Block course Fall 2013
ETH course 227-1049-00L Insights into Neuroinformatics

Neuromorphic Engineering, with Biological and Silicon Retinas

https://www.ini.uzh.ch/~tobi/wiki/doku.php?id=block

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Teaching assistants
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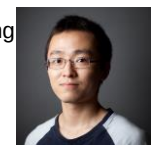
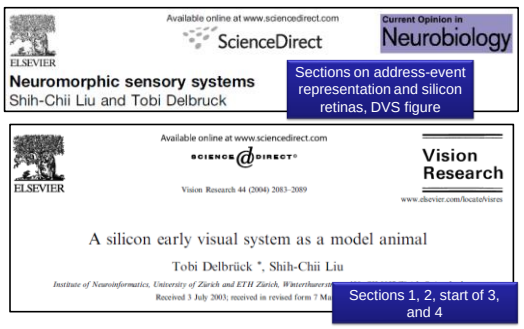


Outline of course

- The biology of the retina
  - How retinas uses adaptive photoreceptors and horizontal cells, together with bipolar cells, to compute rectified local contrast
  - The Physiologist's Friend Chip
  - The Dynamic Vision Sensor
- Silicon technology and the operation of a single transistor
  - CMOS vs. complementary channels in neurons
- Neuromorphic Engineering (NE)
  - Context of electronics (synchronous logic)
  - Motivation for NE by contrasting computers and brains

Reading

see https://www.ini.uzh.ch/~tobi/wiki/doku.php?id=block

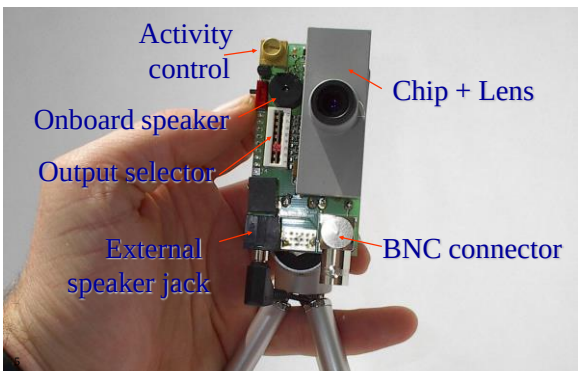


Practical work with

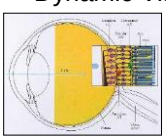
Physiologist's Friend Chip

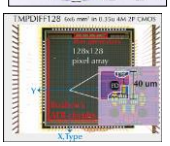
Dynamic Vision Sensor (DVS) silicon retina

The Physiologist's Friend Chip



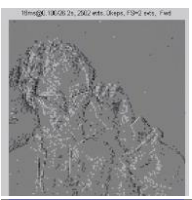
Dynamic Vision Sensor (DVS) Silicon Retina

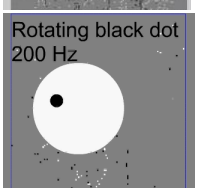




1. This silicon retina **asynchronously** outputs **pixel address-events**.
2. Each event represents a fixed ***temporal contrast*** (ΔlogI), corresponding to change in scene reflectance.

1. Models transient pathway in retina.
2. Reduces redundancy
3. Responds quickly and preserves timing
4. Has wide dynamic range





Quiz and Grading

- You will have 30 minutes to individually answer a quiz at the end of the course
- Your grade will be based on a combination of quiz and your group report

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Schedule

Day 1 (13:00-17:00)
- Lecture on biological retina
- Tutorial on using Physiologist's Friend and DVS
- Start first practical (split into groups and select either Physio Friend or DVS for first exercise)
- Read parts of Physio Friend paper and Neuromorphic Sensory Systems

Day 2 (morning, 9:00-12:00)
- Lecture on electronics and transistors
- Practical work
- Finish reading papers

Afternoon (13:30-17:00)
- Lecture continued
- Finish practical work, write reports
- Quiz

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Biological Retinas

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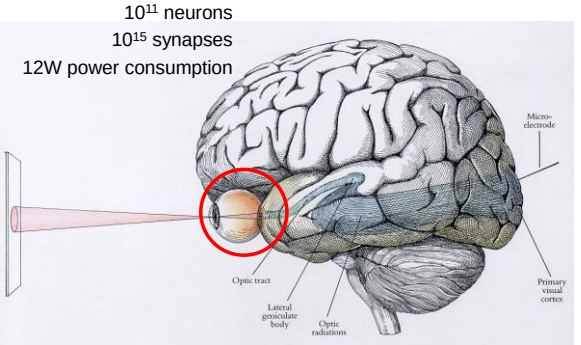
How do we see?

10^{11} neurons
10^{15} synapses
12W power consumption



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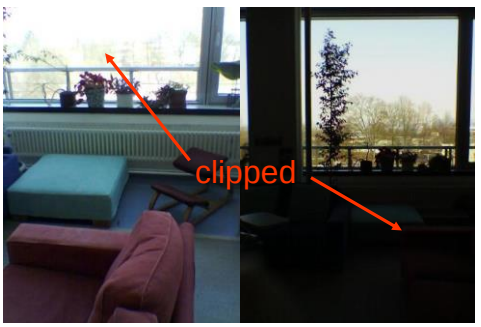
Is your eye a camera?



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Light ranges

1 lux of sunlight is about 10^4 photons/um^2/sec

Direktes Sonnenlicht	100'000 Lux
Sonniger Tag	10'000 Lux
Bedeckter Tag	1'000 Lux
Büro	100 Lux
Einbrechende Dämmerung	10 Lux
Dämmerung	1 Lux
Vollmond	0.1 Lux
Viertelmond	0.01 Lux
Klare mondlose Nacht	0.001 Lux
Bedeckte mondlose Nacht	0.0001 Lux

Camera range
Entire range

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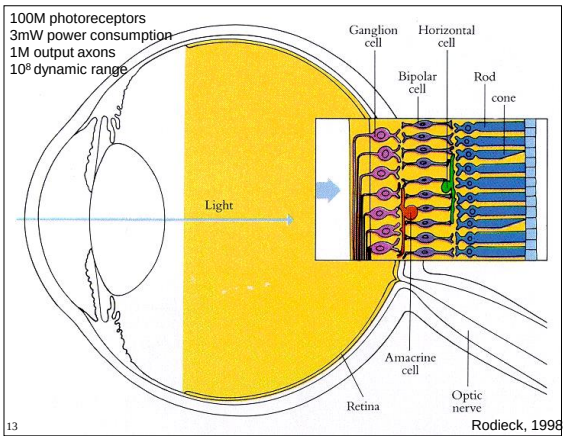

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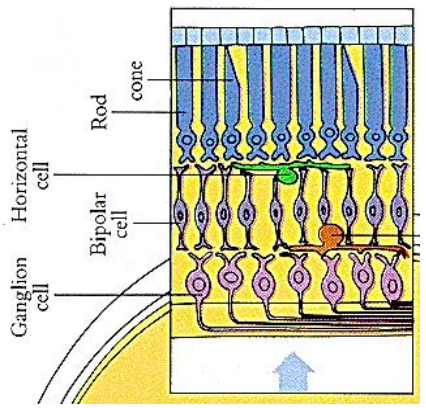

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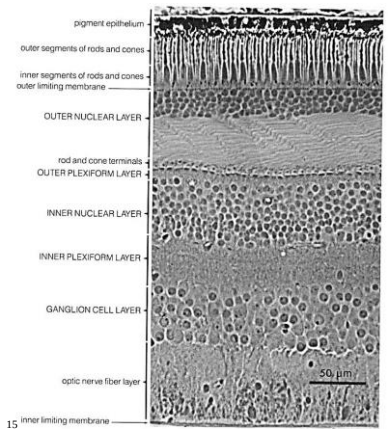

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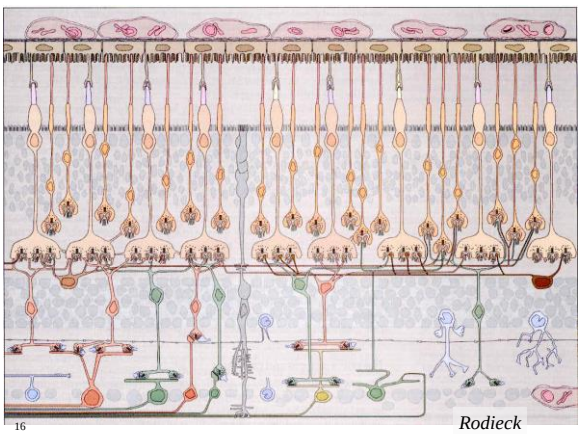
Cross section of human retina



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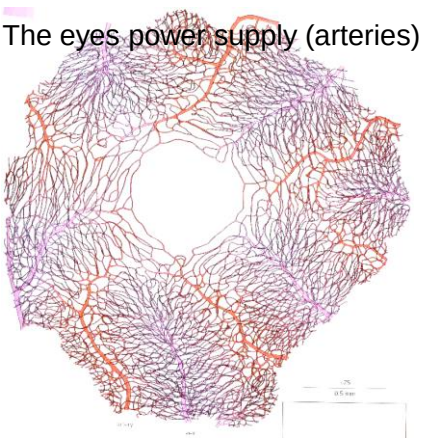
Rodieck

The eyes power supply (arteries)



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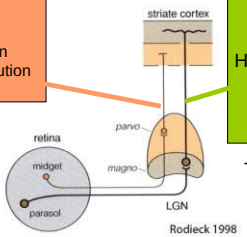
All animals (from insects to us) partition vision into **sustained** and **transient** visual pathways

Sustained (Parvo, X)
Has sustained response
Sees color
Low contrast gain
Higher spatial resolution
Slower

Transient (Magno, Y)
Blind to DC
Monochrome
High contrast gain
Lower spatial resolution
Faster



Standard image sensors do this

Temporal contrast sensor does this

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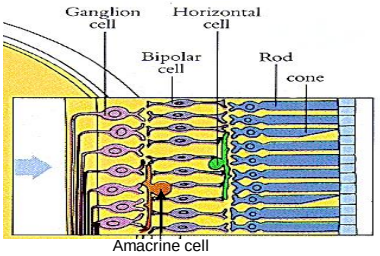
Three layer retina model

Photoreceptors – bipolar cells – ganglion cells
Horizontal cells Amacrine cells



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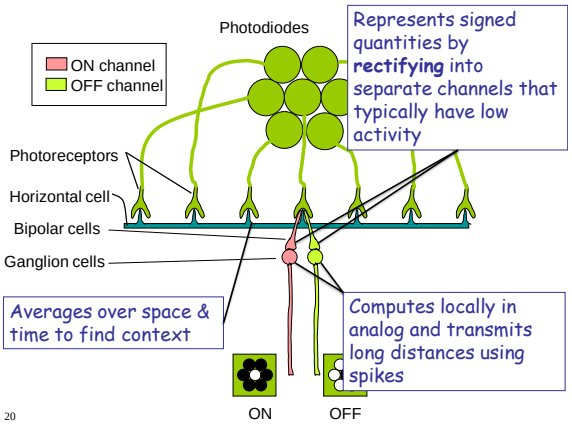

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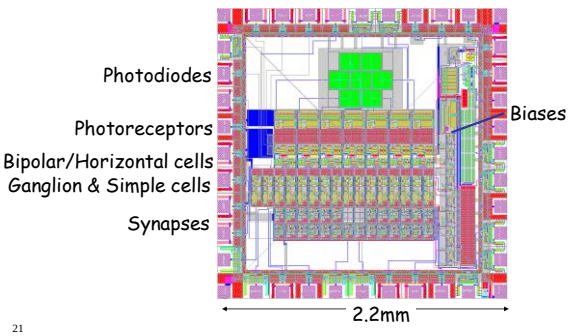
Physio Friend Layout



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Photoreceptors

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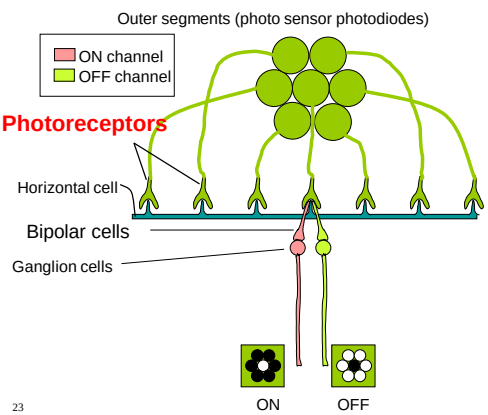

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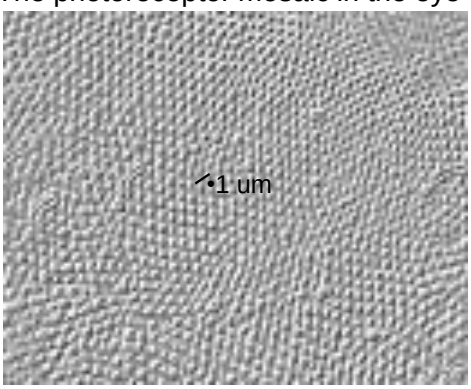
The photoreceptor mosaic in the eye



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Rodieck 1998
The first steps in seeing

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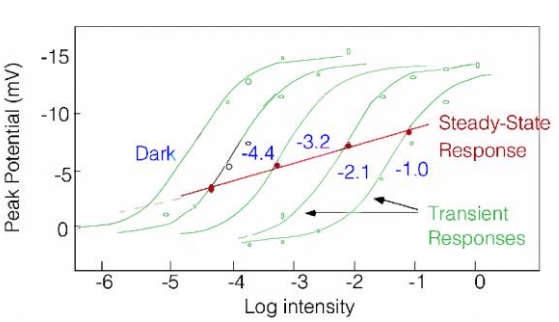
Biological photoreceptors adapt
their operating point and gain



Norman & Perlman 1979

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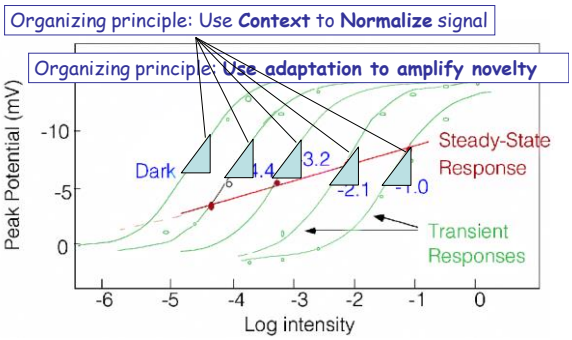
Biological photoreceptors adapt
their operating point and gain



Norman & Perlman 1979

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log(Intensity) is self-normalizing and automatically preserves reflectance differences, by normalizing away the constant illumination term in the product of (scene reflectance) * (illumination)

$$d(\log X) = dX/X$$

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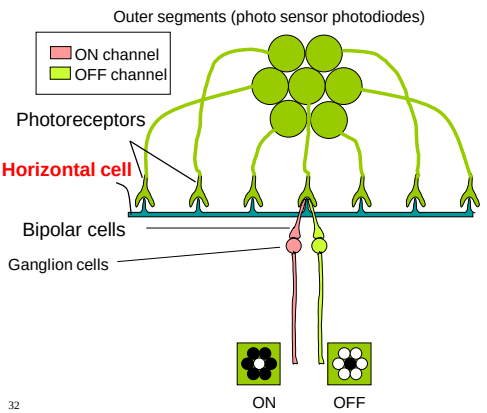

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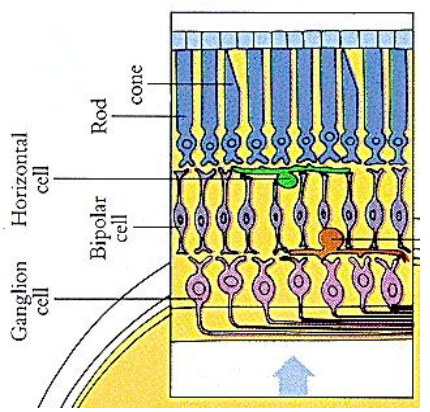

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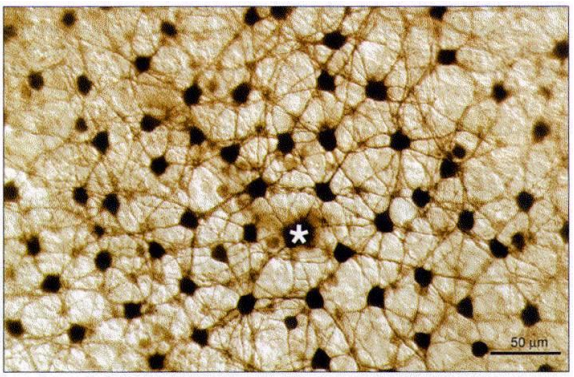

HI horizontal cells labeled following injection of one HI cell (*) ×300
after Dacey, Lee, and Stafford, 1996

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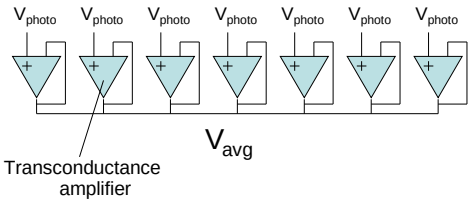
Horizontal cell

A *Follower-Aggregator* averages the photoreceptor outputs to compute the average of the inputs. This average is the *context* which is compared to the photoreceptor.



Because the follower output current saturates, the follower-aggregator computes **mean** for small signals and **median** for large signals

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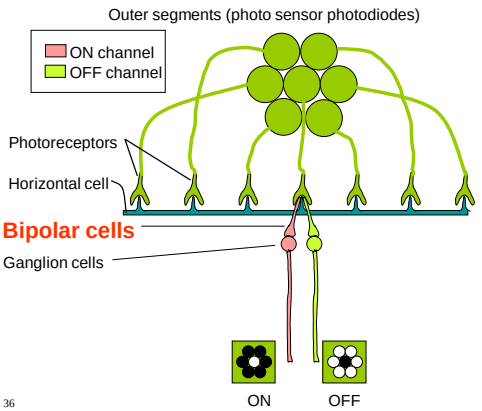

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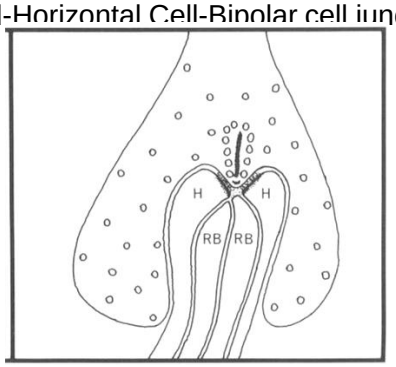
The Triade Synapse: Rod-Horizontal Cell-Bipolar cell junctions



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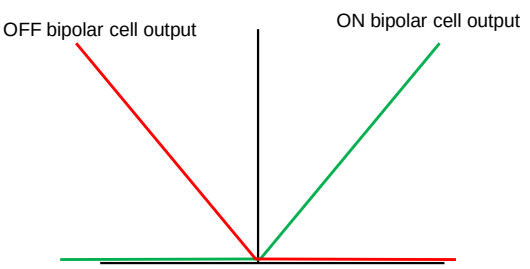
Rectification at the photoreceptor-horizontal cell-bipolar cell synapse



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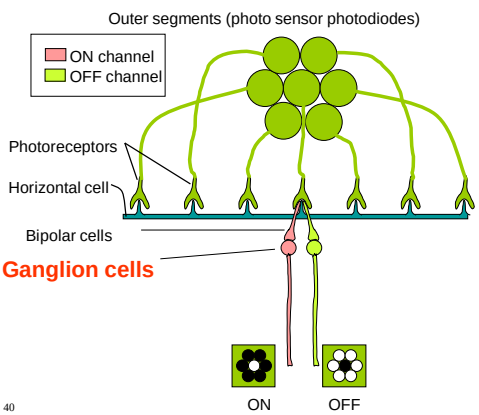

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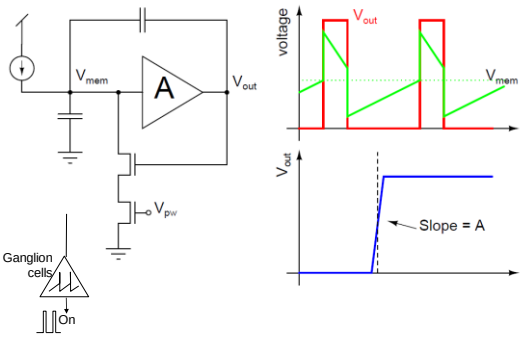
Integrate and Fire neuron circuit turns the graded bipolar cell outputs into ganglion cell spikes



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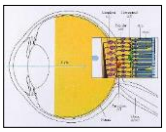
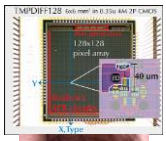
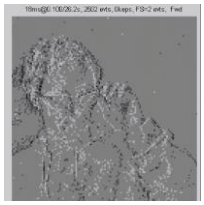
Temporal Contrast **Dynamic Vision Sensor** Silicon Retina

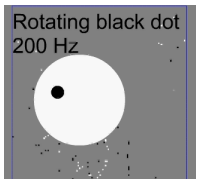




1. This silicon retina **asynchronously** outputs **spiking pixel identities**.
2. Each spike represents a fixed ***temporal contrast*** ($\Delta \log I$), corresponding to change in scene reflectance.

Models transient pathway in retina.
Reduces redundancy
Preserves timing
Has wide dynamic range





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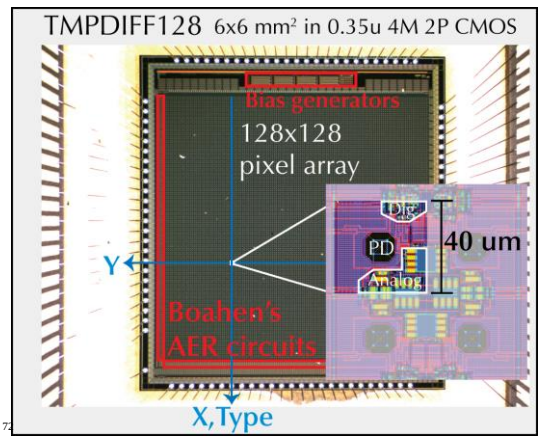

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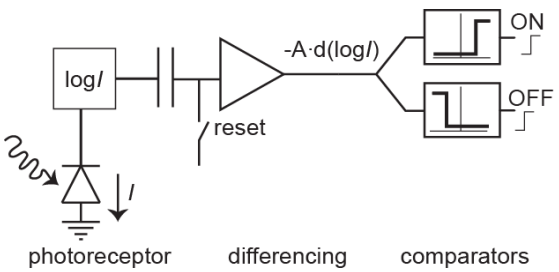
DVS pixel architecture



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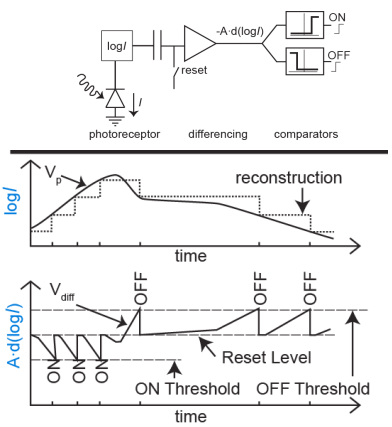

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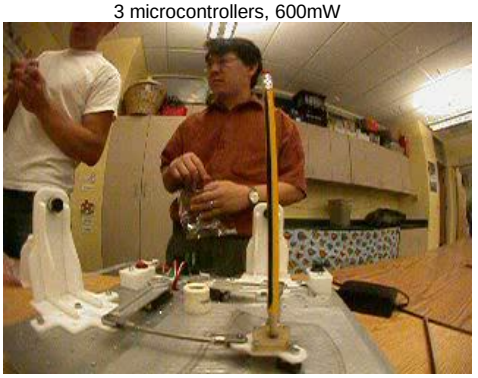
Embedded DVS Pencil Balancer
Jorg Conradt, Matt Cook
3 microcontrollers, 600mW



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