Block course on Computational Neuroscience Fall 2008

Vision: human (retina) and electronic (cameras)

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Reminder for preparing for final presentations:

- Tuesday afternoon and Wednesday morning are for preparation.
- Weds afternoon 13:00-16:00 presentations by 4 groups. Each person in each group must present part of the presentation.
- The presentations must come from different parts of the block course

Reading

Hands-on work

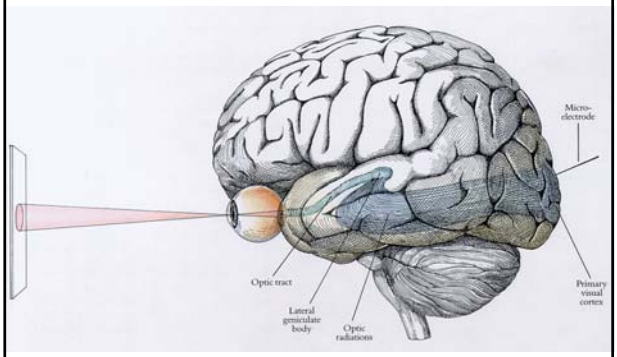
Measuring photoreceptor and horizontal cell responses on PhysioFriend chip and comparing with theory and measured stimulus contrast

Measuring spike responses on spiking silicon retina in response to moving edge stimulus and plotting histograms of responses to measure response variability

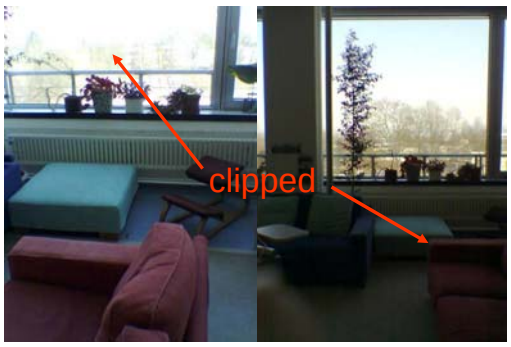
Literature research work

Prepare a presentation on the state of retinal prosthetics

How do we see?



Is your eye a camera?

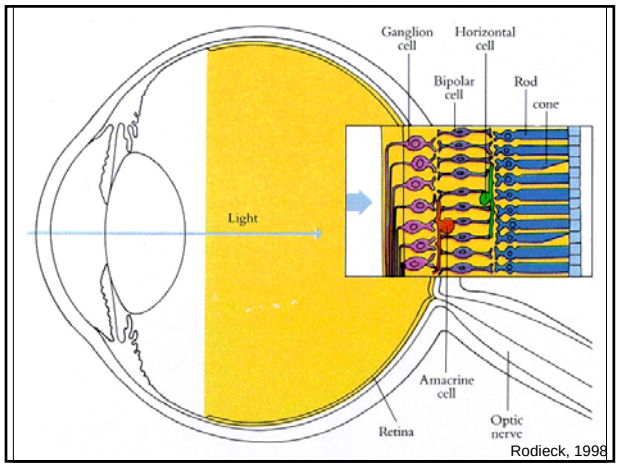


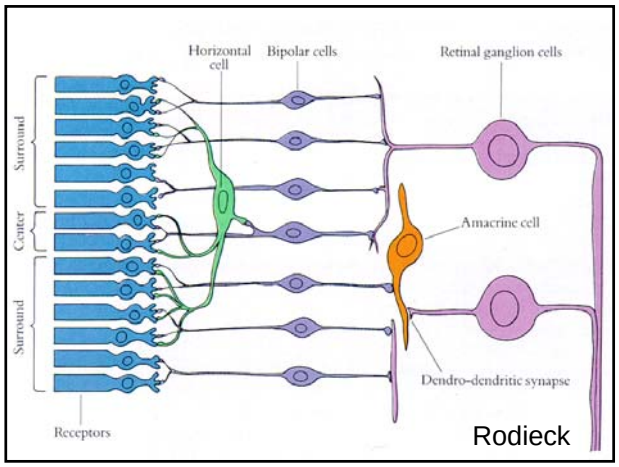
Helligkeiten

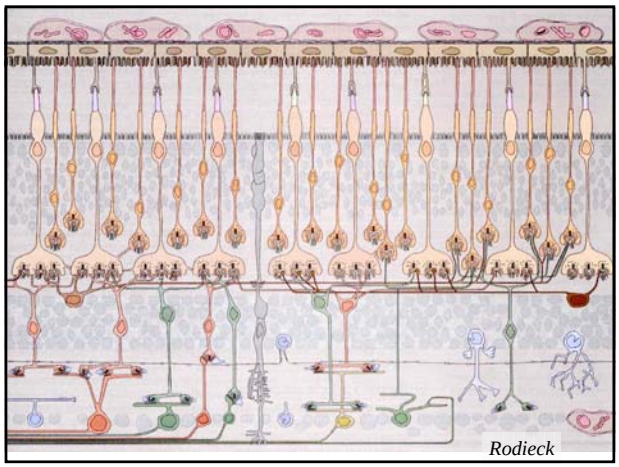
Direktes Sonnenlicht	100'000 Lux
Sonniger Tag	10'000 Lux
Bedeckter Tag	1'000 Lux
Büro	100 Lux
Einbrechende Dämmerung	10 Lux
Dämmerung	1 Lux
Vollmond	0.1 Lux
Viertelmond	0.01 Lux
Klare mondlose Nacht	0.001 Lux
Bedeckte mondlose Nacht	0.0001 Lux

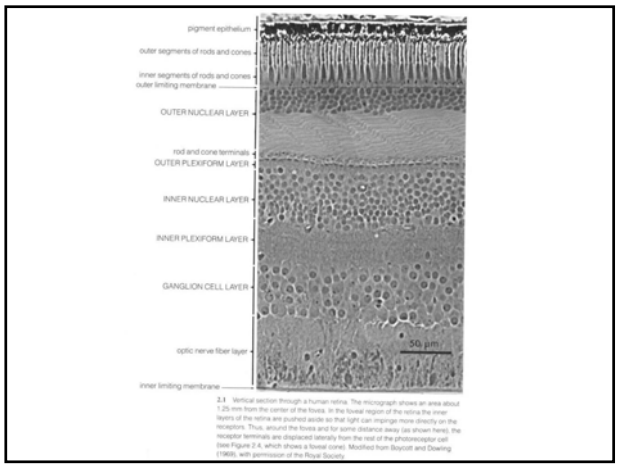
Bild Auflösung

Gesammter Bereich







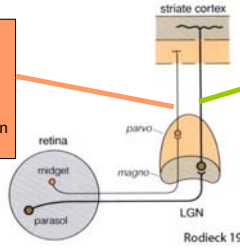


Neuromorphic motivation for temporal contrast response

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

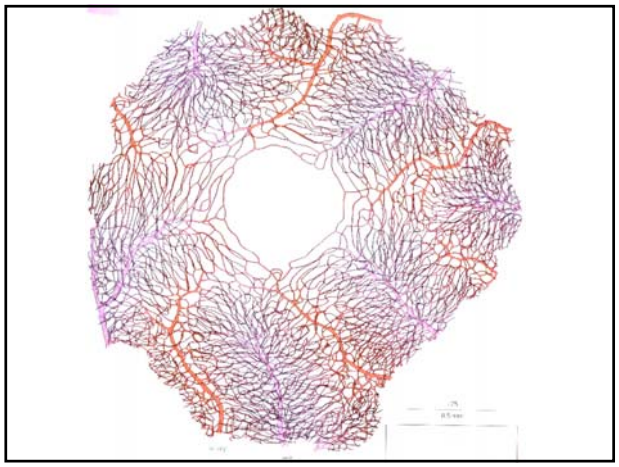
Standard image sensors do this

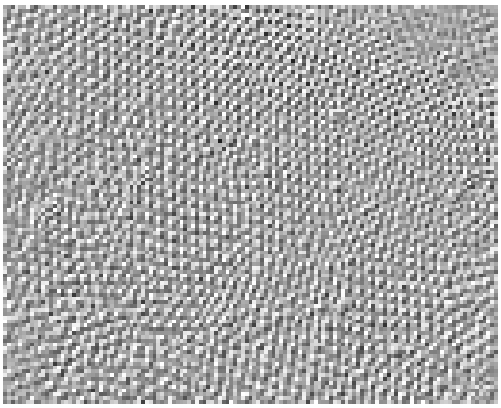


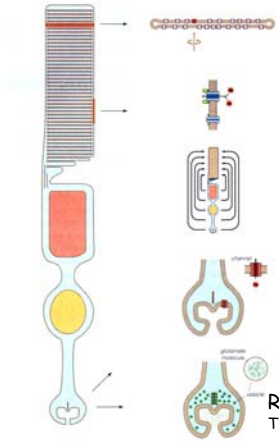
Transient (Magno, Y)
Blind to DC
Monochrome
High contrast gain
Lower spatial resolution
Faster

Temporal contrast sensor does this

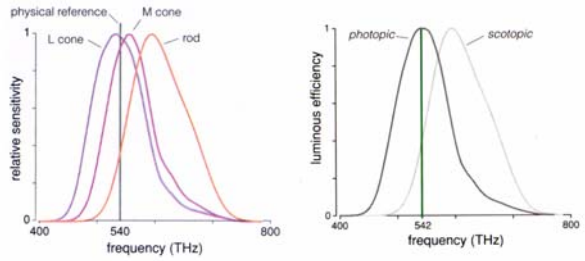
Rodieck 1998



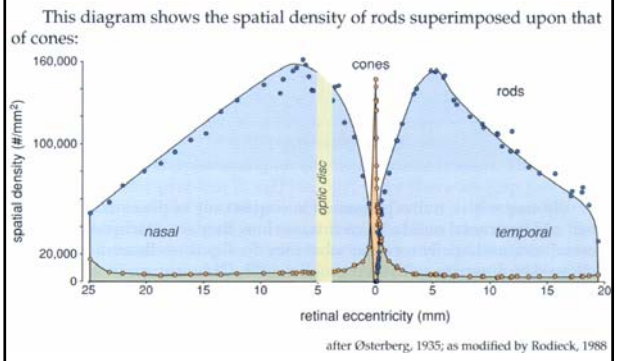




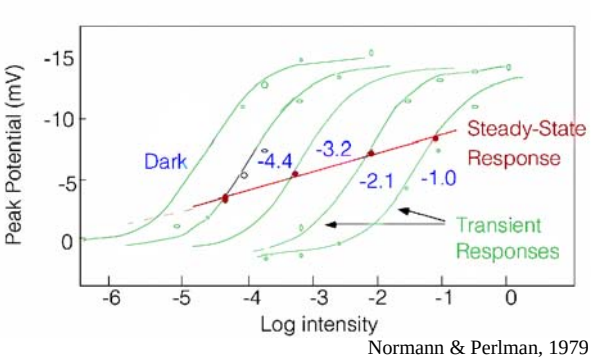
Cones and rods have different spectral sensitivities



And different spatial distributions in the retina

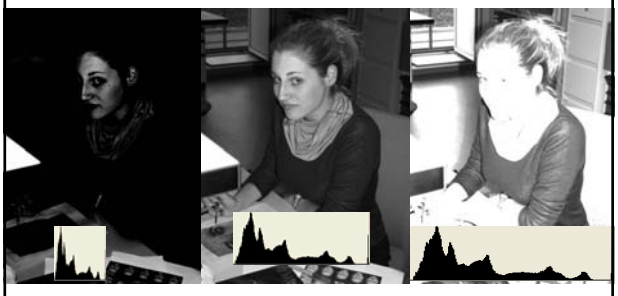


Biological photoreceptors amplify changes more than DC



Normann & Perlman, 1979

The *contrast* of reflective scenes is invariant to illumination

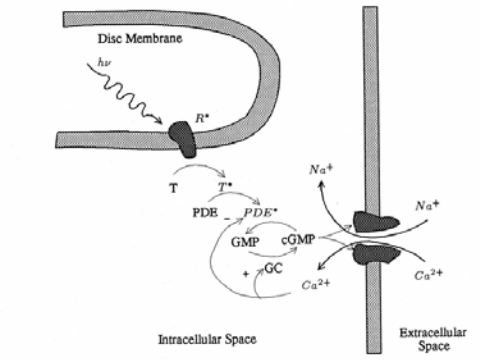


A logarithmic representation of luminance preserves reflectance

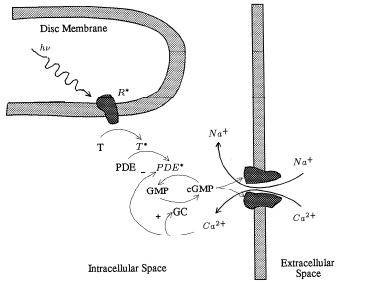
log(X) is self-normalizing and automatically preserves reflectance differences

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

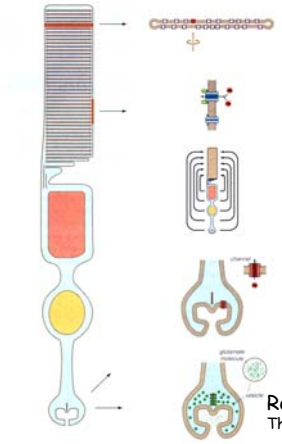
Biological phototransduction uses distributed chain of amplifiers



Mahowald, 1992



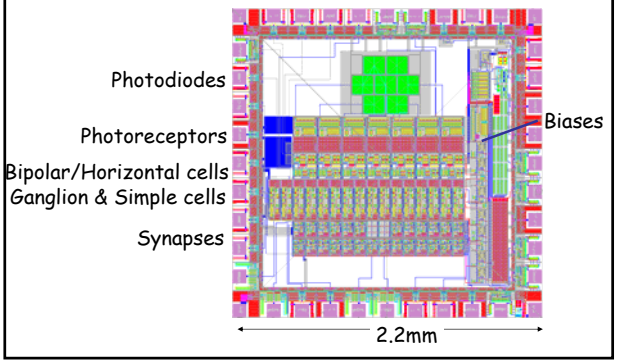
One activated rhodopsin molecule (R^*) activates about 500 transducin molecules (T), which are eventually inactivated by phosphorylation. Activated transducin molecules activate phosphodiesterase (PDE), which then destroy about 2000 cGMP molecules per second. The concentration of cGMP controls the number of open channels in the cell membrane. In the dark, cGMP levels are high, leaving the channels open. Na^+ ions flow in through the open channels and depolarize the cell. Lowering the cGMP concentration causes the channels to close, so the cell hyperpolarizes in the light. Ca^{2+} ions also enter the cell, where they inhibit guanylate cyclase (GC) activity and enhance PDE activity. The calcium concentration is a form of negative feedback on the number of open channels in the membrane and is responsible for photoreceptor adaptation.

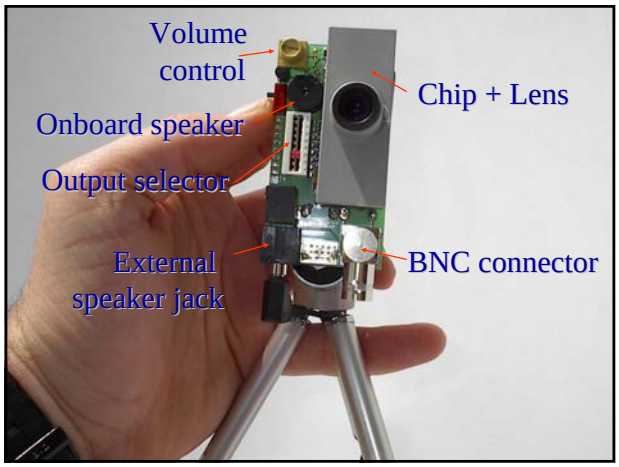


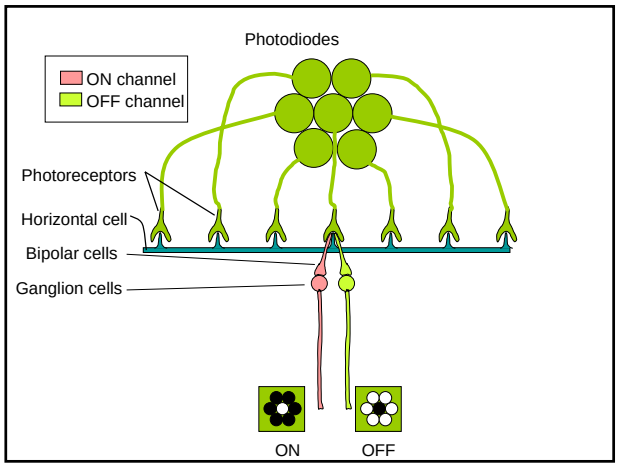
Rodieck 1998
The first steps in seeing

The “Physiologist’s Friend” chip

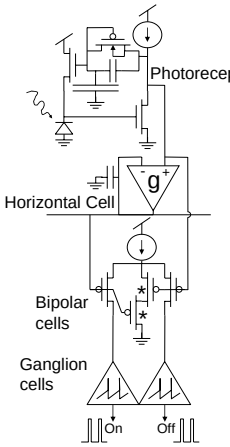
Physio Friend Layout



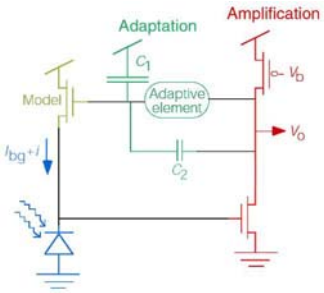




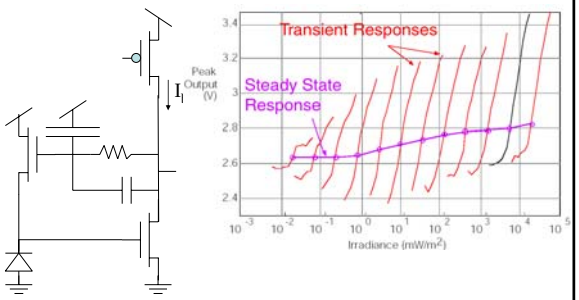
Physiologist's Friend circuit



Adaptive Photoreceptor Circuit



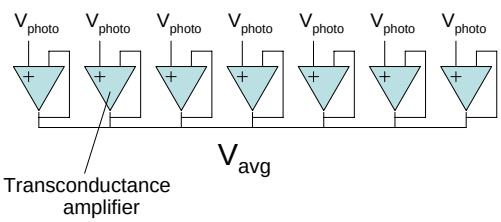
Adaptive photoreceptor (1993)



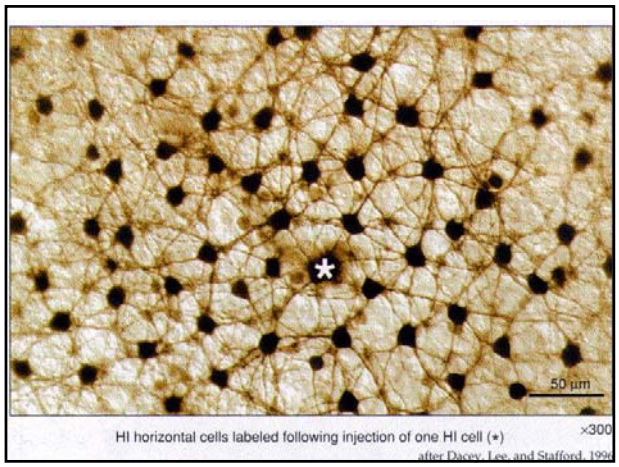
Active feedback increases GBW by factor of ~1000

Horizontal cell

Follower-aggregator averages the photoreceptor outputs to compute the *context.*

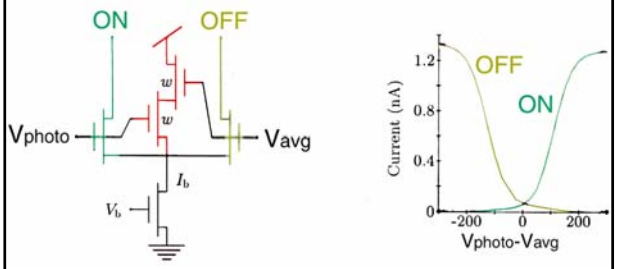


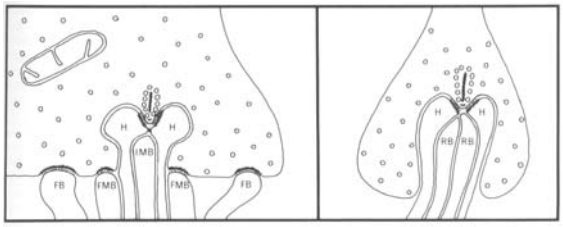
The follower-aggregator computes **mean** for small signals and **median** for large signals



Bipolar Cell (Anti-bump circuit)

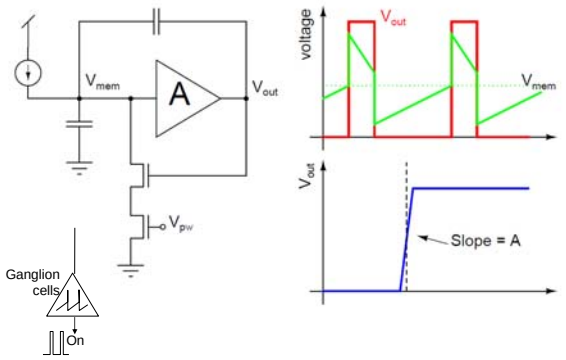
Rectifies into ON and OFF currents



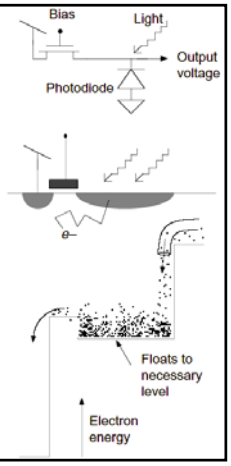


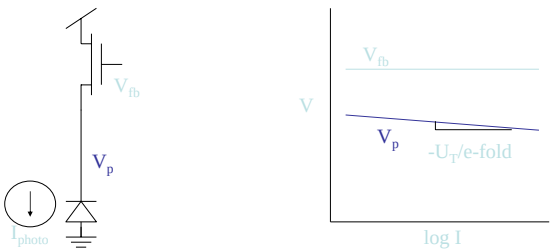
3.7 Schematic drawings showing the arrangements and kinds of junctions made by bipolar cell dendrites and horizontal cell processes with cone (left) and rod (right) receptor terminals in the primate retina. Horizontal cell processes (H) always end laterally and deeper in the invaginations of both the rod and cone terminals. The invaginating midget bipolar dendrites (IMB) end as the central element in the cone terminal invaginations, whereas the rod bipolar dendrites (RB) end as the central elements in the rod terminal invagination. The flat midget bipolar dendrites (FMB) terminate at basal junctions that are in close proximity to an invagination, whereas the dendrites of the other flat bipolar cells (FB) usually contact the basal surface of the cone terminal somewhat away from the invaginations.

"Axon-hillock" spiking soma circuit turns the bipolar outputs into ganglion cell spikes



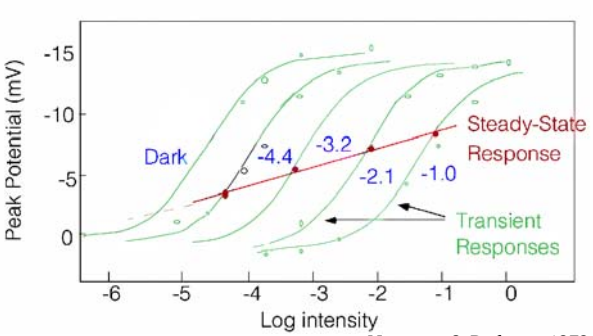
A simple logarithmic photoreceptor circuit





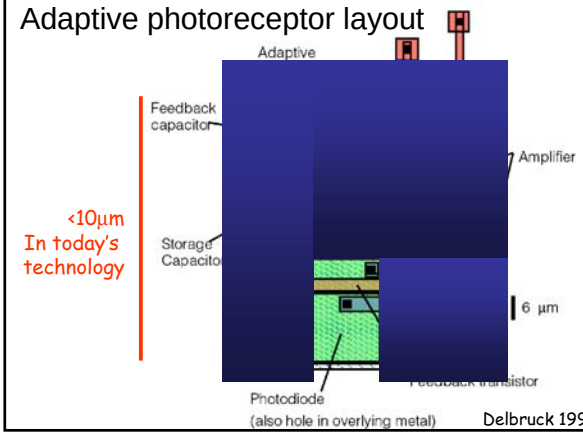
Problem is that mismatch of DC levels is larger than signal

Biological photoreceptors amplify changes more than DC



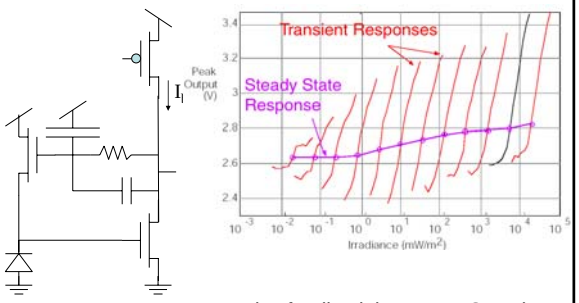
Normann & Perlman, 1979

Adaptive photoreceptor layout



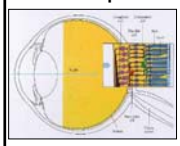
Delbruck 1993

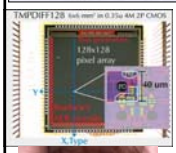
Adaptive photoreceptor (1993)



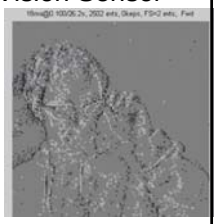
Active feedback increases GBW by factor of ~1000

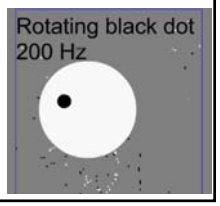
Temporal Contrast Dynamic Vision Sensor





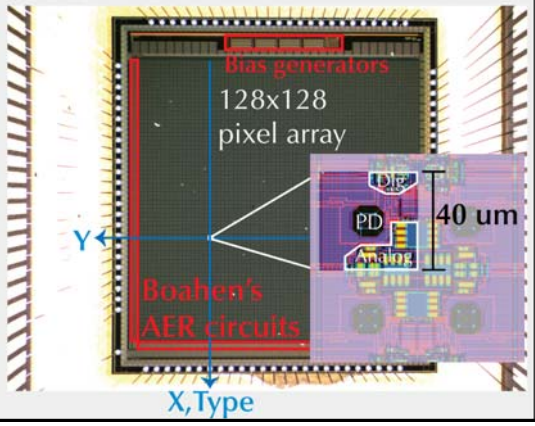
1. This silicon retina **asynchronously** outputs **spiking pixel identities**.
2. Each spike represents a fixed ***temporal contrast*** (Δlogl), corresponding to change in scene reflectance.





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

TMPDIFF128 6x6 mm² in 0.35u 4M 2P CMOS



DVS pixel architecture