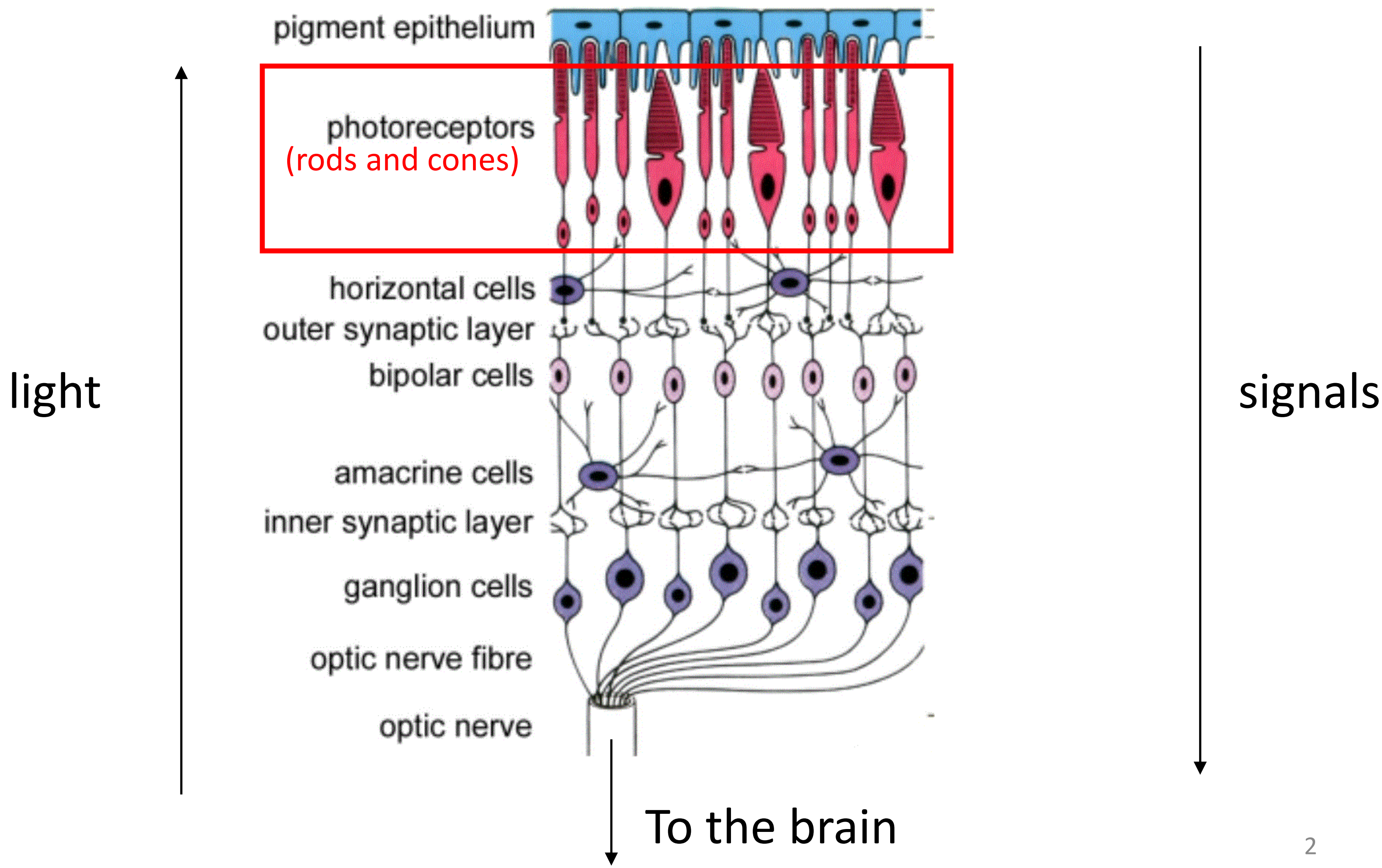
COMP 546

Lecture 4

Retina

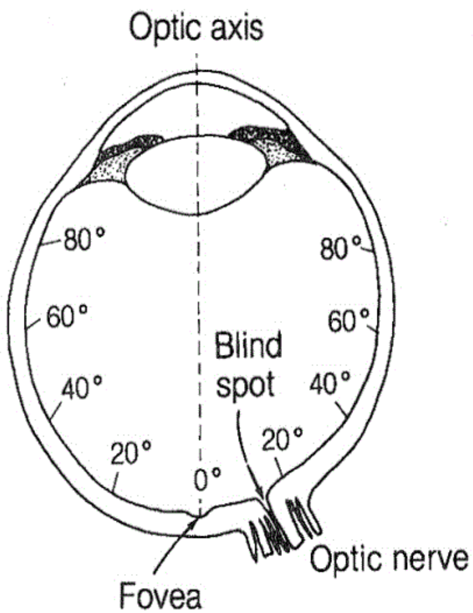
Tues. Jan. 23, 2018

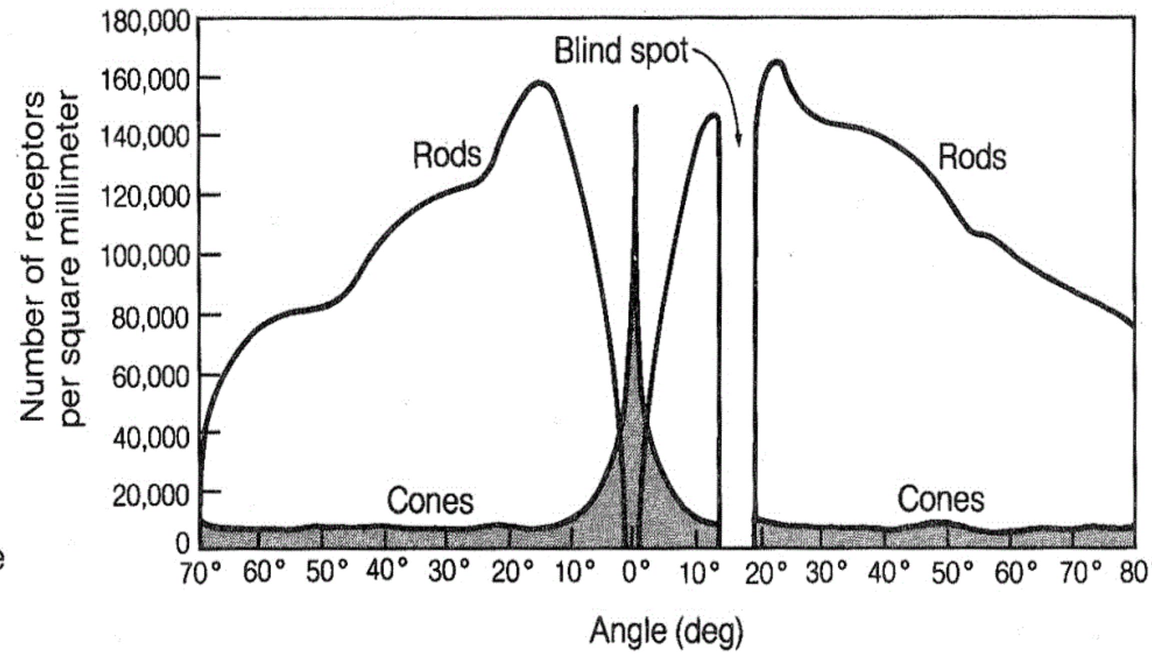
Layers of the Retina



Photoreceptor (rod and cone) density

This is the left eye. Why?



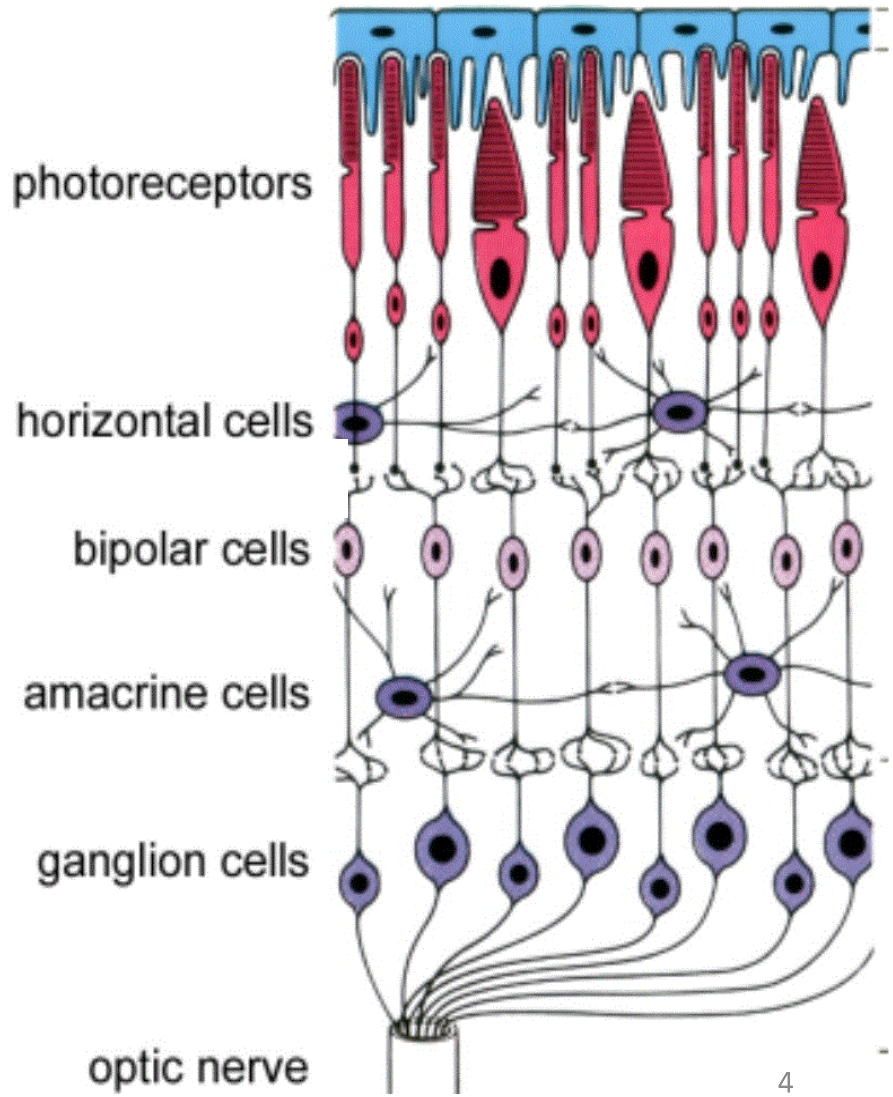


Cone density is very high in the center of the field of view.
This area of the retina is called the *fovea*.

Responses of cells in the Retina

continuous

discrete ("spikes")



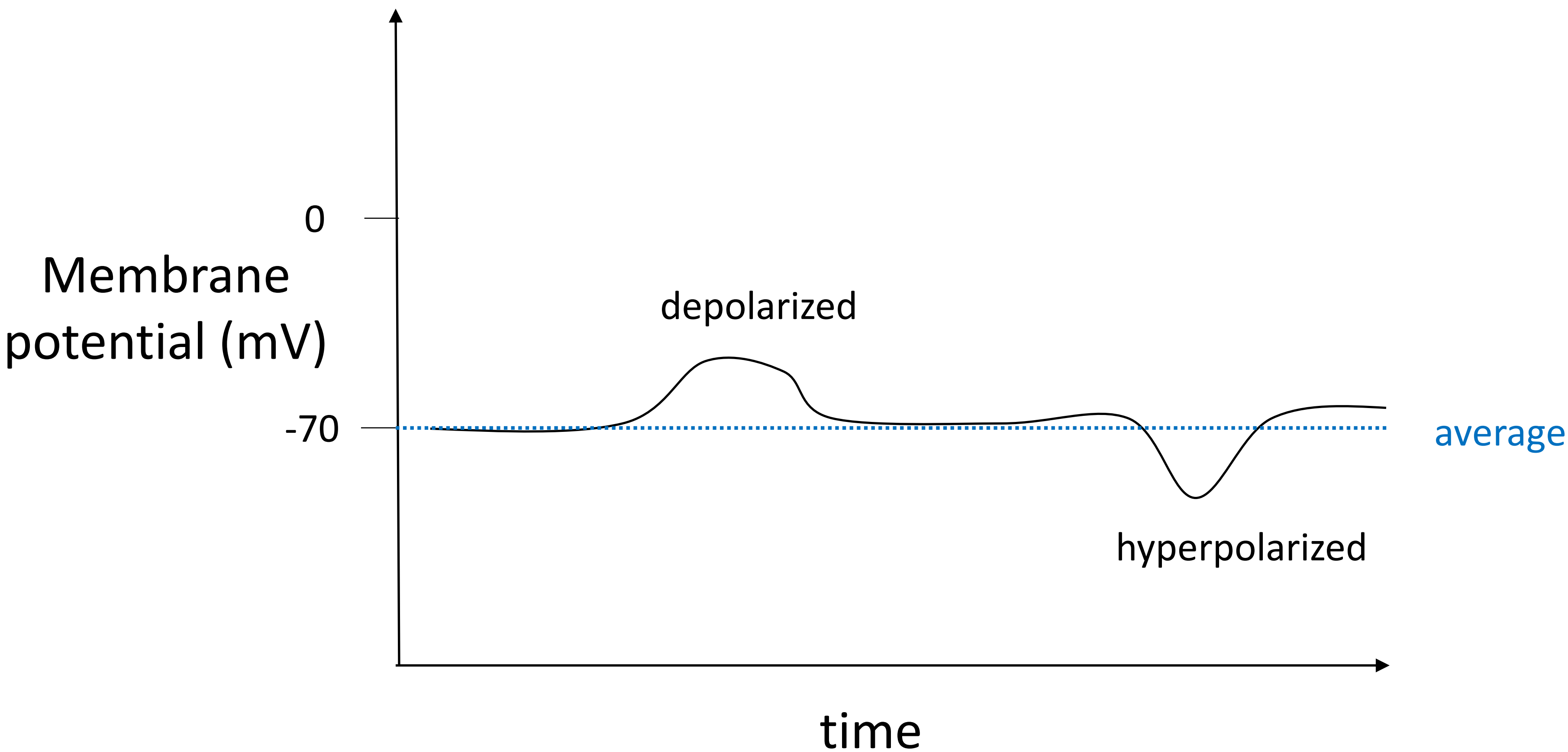
ASIDE:

neural coding using spikes

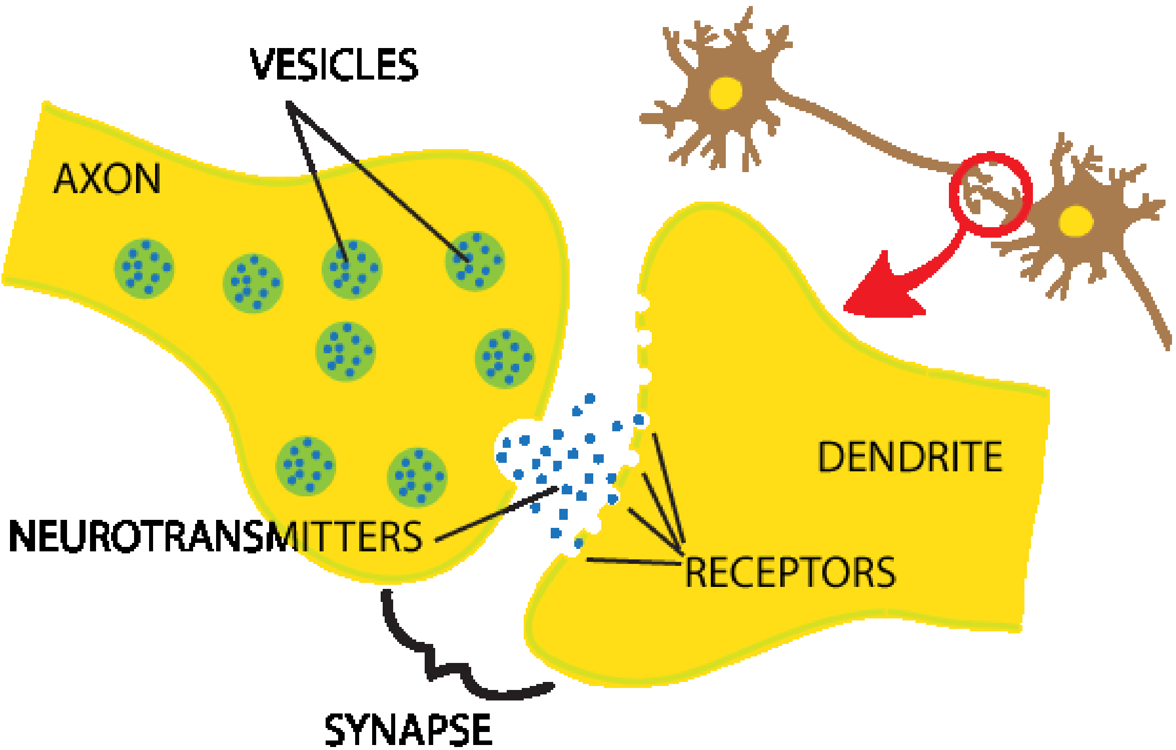
(retinal ganglion cells)

I mentioned this in lecture 0.

Response of neuron
(measured by experimenter)



Signalling between cells at synapse
(not measured by experimenter)



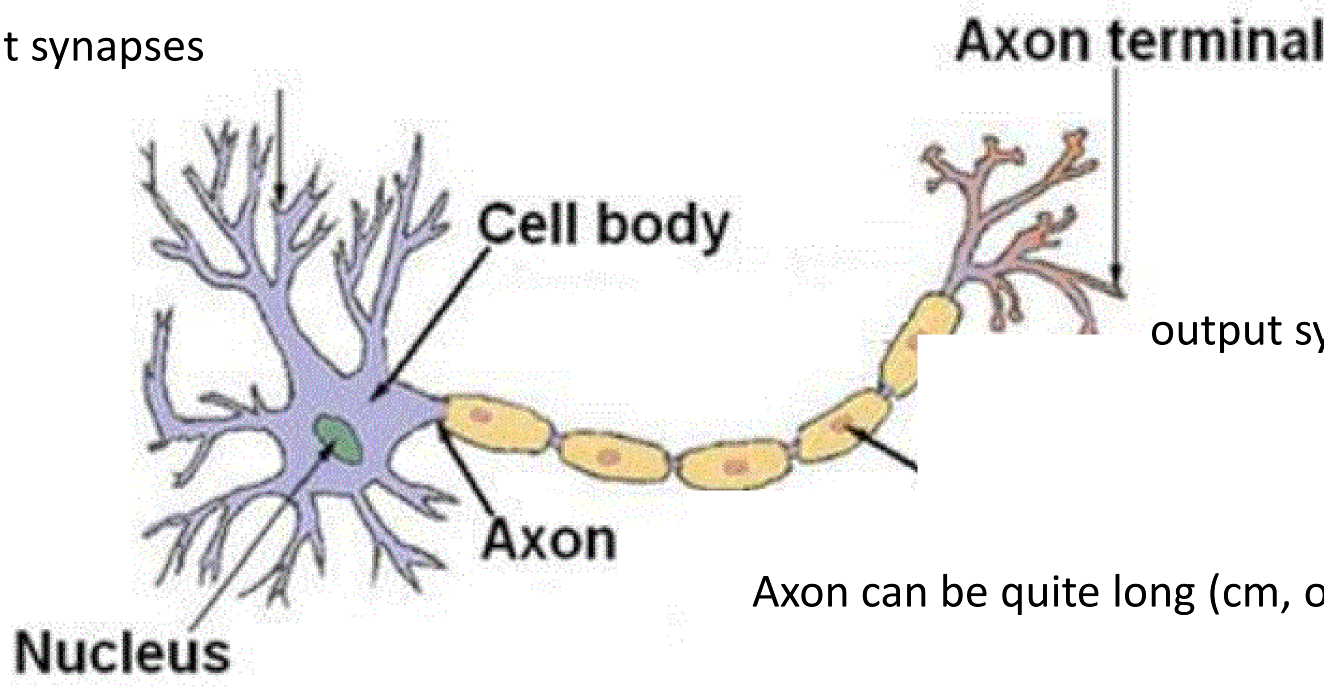
Release rate of neurotransmitters depends on the membrane potential.

Neurotransmitters can be either excitatory (depolarizing) or inhibitory (hyperpolarizing).

pre-synaptic cell → post-synaptic cell

Q: How do nerve cells signal over long distances ?

input synapses

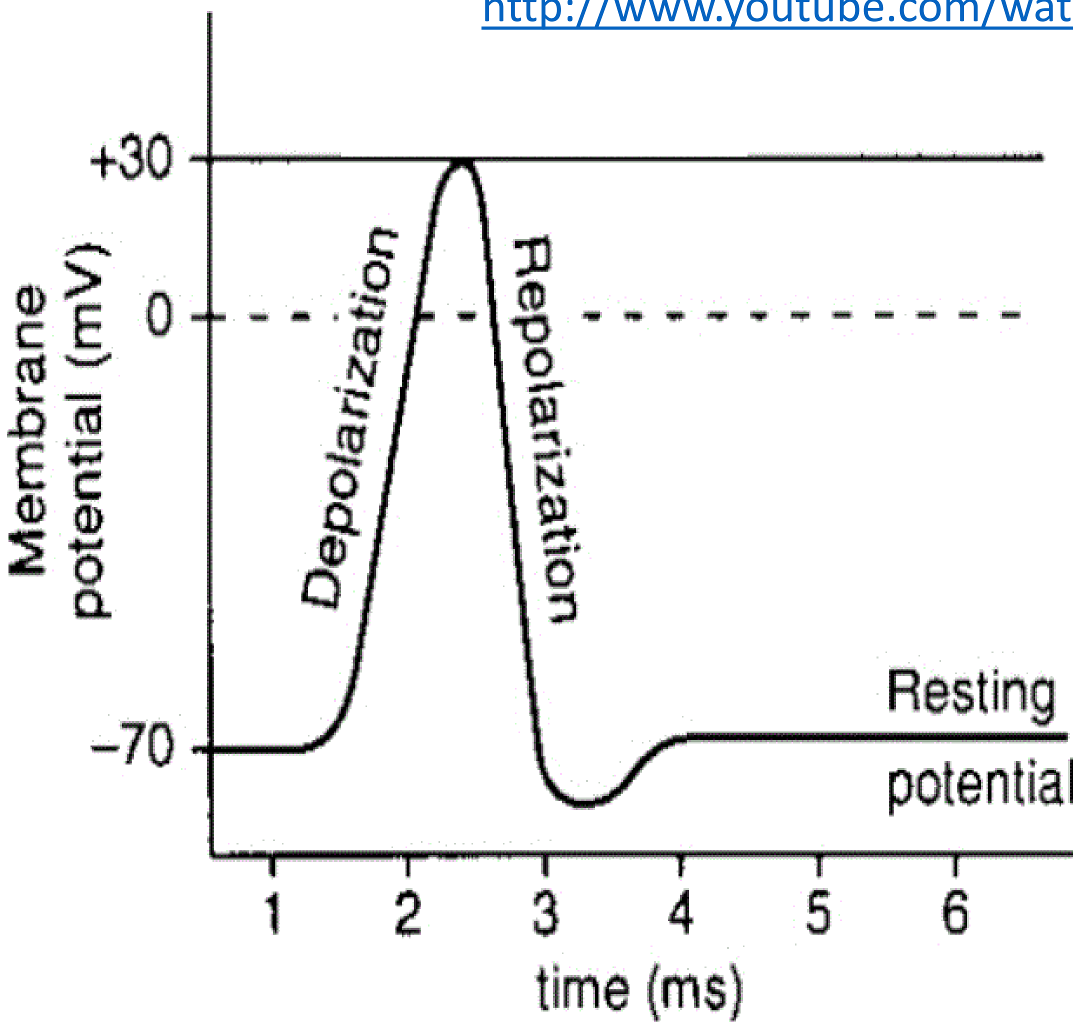


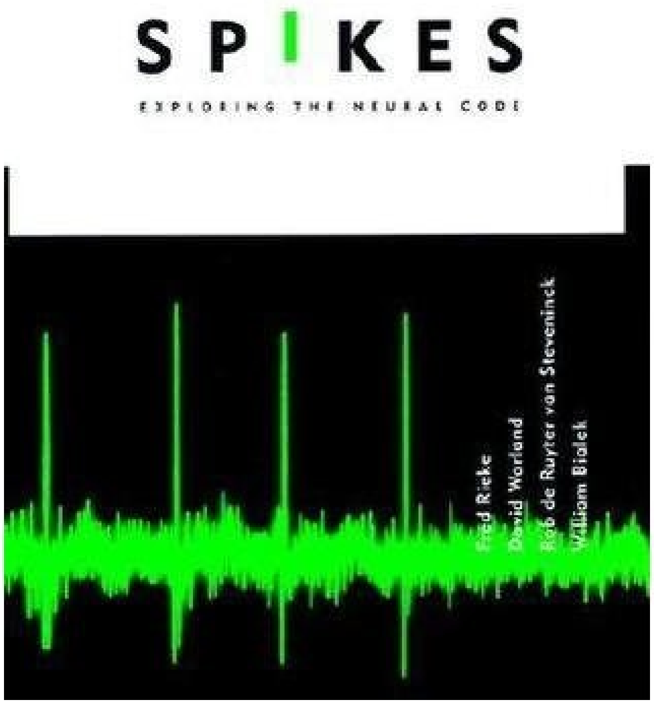
output synapses

Axon can be quite long (cm, or up to 1 m).

A: Spikes ("Action Potentials")

http://www.youtube.com/watch?v=ifD1YG07fB8

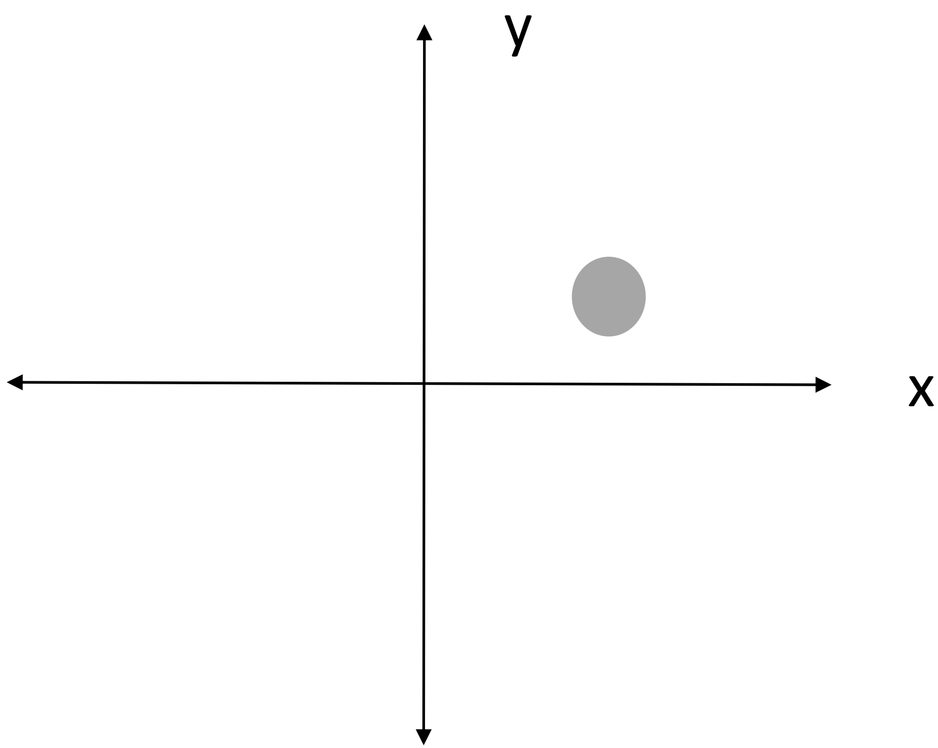




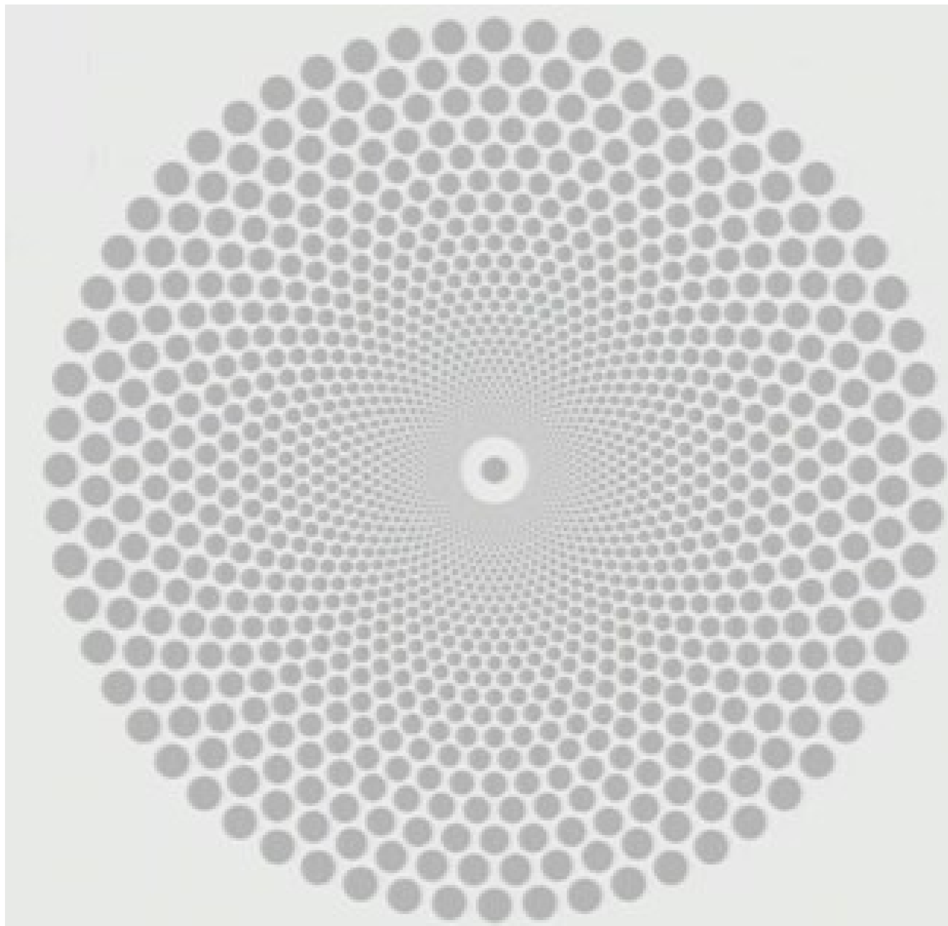
- shape
- speed
- frequency ("firing rate")
- information (see book)

https://mitpress.mit.edu/books/spikes

Receptive Field of a Retinal Cell

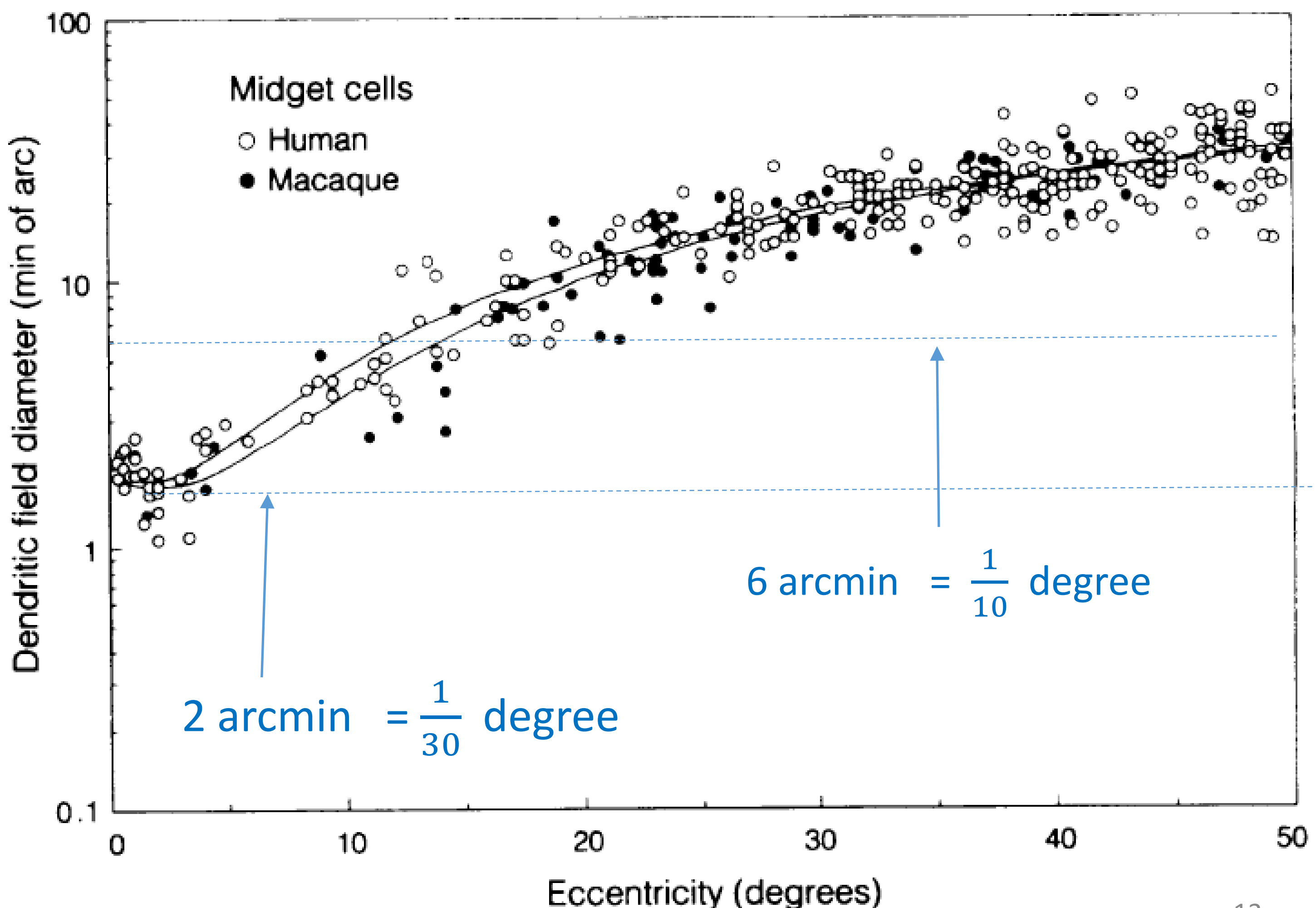


Receptive field sizes increase with eccentricity



Receptive field diameter of retinal ganglion cells

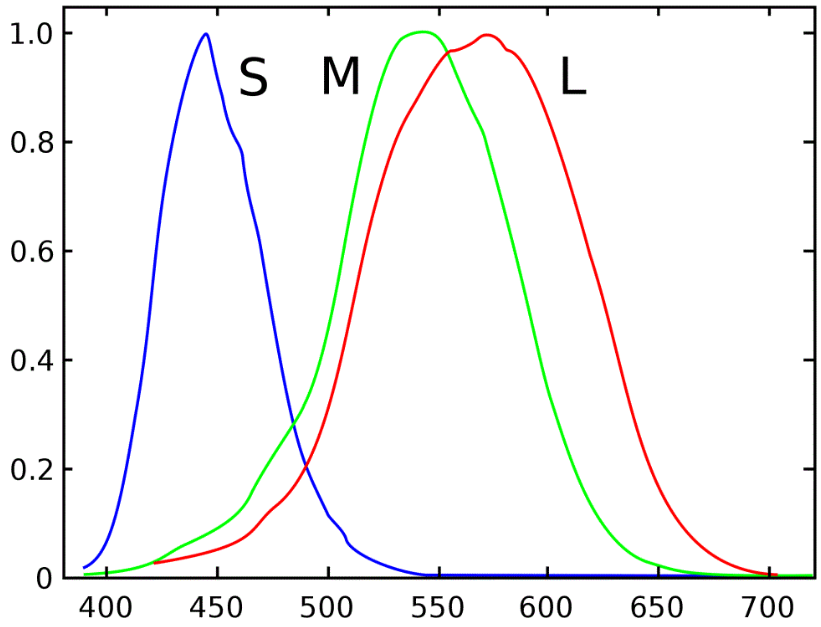
NOTE:
Log scale



Retinal ganglion cells encode image sums and differences :

- spectral (wavelength λ) , “chromatic”
- spatial (x,y)
- temporal (t)
- spectral-spatio-temporal (λ, x, y, t)

Spectral sums and differences



"L + M"

red + green = yellow

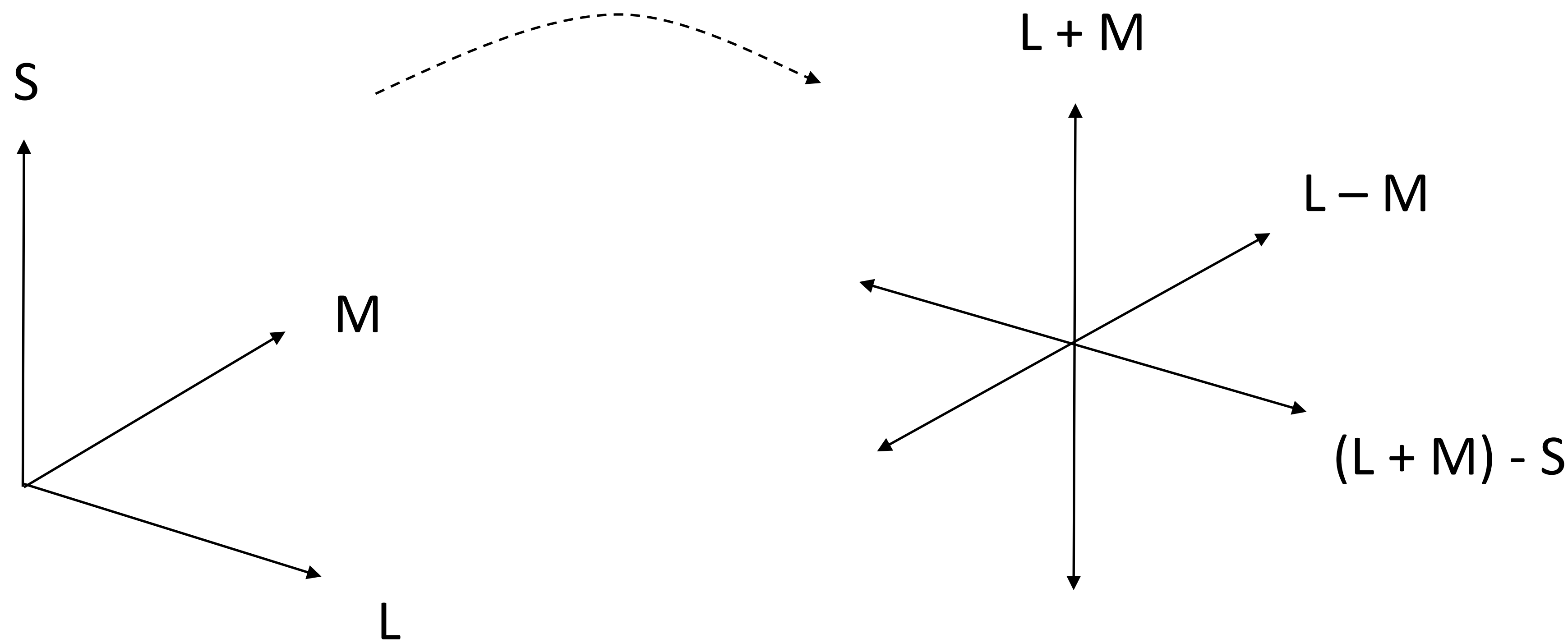
"L - M"

red – green

"(L + M) - S"

yellow – blue

Spectral sums and differences

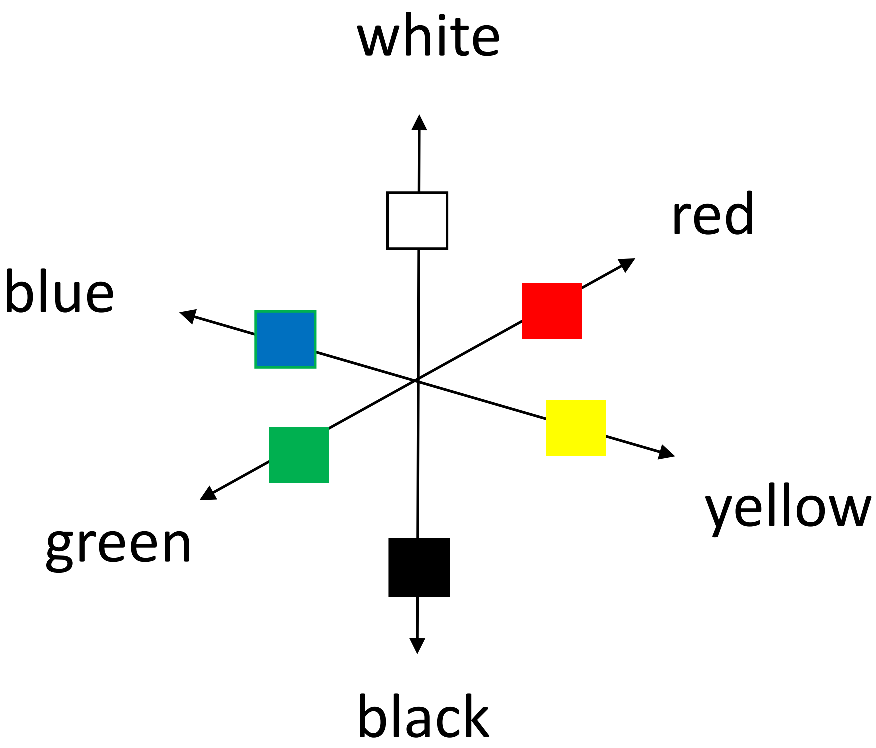


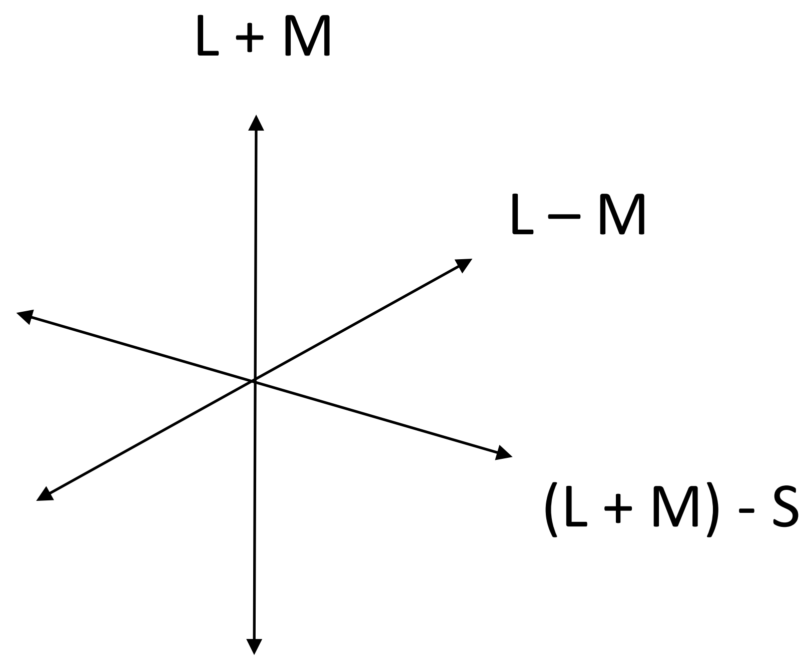
Photoreceptors (cones)

Retinal ganglion cells

“Color Opponency”
(Hering, 19th century)

Neural Mechanism
(modern theory)

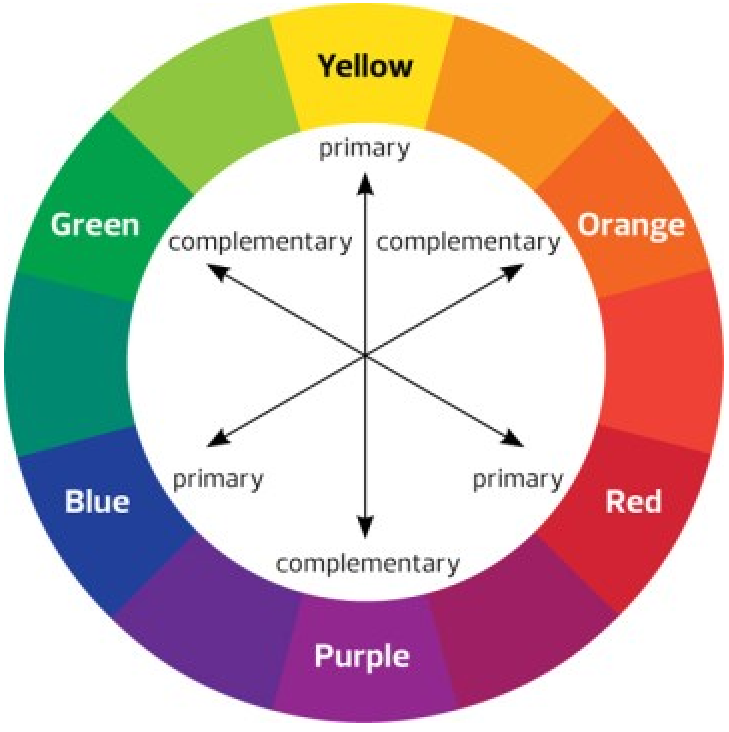




Orange is reddish-yellow. Purple is blueish-red. Cyan is greenish-blue.

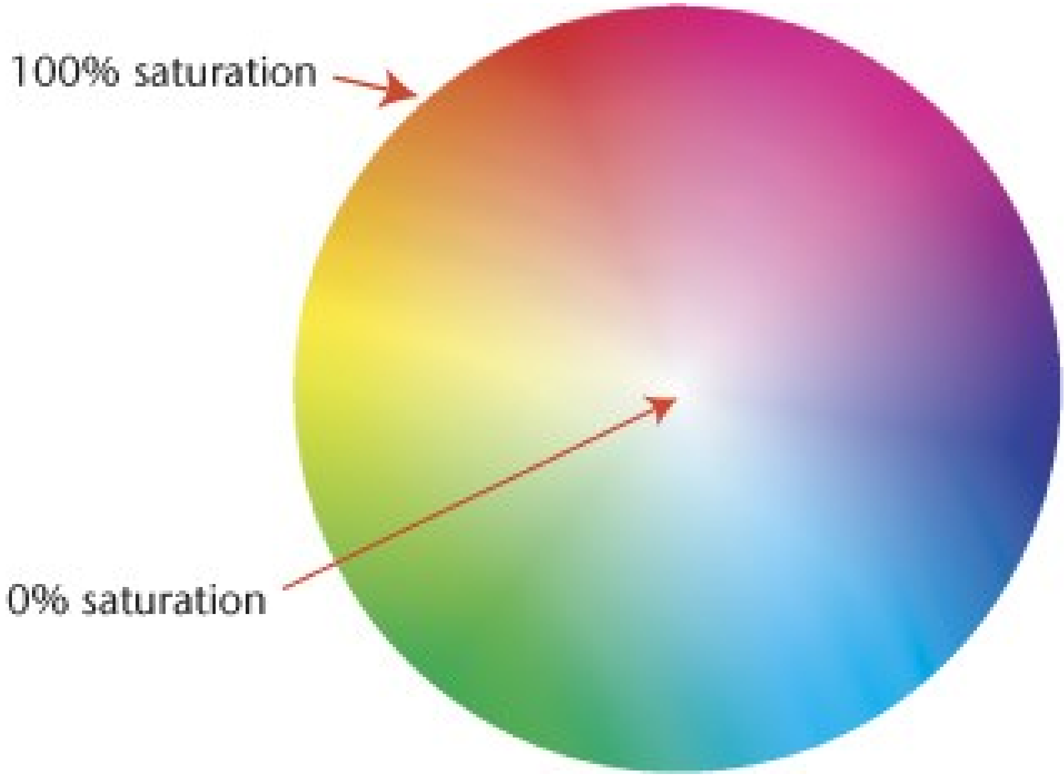
Colors cannot appear reddish-green, blueish-yellow, blackish-white.

ASIDE: Classical Color Wheel

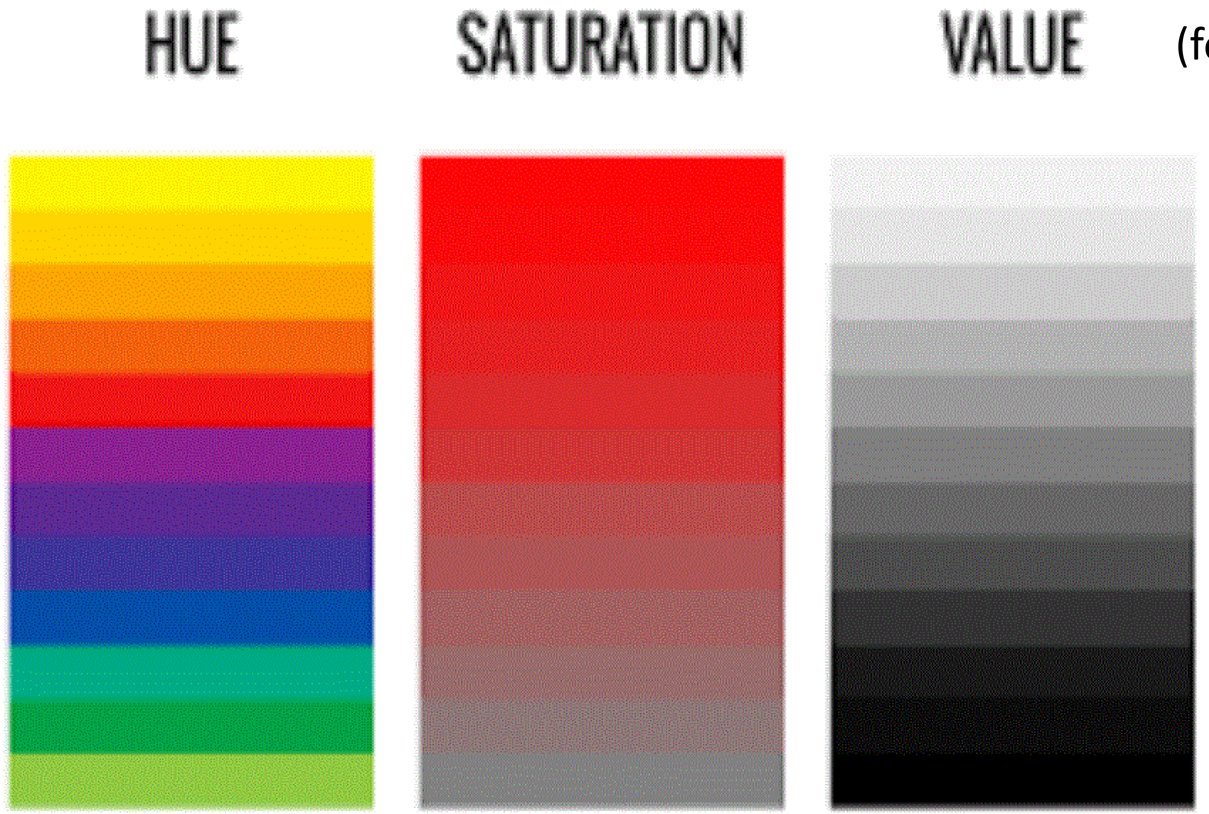


Art class ROYGBV theory of primary, secondary, and complementary colors is based on mixing pigments, not mixing lights.

Polar coordinates for color



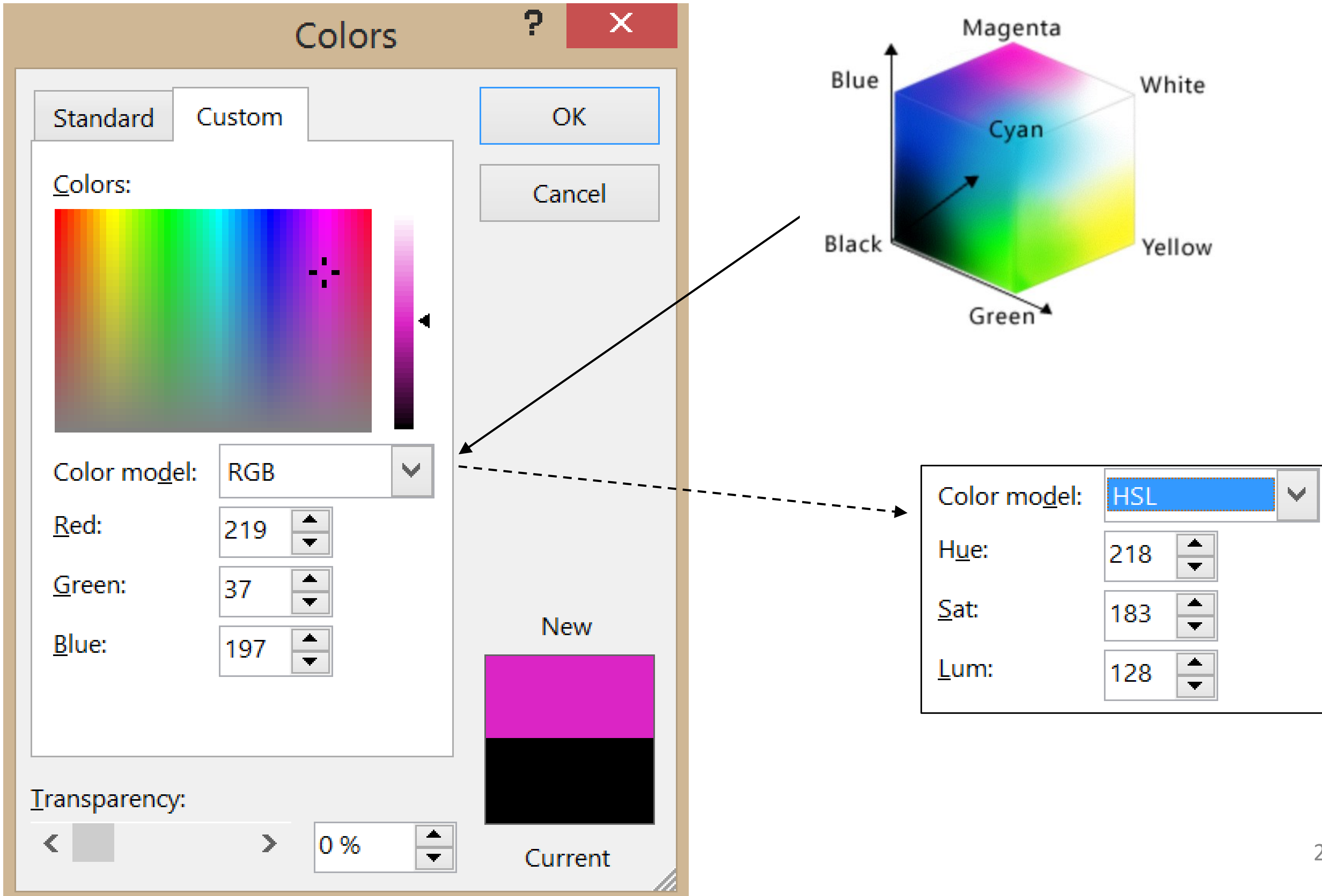
angle = “hue”
radius = “saturation”



(for HSV)

'color‘ name purity intensity

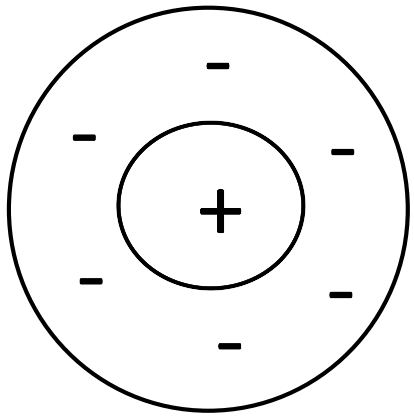
RGB and HSL (similar to HSV)



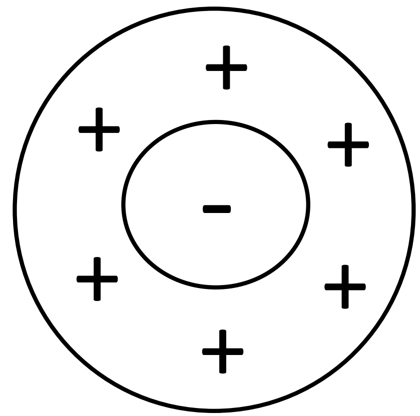
Retinal ganglion cells encode image *differences* :

- spectral (wavelength λ) , "chromatic"
- spatial (x,y)
- temporal (t)
- spectral-spatio-temporal (λ, x, y, t)

Spatial differences:
“center-surround receptive fields”



ON center,
OFF surround

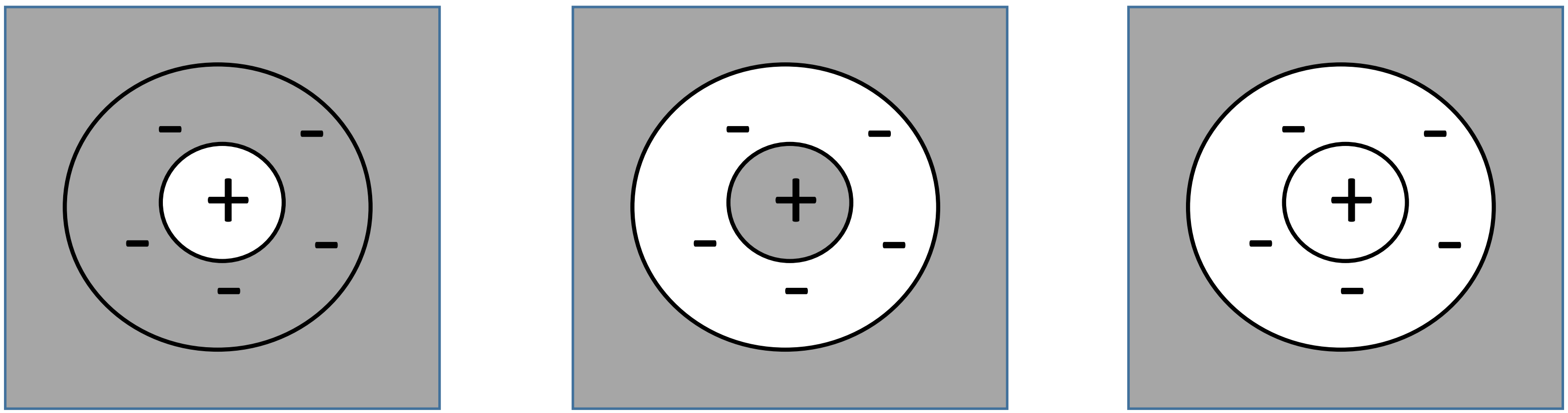


OFF center,
ON surround

+ and - indicate where the cell is excited or inhibited (*de*polarized or polarized) by bright image spot in its receptive field.

e.g. Retinal ganglion cells

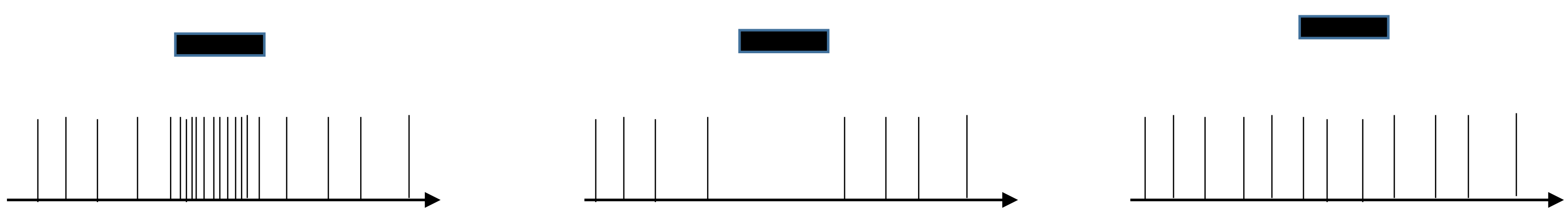
(first experiments on cats done in 1953)



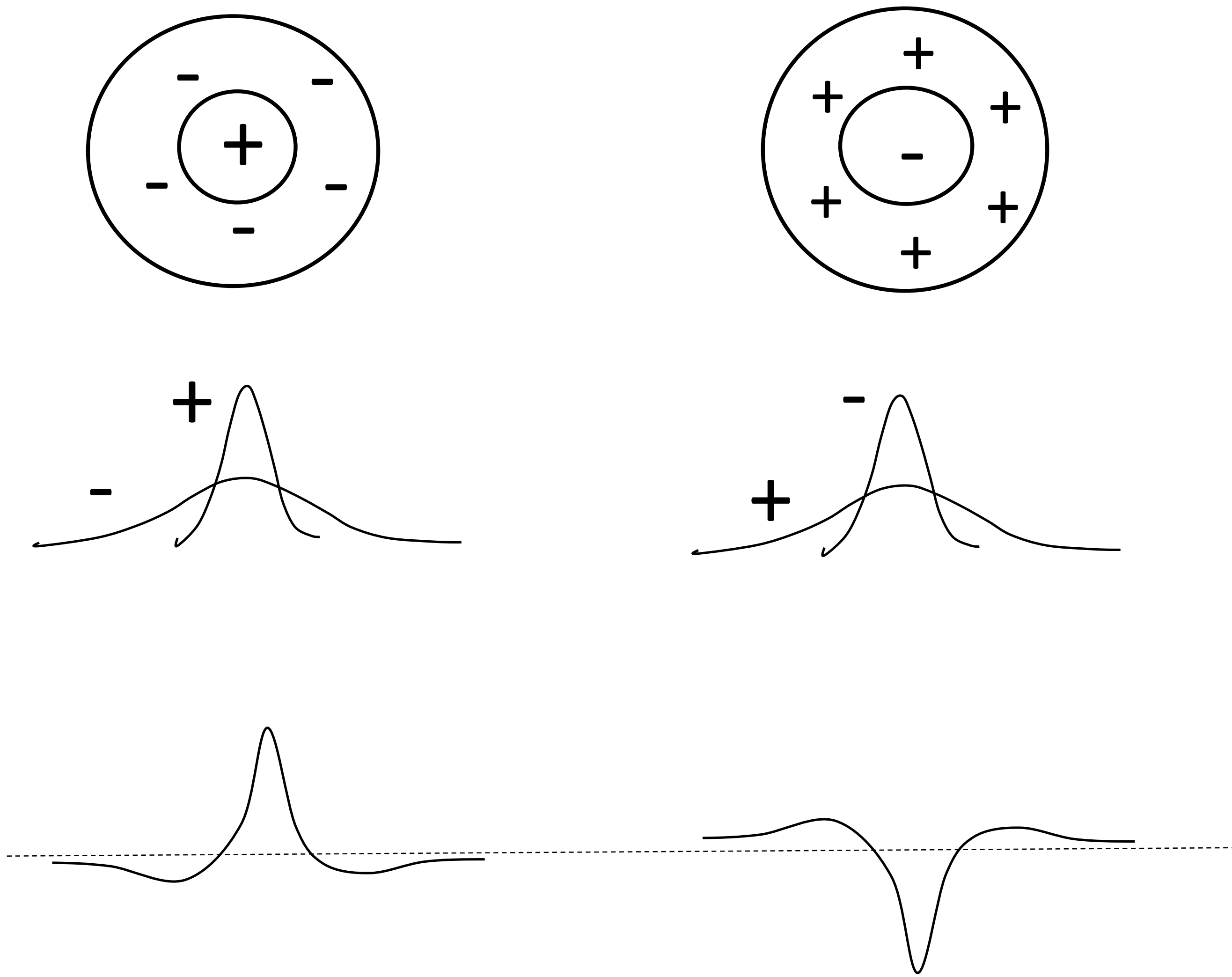
Shine light only in center. (ON center)

Shine light only in surround. (OFF surround)

Shine light in center and surround.



Proposed Mechanism (Rodieck, 1965)

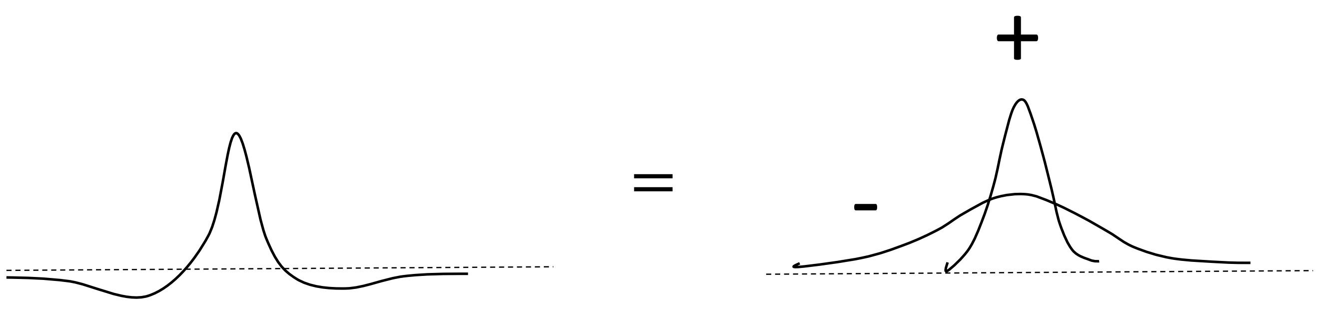


Gaussian model

$$\mathrm{G}(x) \quad = \quad \frac{1}{\sqrt{2\pi}\,\sigma}\; e^{-\frac{x^2}{2\sigma^2}}$$

Difference of Gaussians (DOG) model

$$DOG(x, \sigma_1, \sigma_2) = \frac{1}{\sqrt{2\pi}\sigma_1} e^{-\frac{x^2}{2\sigma_1{}^2}} - \frac{1}{\sqrt{2\pi}\sigma_2} e^{-\frac{x^2}{2\sigma_2{}^2}}$$



2D Gaussian and 2D DOG

$$G(x, y, \sigma) \equiv G(x, \sigma)\, G(y, \sigma)$$

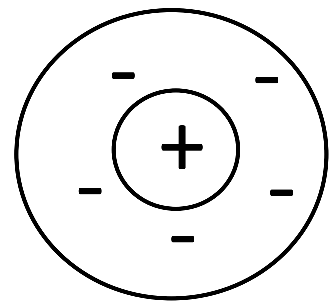
$$= \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} * \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{y^2}{2\sigma^2}}$$

$$= \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

$$DOG(x, y, \sigma_1, \sigma_2) = G(x, y, \sigma_1) - G(x, y, \sigma_2)$$

Response of a cell (DOG)

DOG cell centered at $(x_0\ , y_0\ )$



Response depends on:

$$L = \iint I(x,y)\ \ DOG(x\ - x_0\ , y\ - y_0\ , \sigma_1, \sigma_2)\ \ dx\ \ dy$$

Here I am ignoring temporal properties for simplicity.

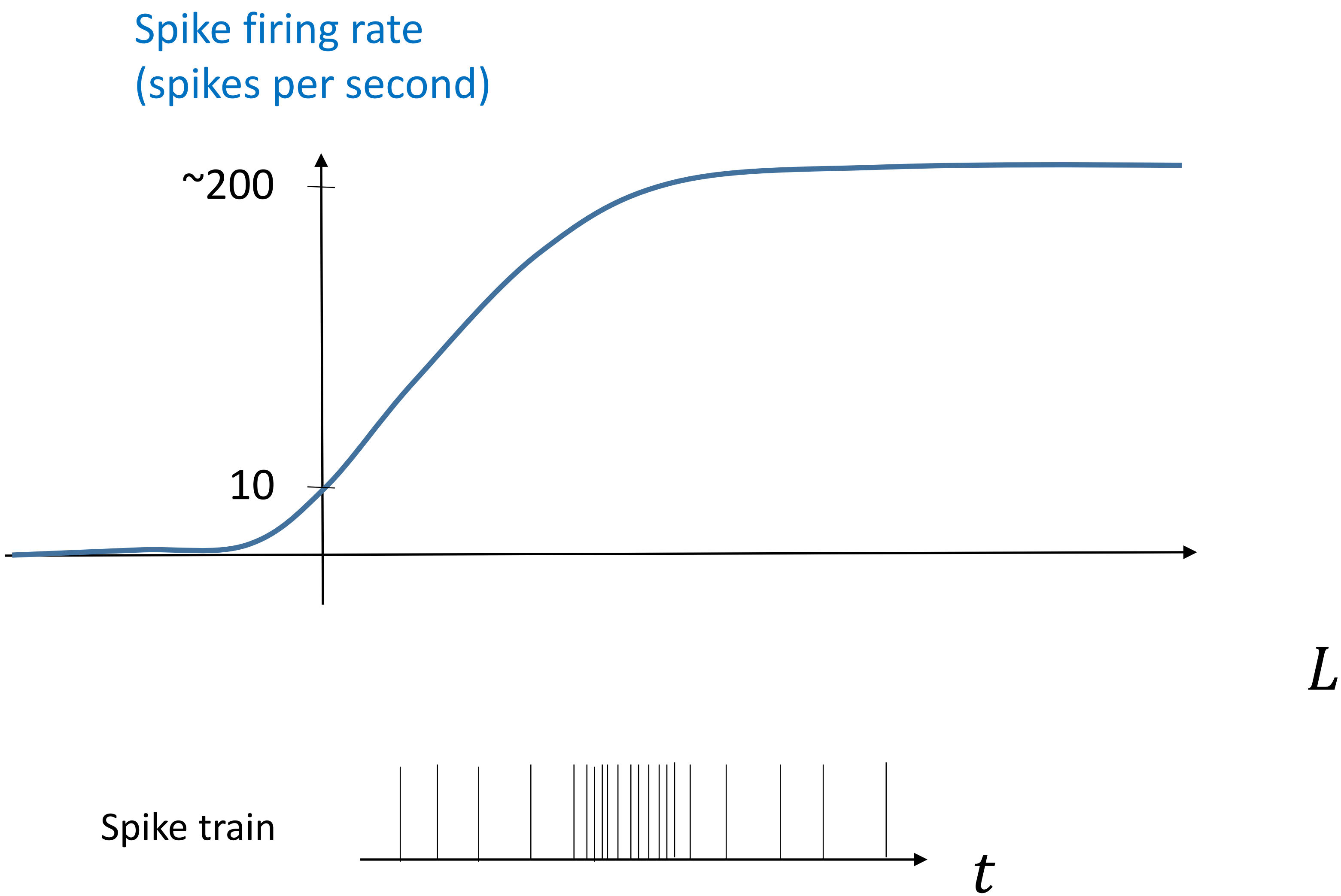
Linear response model

$$L = \iint DOG(x - x_0, y - y_0, \sigma_1, \sigma_2)\, I(x,y)\, dx\; dy$$

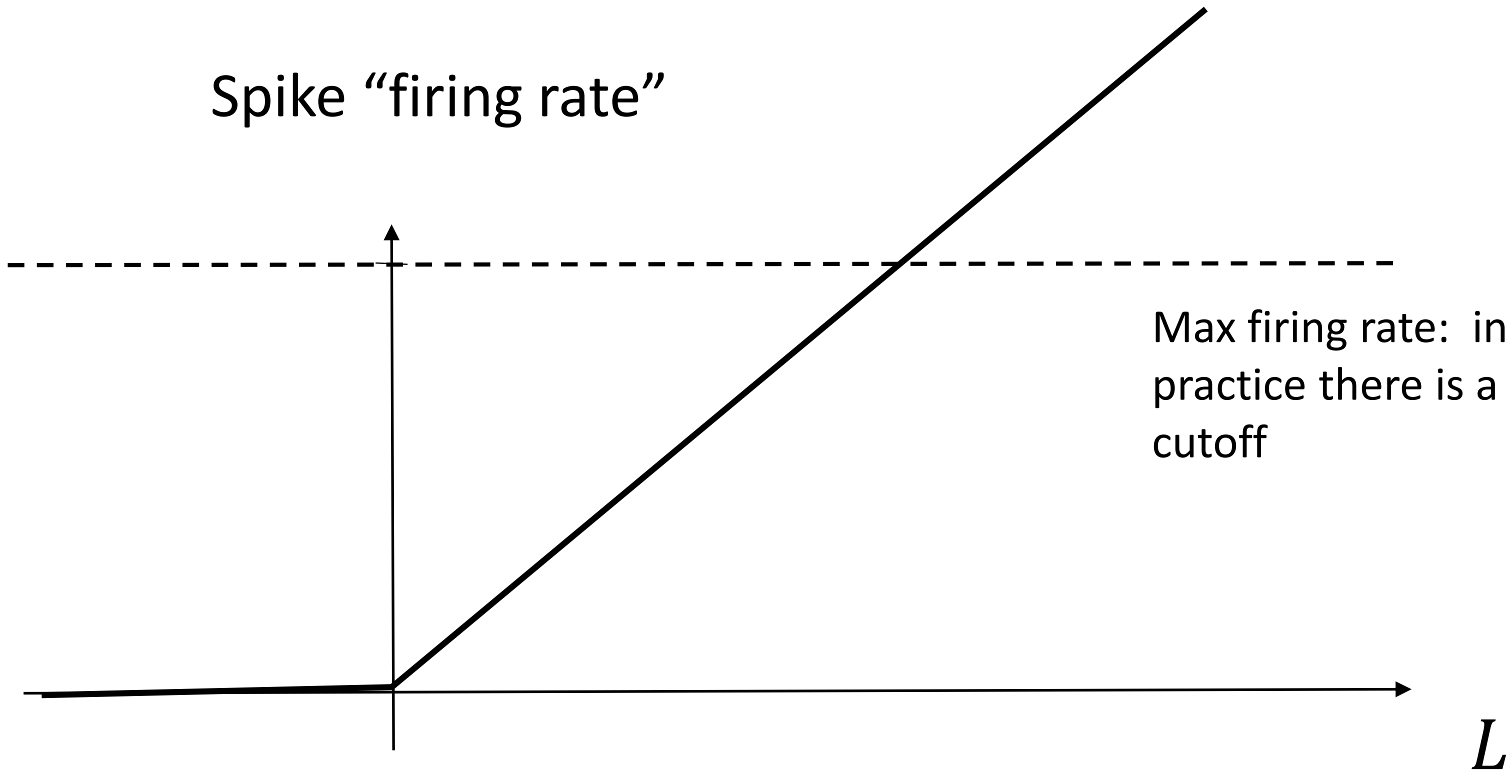
Alternatively we can write it as a sum:

$$L = \sum_{x,y} DOG(x - x_0, y - y_0, \sigma_1, \sigma_2)\, I(x,y)$$

“Static Non-linearity”

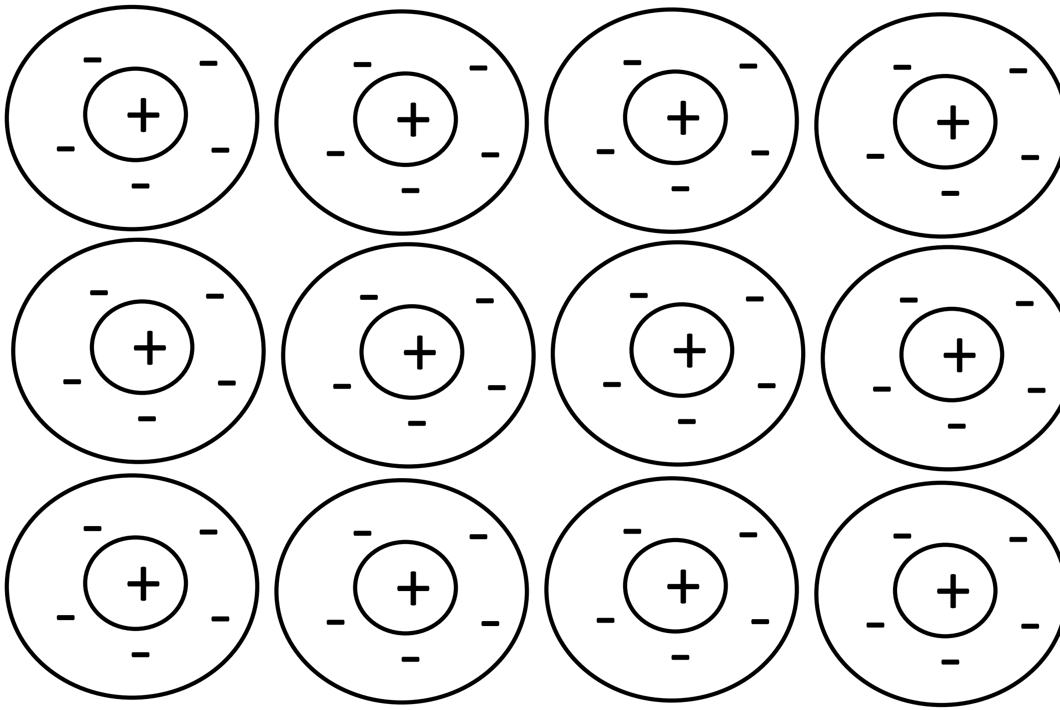


Half-wave rectification model



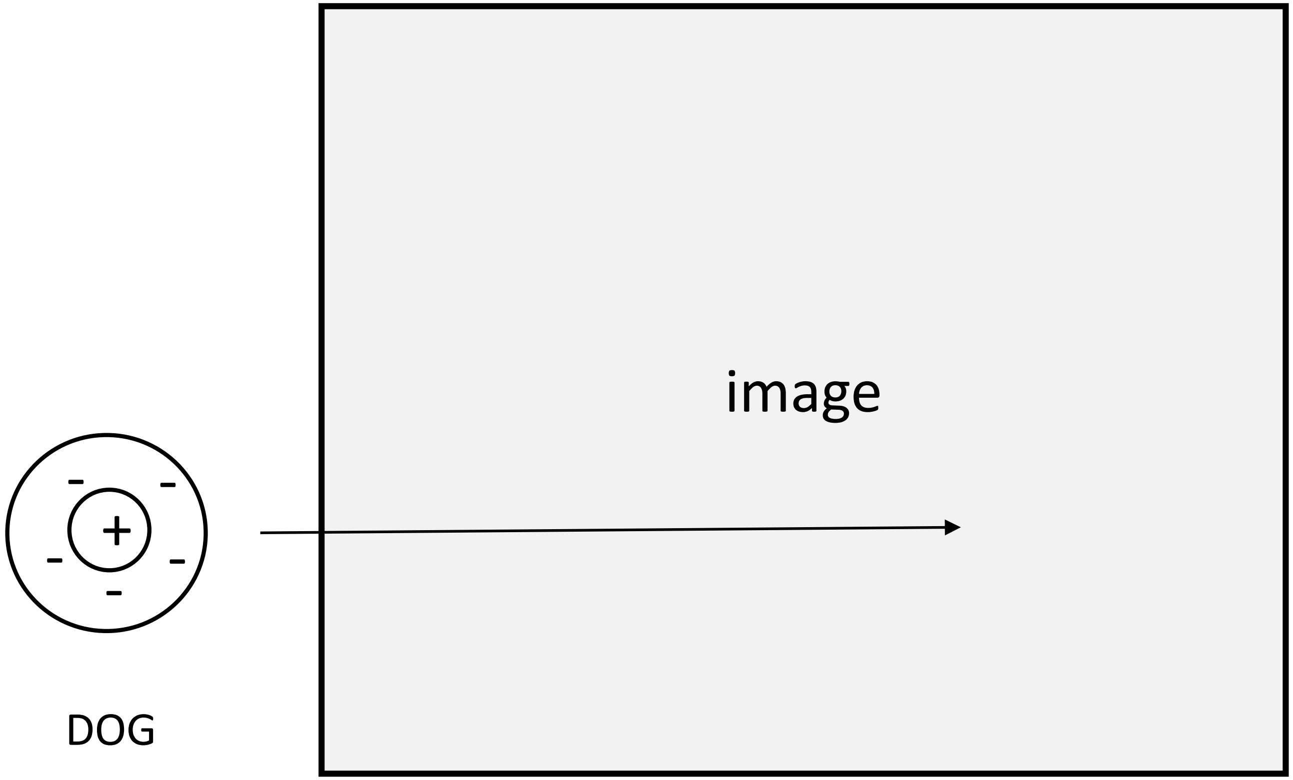
$$L = \max(\,0, \sum_{x,y} DOG(\,x - x_0\,, y - y_0\,, \sigma_1, \sigma_2\,)\;\; I(\,x, y)\,)$$

Responses of a *population* of DOGs



… and many *overlapping ones* which I am not showing because it would be too messy

“Cross correlation”



Responses of a *population* of DOGs

Cross correlation operator

$$L(x_0, y_0) \equiv DOG(x\,, y\,, \sigma_1, \sigma_2) \otimes I(x, y)$$

$$\equiv \sum_{x,y} DOG(\,x, y\,)\; I(x_0 + \, x, y_0 + y)$$

change of variables

$$\equiv \sum_{u,v} DOG(\,u - x_0, v - y_0)\; I(u, v)$$

Cross correlation

$$f(x,y) \otimes I(x,y) \equiv \sum_{u,v} f(u-x, v-y)\, I(u,v)$$

Convolution (to be discussed later)

$$f(x,y) * I(x,y) \equiv \sum_{u,v} f(x-u, y-v)\, I(u,v)$$

Technical detail (boundary effects)