Silicon vision: Retinas (biological and silicon), retinal prosthetics and multi-neuron emulation with silicon

In this part of the block course, you will learn about two topics.

The first topic is about retinas, both biological and silicon. 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*).

This year, for the first time, we also have the opportunity to use a new neuromorphic chip developed at Stanford called the *Hippocampus Chip*. This chip emulates more than 1000 neurons in hippocampus. We will use it to study silicon neurons and synchronization of networks of neurons.

The tutorial part will cover the structure and function of biological retinas, how image sensors (electronic digital cameras) and silicon retina vision sensors are built, and how networks of spiking neurons can synchronize or not depending on the balance and timing of excitation and inhibition.

The practical work will consist of preparing interesting and informative teaching demonstrations that use one of the following systems: the PhysioFiend, the DVS, or the Hippocampus Chip. An additional possible presentation topic is to report on the state of retinal prosthetics.

For your final block course presentation topic, you may do a demonstration, but it must be a different one than the one you showed in this part of the block course. Or you can choose for your final presentation to present a report on the state of the art in retina implant technology for restoring vision.

You must prepare your own slides for presenting the demonstrations and are not allowed to simply copy slides from existing presentations. Or (probably better for your audience) you can draw explanations on the whiteboard. These whiteboard presentations should be rehearsed or at least drawn out on paper before the presentation.

Reading

For reading, we have 3 articles. We will provide you these papers.

1. *"Neuromorphic Electronic Systems,"* invited article by Caver Mead, Proceedings of the IEEE, 1990. This paper outlines the basis for working on neuromorphic electronic systems.
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 how the physiologist's friend chip works.
3. *"Neuromorphic Microchips,"* 2005 article in Scientific American by Kwabena Boahen about his lab's work on neuromorphic electronics.

Projects

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

1. Demonstration using the Physiologist's Friend Chip to show how the retina and simple cells in early cortex work.
2. Demonstration using the DVS to show how using a model of the transient pathway in the retina to make spikes is advantageous for some kinds of vision problems.
3. Demonstration using the Stanford hippocampus chip of neural spike rate adaptation and synchronization in interacting networks of excitatory and inhibitory neurons.
4. Report on state of retina implant prosthetics.

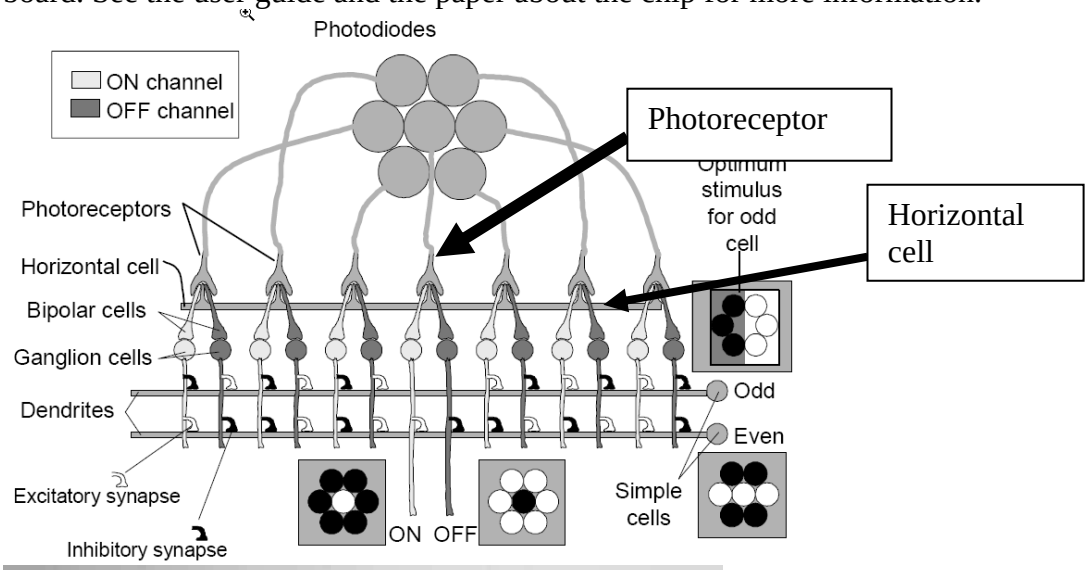
Practical work

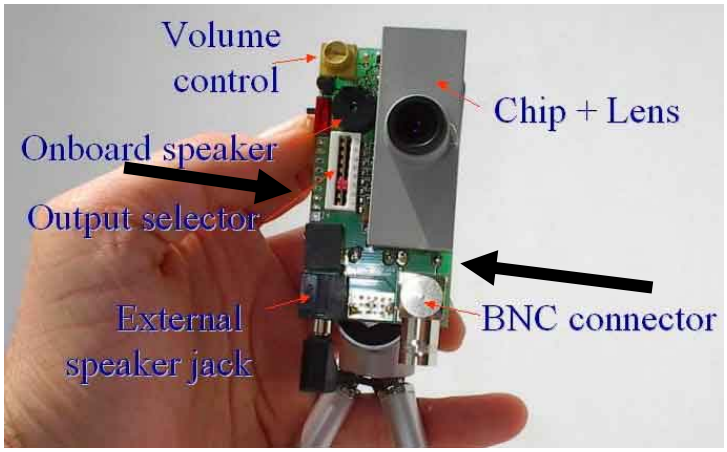
We will have 3 demo setups, one each for the Physiologist's Friend Chip, the Dynamic Vision Sensor, and the Stanford Hippocampus Chip.

Practical work 1. Characterizing physiologist friend chip cells and presenting live demonstration of it's responses.

Your aim here will be to learn about the architecture of the Physiologist's Friend Chip and how to demonstrate it for a group of people. Your final presentation will consist of an interactive demonstration of the chip, along with an explanation of retinal and cortical connectivity.

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





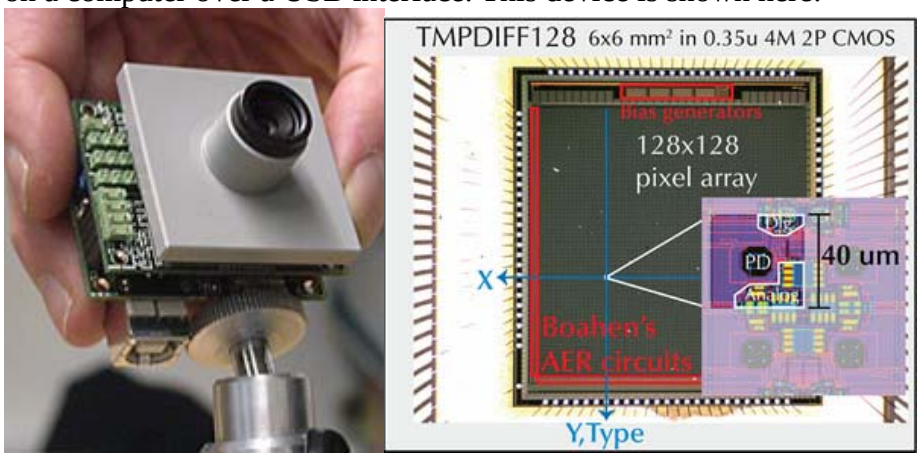
Presentation topic

In your presentation, you will use the PhysioFriend to teach others how the retina and early visual cortex work. Your presentation should demonstrate and explain the following principles:

1. The concept of a *receptive field.*
2. Adaptation to background light intensity and photoreceptor gain control.
3. Complementary channels and rectification (ON/OFF channels) as a general mechanism for representing signed quantities in the nervous system.
4. Center-surround responses as a general mechanism for representing contrast.
5. Push-pull driving of cells as a general mechanism of exciting and inhibiting cells.

Practical work 2. Demonstrating the Dynamic Vision Sensor

In this experiment we have set up one station with the DVS that you can observe and record on a computer over a USB interface. This device is shown here:



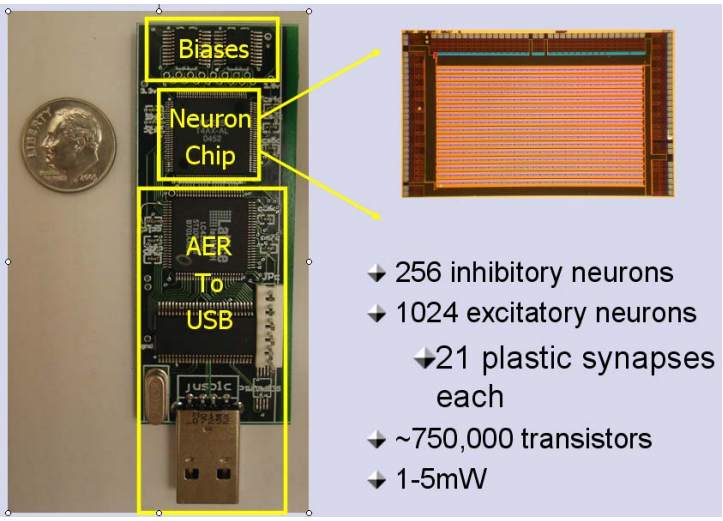
Each retina has 128x128 pixels and the spike output addresses are captured by a computer and displayed for you. This chip is an Address-Event Representation (AER) chip. The pixels respond to movement, or more specifically, to *temporal contrast*. Each spike means that the log intensity has changed by a threshold amount *T* since the last event from that pixel.

Presentation topic

For your presentation, you will explain how the DVS works, what are it's basic characteristics, and what kinds of practical applications it might be used for.

3. Practical work 3: The Stanford Hippocampus Chip

John Arthur's Hippocampus chip is shown in the next illustration. Slides have also been distributed about using the chip for demonstrating single neuron recording, spike rate adaptation, and synchronization in networks of neurons.



Presentation topic

Your aim should be to prepare a report and presentation using the hippocampus chip that demonstrates these 3 features of the chip.

4. 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 and Second Sight, and the now defunct 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, laser-micropore creation, bacteriodhopsin in ganglion cells.
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.