Introductory Course in Neuroscience

Neuromorphic Technology

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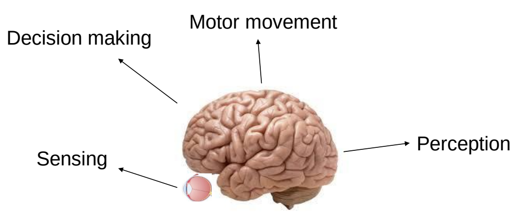
What is neuromorphic technology?

It consists of embodying *organizing principles* of neural computation in electronics, with the aims of

1. Building more efficient electronic systems
2. Understanding brain computation



Supercomputer Blue Gene/P

IBM used a supercomputer to simulate a cat-scale model (10^9 neurons, 10^{13} synapses) with 24,576 processors, burning 20MW and running at 1700X slower than real time

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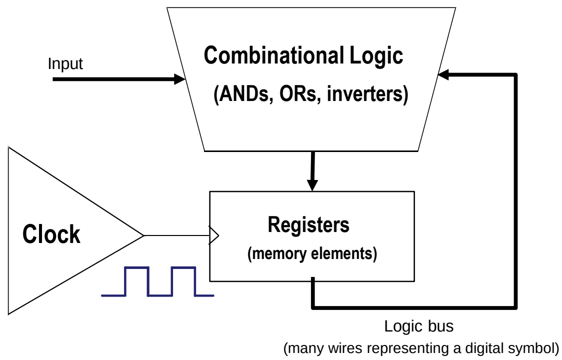
Computers are built from synchronous logic



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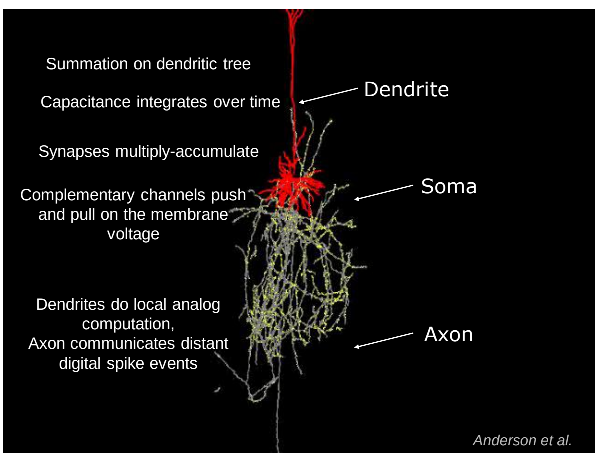

Computer	Brain
Fast semi-global clock (>1 GHz)	Self-timed, data driven (~1-100Hz)
Bit-perfect deterministic logical state	Synapses are stochastic! Computation switches digital→analog→digital
Memory distant to computation	Synaptic memory at computation
Power consumption (100W/cm^2)	Power consumption (10mW/cm^2)
Sequential computation	Parallel computation

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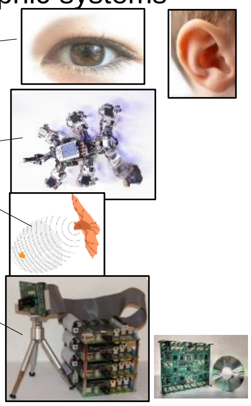
Types of neuromorphic systems

- **Neuromorphic sensors** —electronic models of retinas and cochleas
- **Smart sensors** (e.g. tracking chips, motion sensors, presence sensors, auditory classification and localization sensors)
- **Central pattern generators** – for locomotion or rhythmic behavior
- **Models of specific systems:** e.g. *bat sonar echolocation*, electric fish lateral line
- **Multi-chip large-scale systems** that use the *address-event representation* (spikes) for inter-chip communication and are used for studying models of neuronal (cortical) computation and synaptic plasticity for learning



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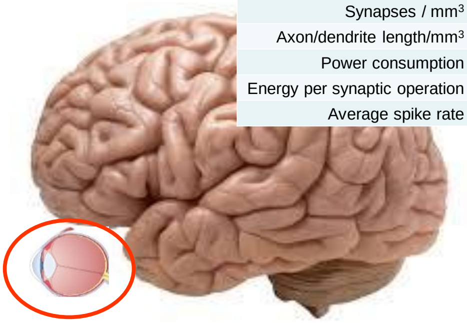
The world of neuromorphic labs (2016)

(Carver Mead, late 1980's)



Neurons	10^{10}
Synapses	10^{15}
Synapses / mm³	10^{9}
Axon/dendrite length/mm³	~1km
Power consumption	20W
Energy per synaptic operation	10^{-13}J
Average spike rate	0.1Hz

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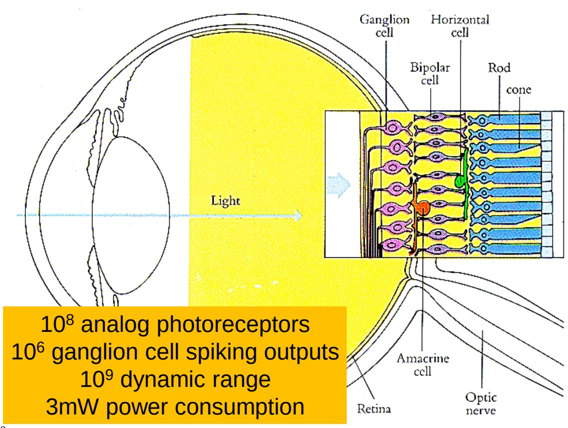

10^{8} analog photoreceptors
10^{6} ganglion cell spiking outputs
10^{9} dynamic range
3mW power consumption

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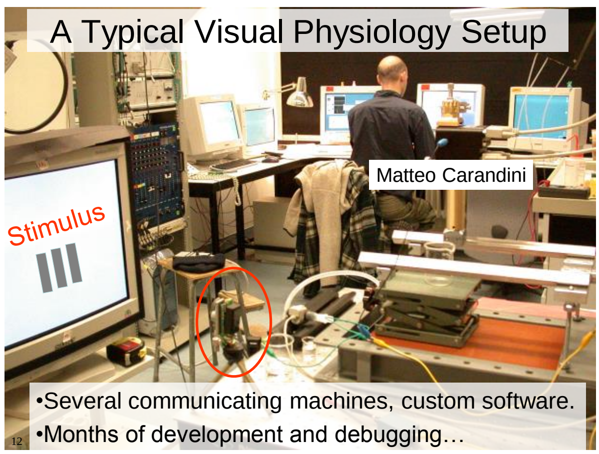
The Physiologist's Friend chip

Simple electronic model of early visual processing

A Typical Visual Physiology Setup



- Several communicating machines, custom software.
- Months of development and debugging…

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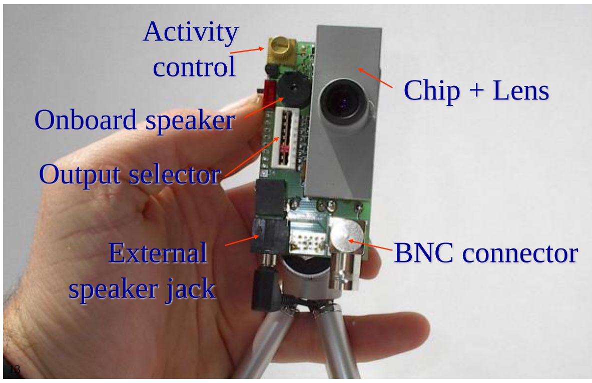
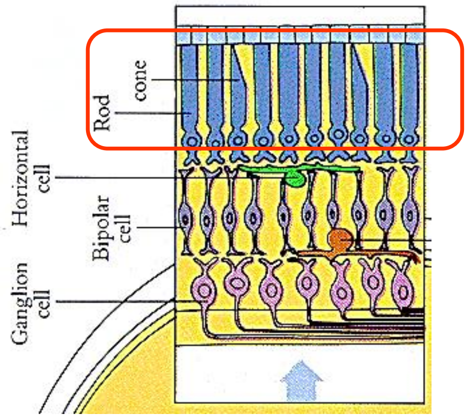
The Physiologist's Friend Chip





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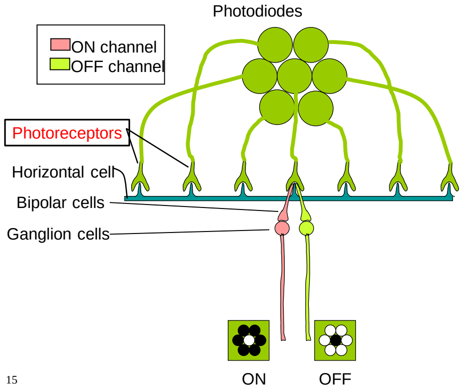
Retina model on Physiologist's Friend Chip



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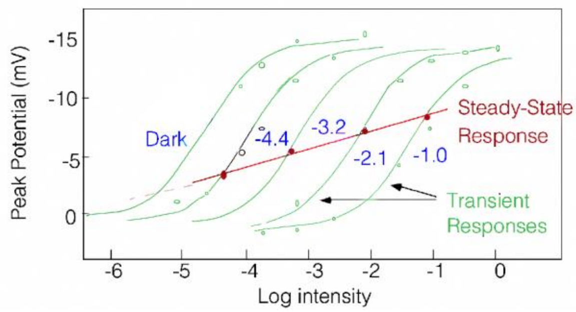
Biological photoreceptors adapt their operating point and gain



16 *Norman & Perlman 1979*

A logarithmic (or self-normalizing) representation of intensity is useful for representing object reflectance differences, rather than the illumination conditions.

- Two objects of different reflectance produce a ratio of luminance values.
- The difference of two log values represents this ratio, independent of the illumination.

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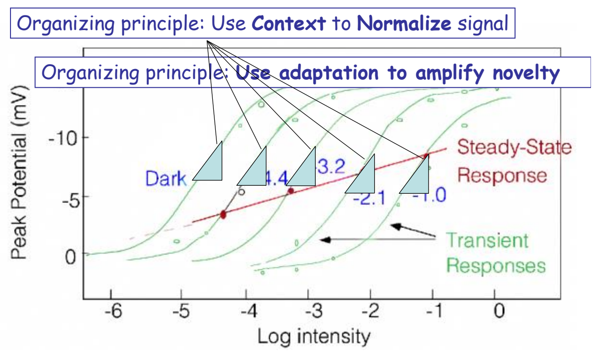
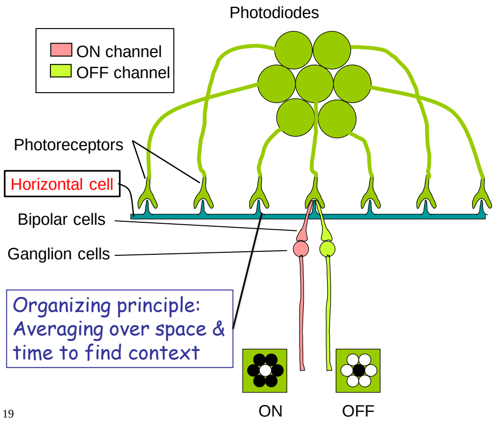
Biological photoreceptors adapt their operating point and gain



18 *Norman & Perlman 1979*



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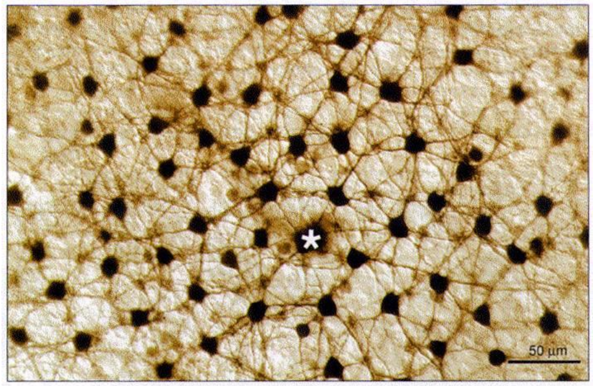

HI horizontal cells labeled following injection of one HI cell (*) ×300

after Dacey, Lee, and Stafford, 1996

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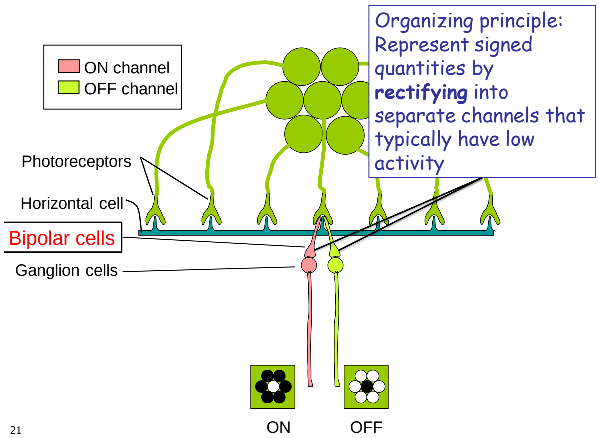

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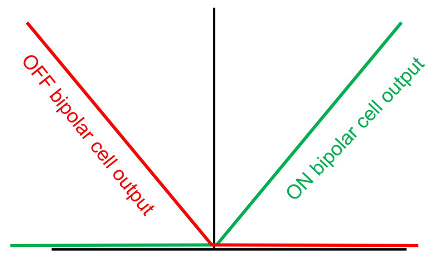
Rectification



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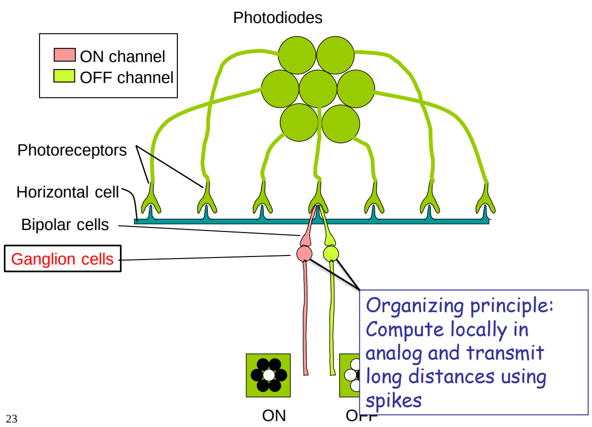

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Physiologist's Friend demo

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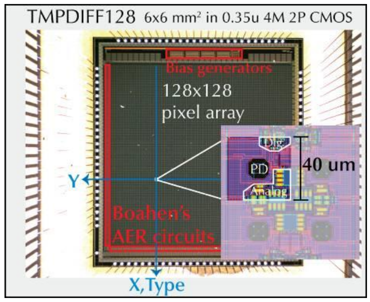
The dynamic vision sensor silicon retina

Dynamic Vision Sensor Silicon Retina (DVS)



1. The DVS ***asynchronously*** transmits ***address-events.***
2. The events represent ***temporal contrast*** , like transient ganglion cells.

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Lichtsteiner et al. ISSCC 2006

Demo of DVS

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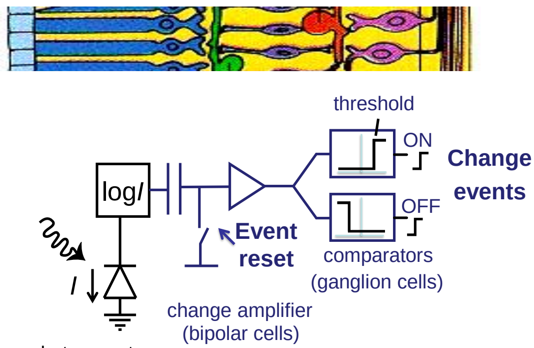
Dynamic Vision Sensor (DVS) pixel



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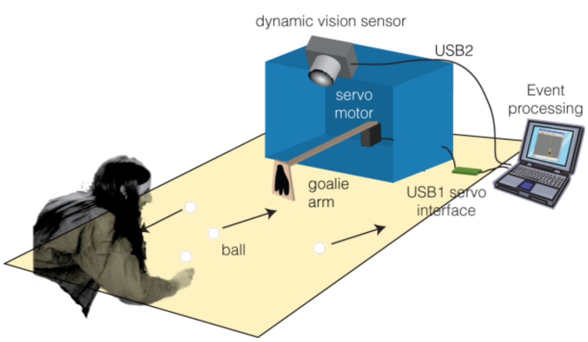
(Lichtsteiner et al., 2007)

Robot Goalie



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Achieves 550 "FPS" and 3 ms reaction time at 4% processor load

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Examples of organizing principles of neuromorphic technology demonstrat

1. **Averaging over space & time** to control noise and find signal context
2. **Using context to normalize** signals
3. **Representing signed quantities by rectifying** into ON and OFF channels, again to avoid burning power to represent zero
4. Using **adaptation** to **amplify novelty** to overcome noise and imprecision
5. Computing **locally in analog** and **communicating remotely using events** to optimize use of power and reliably transmit information

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Resources (hyperlink)

Background reading:

- C. Mead (1990) **Neuromorphic Electronic Systems**, Proceedings of the IEEE, vol 78, No 10, pp 1629-1636.
- S.C. Liu, T. Delbruck (2010) **Neuromorphic Sensory Systems**, Current Opinions in Neurobiology

Demonstrations

- T. Delbruck, S.C. Liu (2014), **A silicon visual system as a model animal**, (2004). Vision Research, vol. 44, issue 17, pp. 2083-2089 - *About the electronic model of the early visual system.*
- **Dynamic Vision Sensor** - *Describes the dynamic vision sensor silicon retina demonstrated in the lecture.*

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