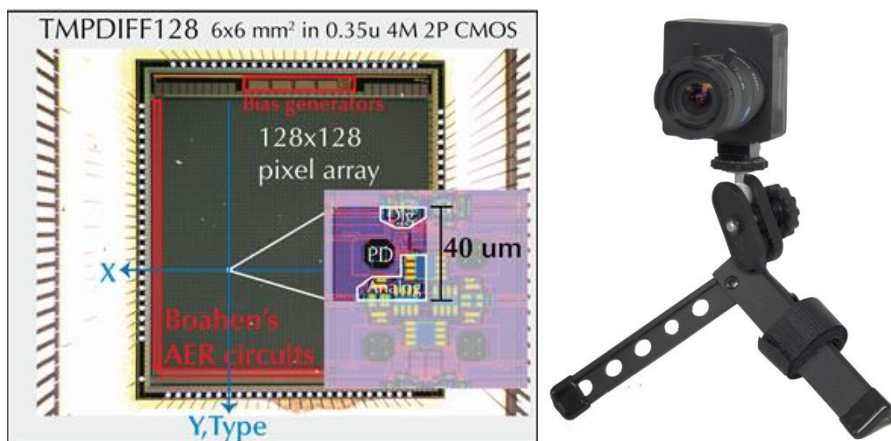
Where S_{chip} is the size of the photodiode on the chip. Report this number in micron (μm) units. How does your measurement compare with the actual size on the chip of about $170\mu\text{m}$?

Also your report should explain the following principles:

1. The concept of a *receptive field*.
2. The functional effect of photoreceptor adaptation to background light intensity and photoreceptor gain control. You don't need to explain the mechanism here, just what is the effect of adaptation and gain control. To explain the response, you can sketch the photoreceptor response in various ways, e.g. with the x-axis being time, log intensity, and temporal frequency. For the temporal response, you should show what would happen if you observed a particular step response and then put sunglasses over the photoreceptor to reduce all light intensities by a factor of 10 (for example).
3. Why the center-surround retinal receptive fields respond transiently to overall changes in the brightness of the scene; for instance, when you listen to the ON center ganglion cell, why does it make a burst of ON spikes when you suddenly change the stimulus from uniform black to uniform white?
4. Complementary channels¹ and rectification² of signed quantities into e.g. ON/OFF channels as a mechanism for representing signed quantities in the nervous system.
5. Center-surround responses as a mechanism for representing spatial contrast. Also explain if the surround is low-pass filtered so that it is delayed, then how the center-surround response represents spatio-temporal contrast.

3. Practical work 2: Learning to use the Dynamic Vision Sensor silicon retina to record a slow motion video

In this experiment we have set up several stations in the INI “dungeon” (floor D) with the DVS that you can observe and record on a computer over a USB interface. This device is explained on siliconretina.ini.uzh.ch and is shown here:



Each retina has 128×128 pixels and the spike output addresses are captured by a computer and displayed for you in the jAER software. This chip is an Address-Event Representation (AER) chip which means that the output of the camera is a stream of time-stamped address-events, which are active pixel addresses. The pixels respond to

¹ *Complementary* here means opposite but forming something greater than either alone, e.g. ON and OFF channels are complementary and combine to form the complete (signed) signal.

² *Rectification* here means to convert signed quantities into absolute value positive unsigned quantities.

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 way, the chip mimics the optic nerve output of the eye, but instead of using a wire (axon) for each cell, it instead multiplexes the pixel addresses onto a shared digital communication channel (the AER bus).

To start the viewer that shows the output of the DVS plugged into the USB port do the following: On a linux machine, log in with username “dlab” and password “biology”, open a terminal window from the Start menu, and enter “**.jAERViewer.sh**” to the prompt. If you have problems, ask the instructors for help. The retina output will then be shown in a window, where you can start and stop recording via the “Start Logging” button. The operation of the viewer will be demonstrated in class.

Make your own slow-motion video of something moving quickly, for example, a pen dropping onto the table, a spinning coin, a pencil breaking in half, a balloon popping, an infrared remote control blinking, milk drops falling and splashing, the pencil balancer pencil falling, or something else that you choose. Play back the video using the “Flex time” mode (constant event rate), rather than constant time slice. You can access this playback mode from the *View* menu. What does flex-time playback do when playing back such a recording?

Or choose a surveillance subject, for instance the activity looking down from the top level of the large hall of the university. You can make a long recording of 30 minutes for example. You will need your own laptop for this and to install the jAER software on it.

1. Remember the single most important maxim of machine vision: “Lighting, lighting and lighting.” If you don’t have the right lighting, your recording will be bad. Lighting includes not only the amount of light but the direction of the light, because this direction influences the contrast that you obtain.
2. When making a recording, it is very helpful to make sure the lens is properly focused to be as sharp as possible and the aperture should be as open as possible to maximum the amount of light. We have seen many cases of poor focusing!
3. If you are getting too few events, then you can try to reduce the event threshold – hit the *HW Configuration* button at the lower left corner of the AEViewer window and adjust the event threshold slider.
4. If you are not capturing fast motion, then you can try to increase the photoreceptor bandwidth. Use the configuration control panel to adjust the photoreceptor bandwidth.

3.1. Report on the Dynamic Vision Sensor

For your report, you should explain how the DVS pixel works by drawing the schematic and explaining, how it works, and how it mimics the transient pathway in a very simplified biological retina.

Please give the instructor your best recordings. Include

1. the recordings
2. Use Subject “**Block course DVS recordings from Julie, Samuel**” (replace names with your names)
3. Fill in the Message with what each recording shows and any other notes about the recording.

Please use this HighTail drop box folder to upload these large files. The address for the HighTail upload drop box is

<https://dropbox.hightail.com/tobidelbruck1158659>

Here’s what it looks like:

