Block course on neuroscience Fall 2007

Vision: human (retina) and electronic (cameras)

Tobi Delbruck
Inst. of Neuroinformatics
UZH-ETH Zurich

Reminder:

- 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

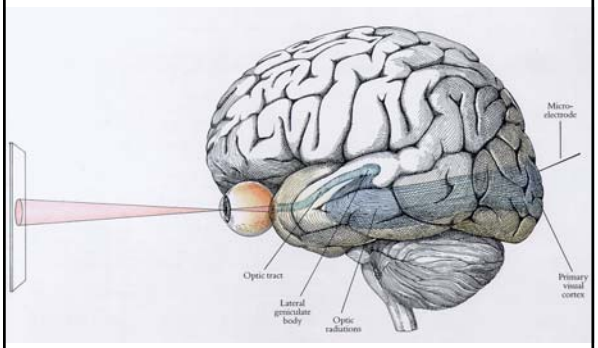
Measuring photoreceptor and horizontal cell responses on PhysioFriend chip and comparing with theory and measured stimulus contrast

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

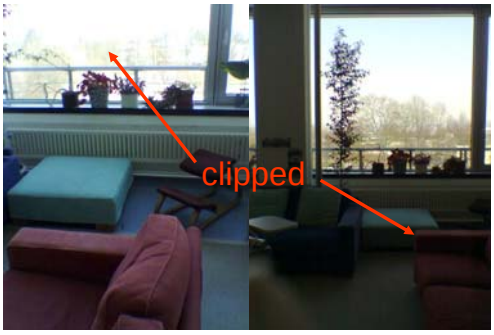
Literature research work

Prepare a presentation on the state of retinal prosthetics

How do we see?



Is your eye a camera?

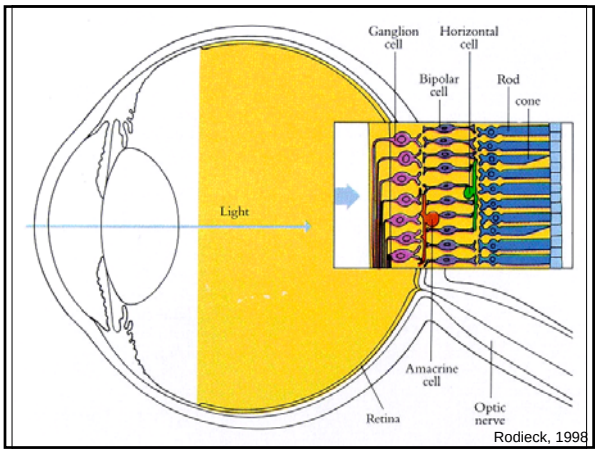


Helligkeiten

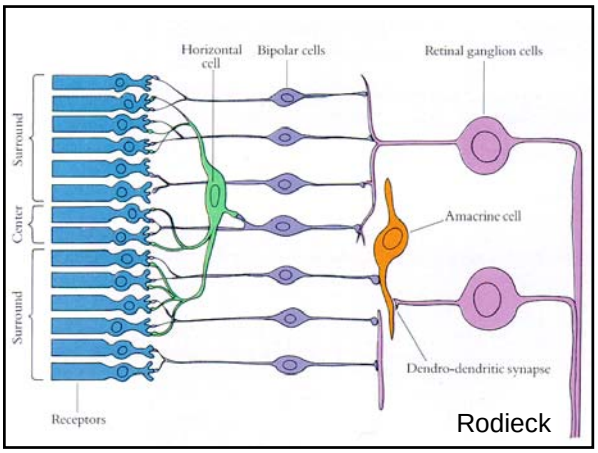
Direktes Sonnenlicht	100'000 Lux
Sonniger Tag	10'000 Lux
Bedeckter Tag	1'000 Lux
Büro	100 Lux
Einbrechende Dämmerung	10 Lux
Dämmerung	1 Lux
Vollmond	0.1 Lux
Viertelmond	0.01 Lux
Klare mondlose Nacht	0.001 Lux
Bedeckte mondlose Nacht	0.0001 Lux

Bild Auflösung

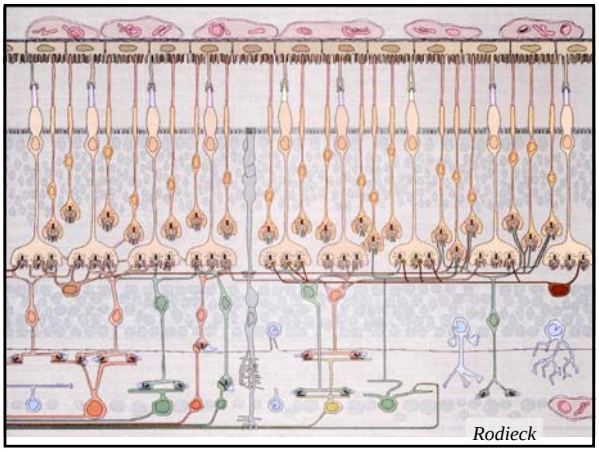
Gesammter Bereich

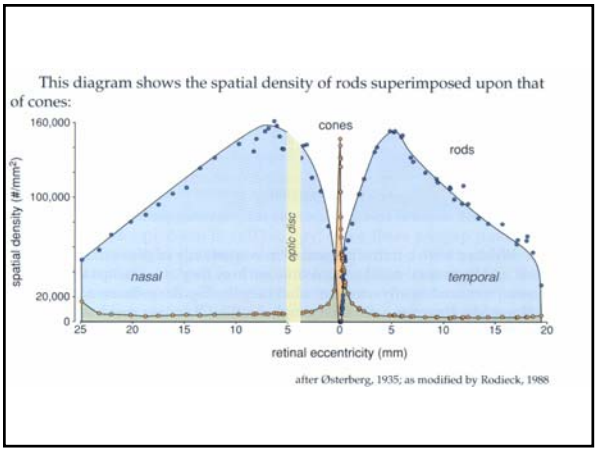


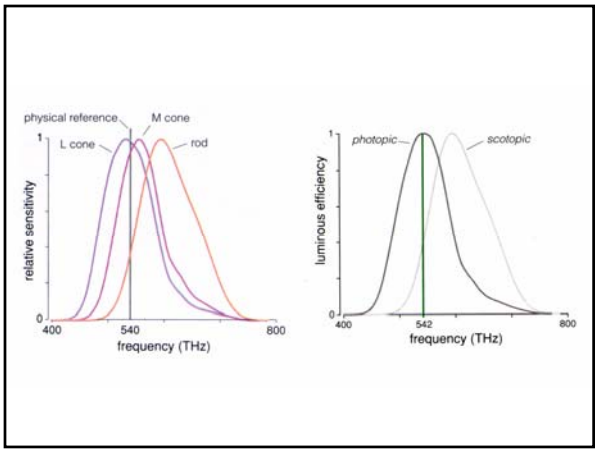
Rodieck, 1998

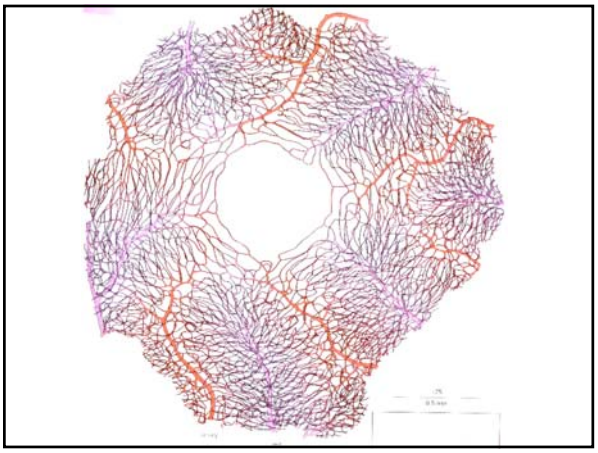


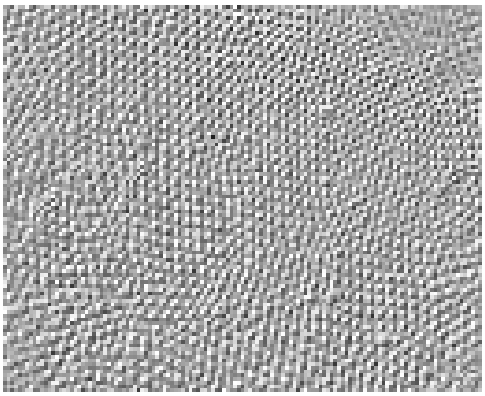
Rodieck

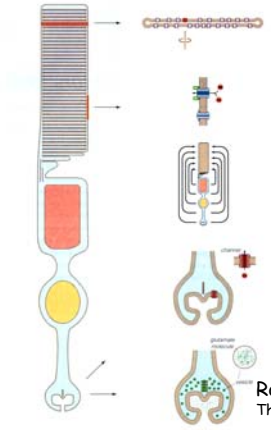

Rodieck



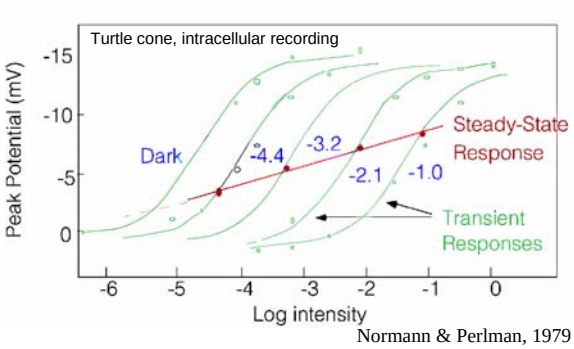






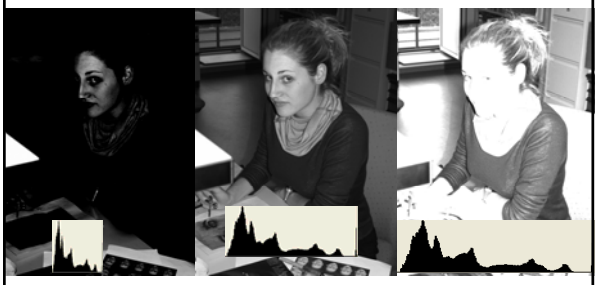


Biological photoreceptors amplify changes more than DC



Normann & Perlman, 1979

The *contrast* of reflective scenes is invariant to illumination

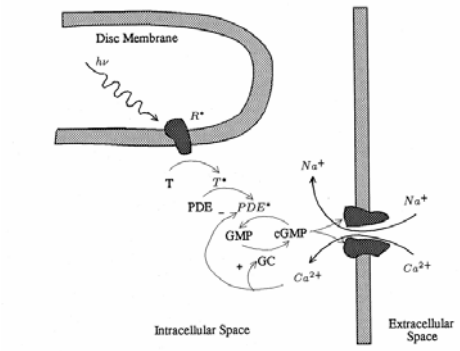


A logarithmic representation of luminance preserves reflectance

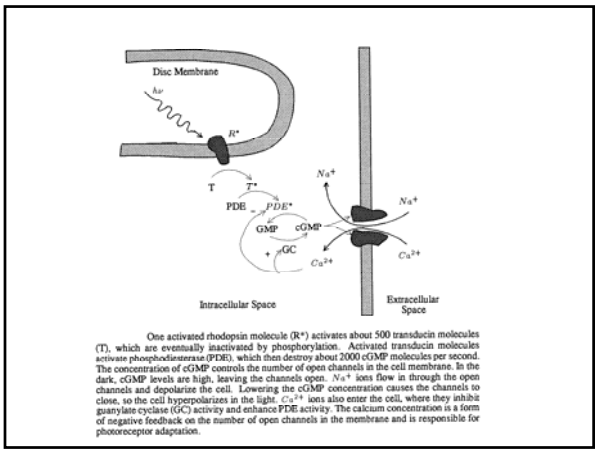
log is self-normalizing and automatically preserves reflectance differences

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

Biological phototransduction uses distributed chain of amplifiers

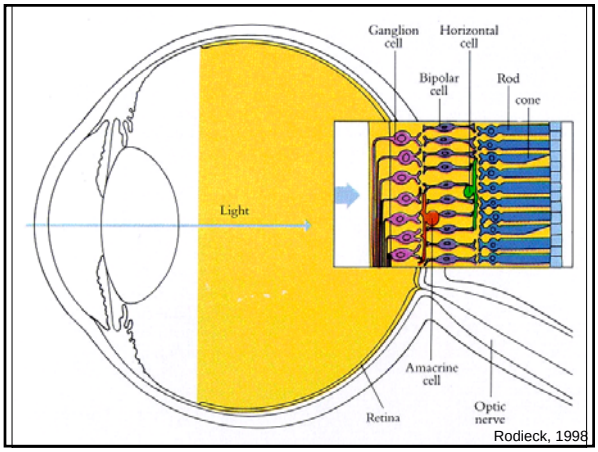


Mahowald, 1992

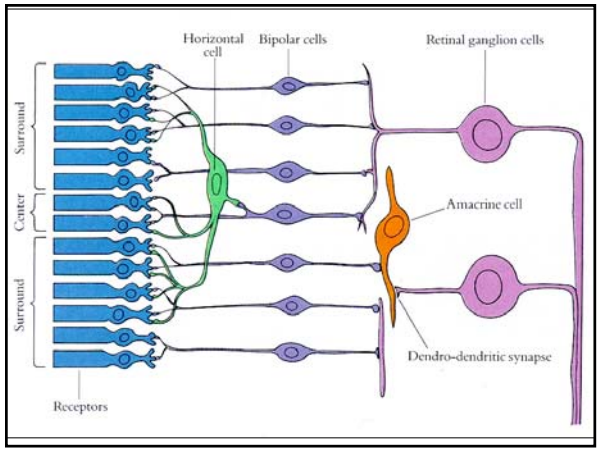


One activated rhodopsin molecule (R*) activates about 500 transducin molecules (T), which are eventually inactivated by phosphorylation. Activated transducin molecules activate phosphodiesterase (PDE), which then destroy about 2000 cGMP molecules per second. The concentration of cGMP controls the number 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.

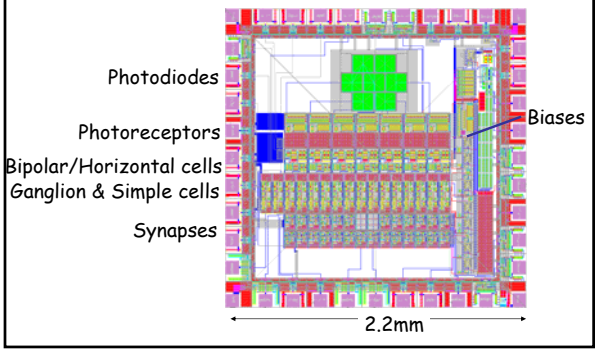
The “Physiologist’s Friend” chip

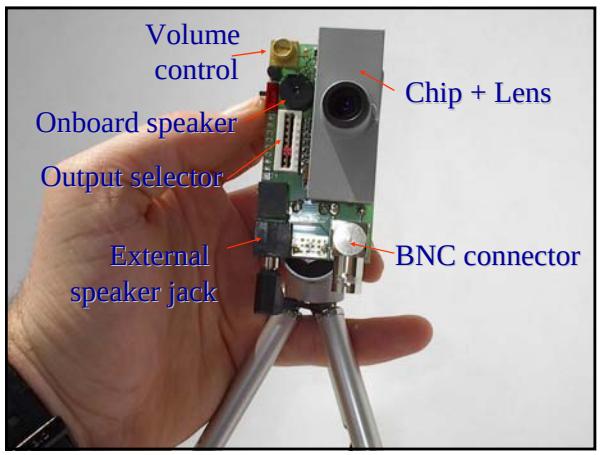


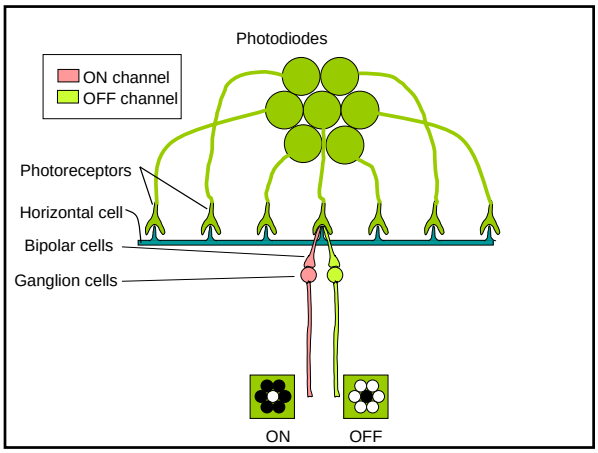
Rodieck, 1998



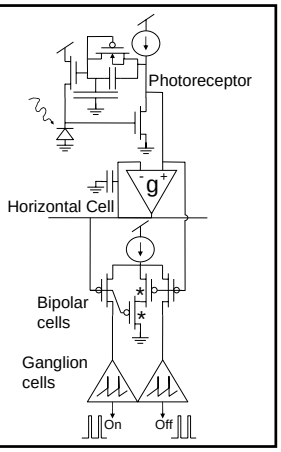
Physio Friend Layout



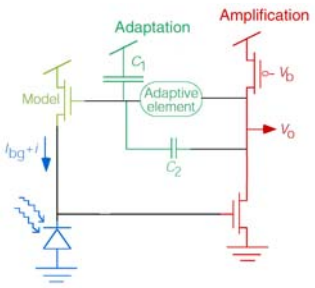




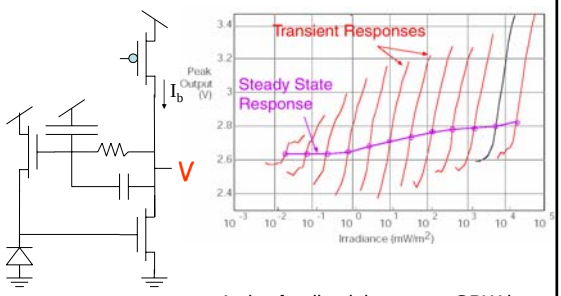
Physiologist's Friend circuit



Adaptive Photoreceptor Circuit



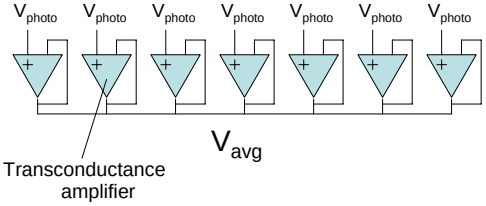
Adaptive photoreceptor (1993)



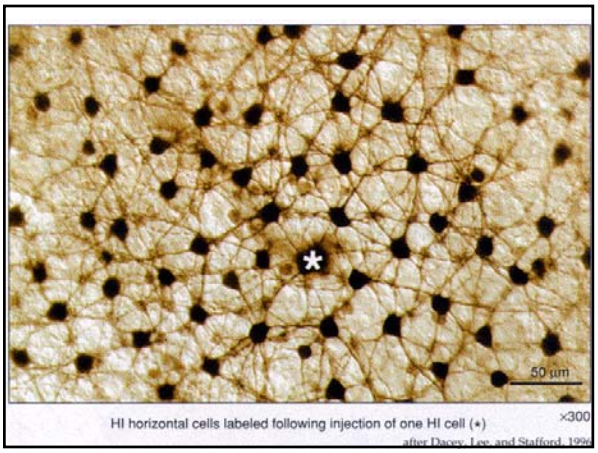
Active feedback increases GBW by factor of ~1000

Horizontal cell

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

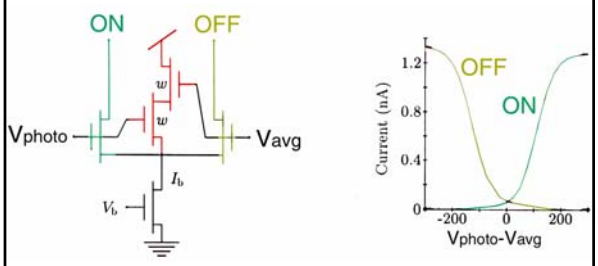


The follower-aggregator computes **mean** for small signals and **median** for large signals

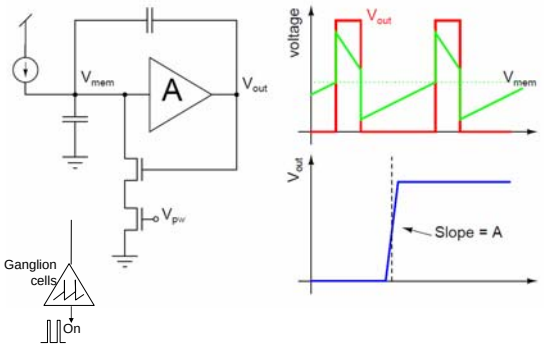


Bipolar Cell (Anti-bump circuit)

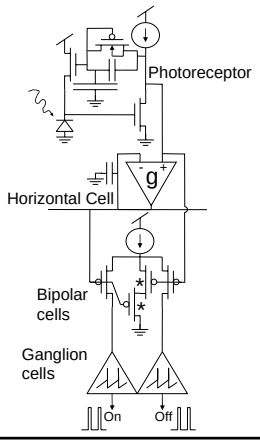
Rectifies into ON and OFF currents



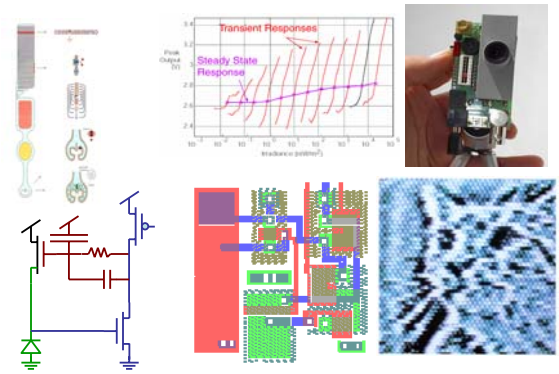
"Axon-hillock" spiking soma circuit turns the bipolar outputs into ganglion cell spikes

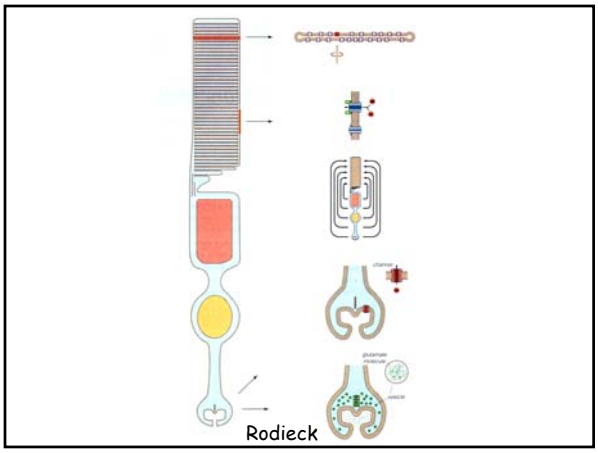


Physiologist's Friend circuit

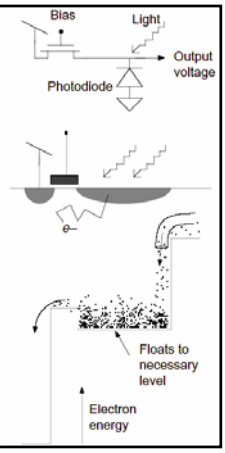


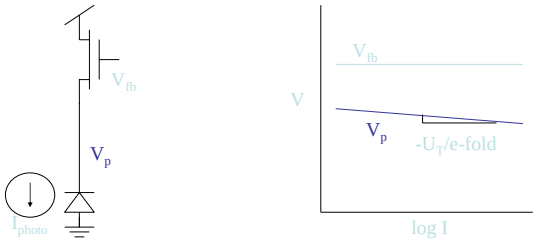
Understanding silicon photoreceptors





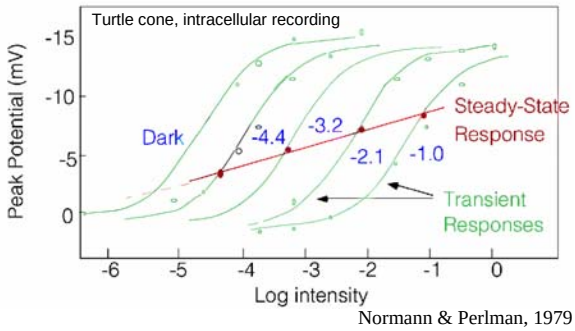
A simple logarithmic photoreceptor circuit





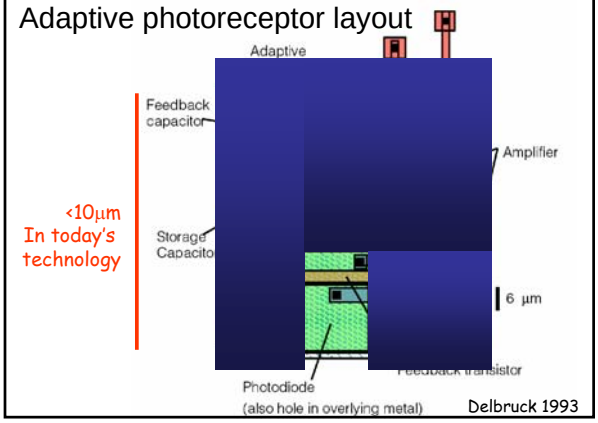
Problem is that mismatch of DC levels is larger than signal

Biological photoreceptors amplify changes more than DC

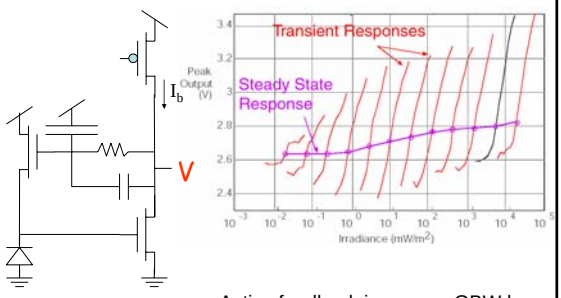


Normann & Perlman, 1979

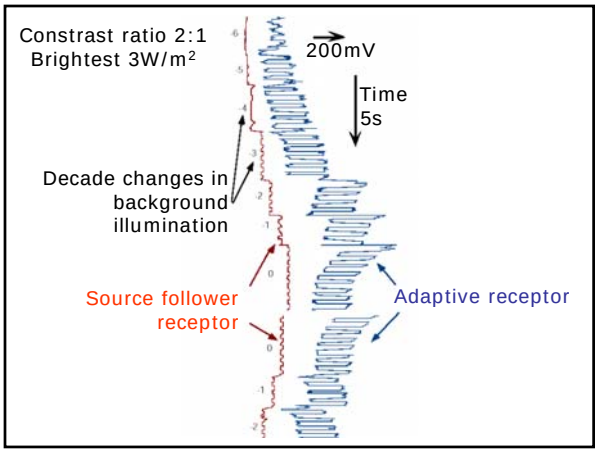
Adaptive photoreceptor layout



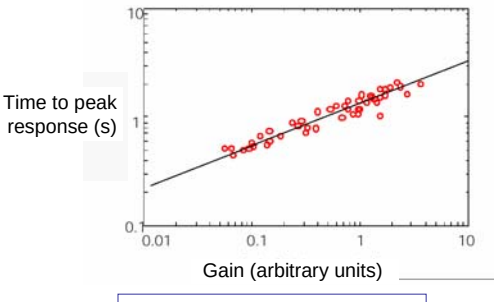
Adaptive photoreceptor (1993)



Active feedback increases GBW by factor of ~1000

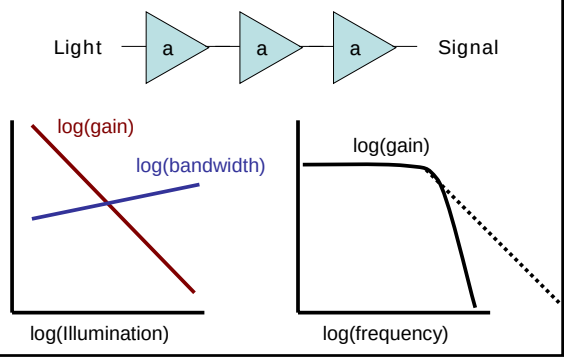


In biological photoreceptors, the rise time is not proportional to the gain

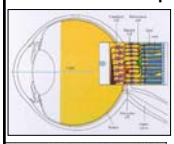


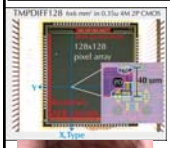
Rise time ~ $Gain^{0.25}$

Advantage of multistage amplification

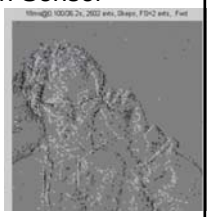


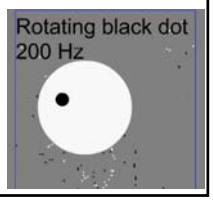
Temporal Contrast Vision Sensor





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