Vision Part 2

Informatics 1 Cognitive Science

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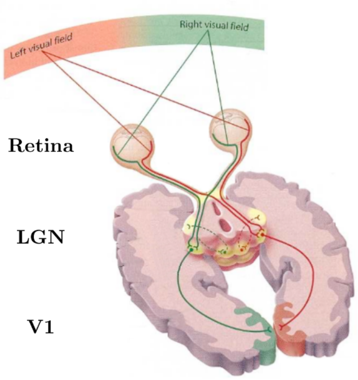
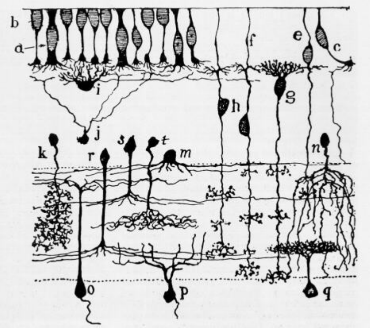
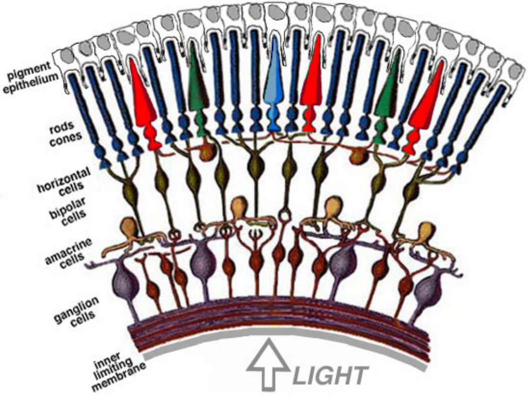
The Visual System



Light → Retina → Lateral Geniuclate Nucleus (LGN) → Primary Visual Cortex (V1)
Information also travels to other sub-cortical brain areas. Visual cortex activation is required for conscious perception.

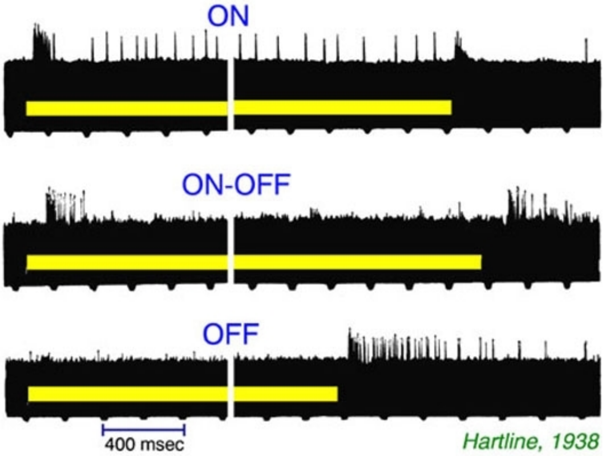
Retinal anatomy





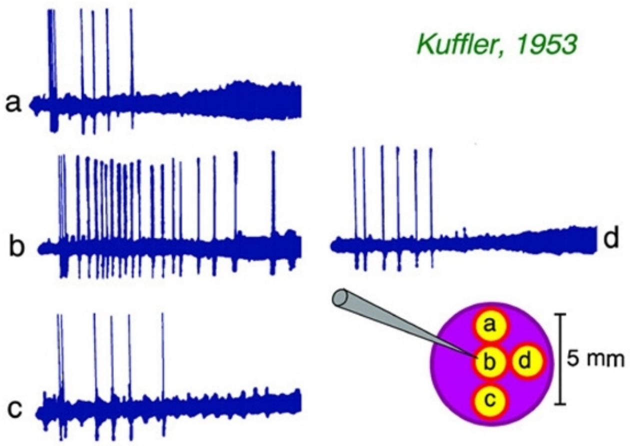
The retina a multi-layered structure. Photoreceptors (rods for dark vision and cones for colour vision) convert light into electrical potentials. The axons of *retinal ganglion cells* send this activity the rest of the brain.

Retinal Light Responses



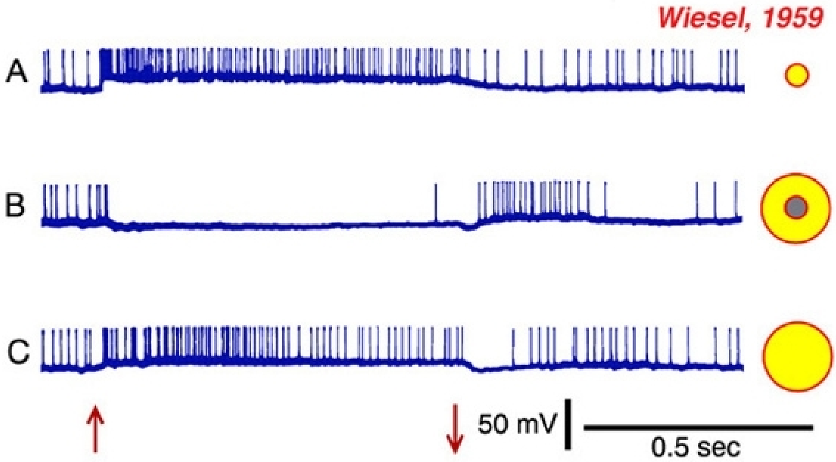
Retinal ganglion cells signal changes in an image. Shown are extracellular recordings from an On cell, an On-Off cell, and an Off cell in the cat retina.

Retinal Receptive Fields



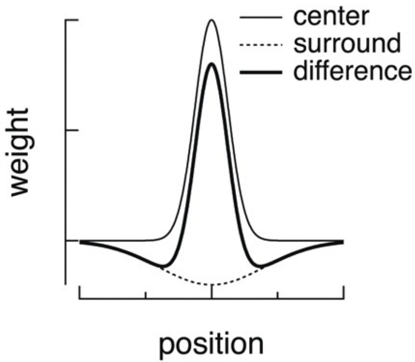
Each retinal ganglion cell integrates light from a small area in visual space, the *receptive field* (RF).

Retinal Receptive Fields



Retinal receptive fields have a *centre-surround* structure.

Difference of Gaussians (DoG) Receptive Field



Retinal receptive fields are well described by the difference of two Gaussians:

$$R(x,y) = W_c e^{-\frac{x^2+y^2}{2\sigma_c^2}} - W_s e^{-\frac{x^2+y^2}{2\sigma_s^2}}$$

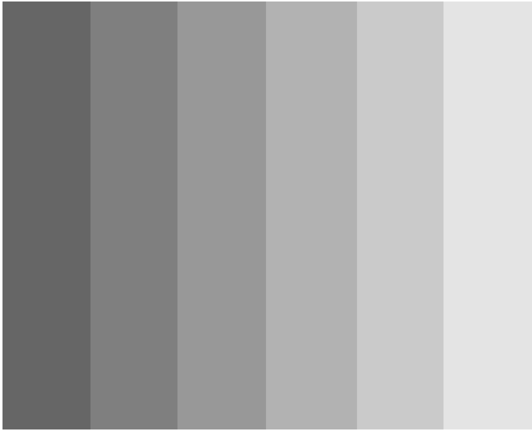
Spatial filtering of the DoG Receptive Field

A wide Gaussian RF emphasises coarse image structure (middle). A DoG reveals contrast changes in the image (right). Note that the "activity levels" on the right are much lower, this amounts to compression of the image.

Retinal RFs adapt to external conditions

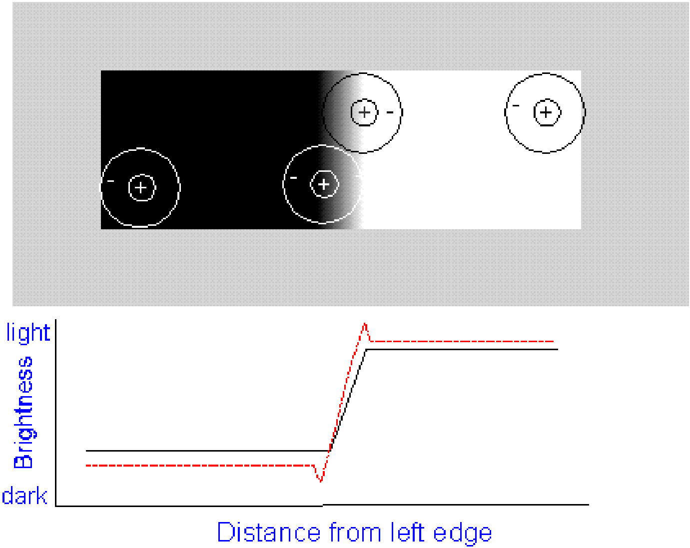
A) Original image. B) Edge enhanced version (DOG filtered). C) A, with noise added, to simulate low luminance condition (weaker SNR, photon noise). D) The same edge enhancement does not gain anything. E) In this case a using weaker surround works better (simulated receptive field changes under low-light conditions). (image credit Mark van Rossum)

The Mach Band illusion



Edges appear enhanced relative to the areas between them.

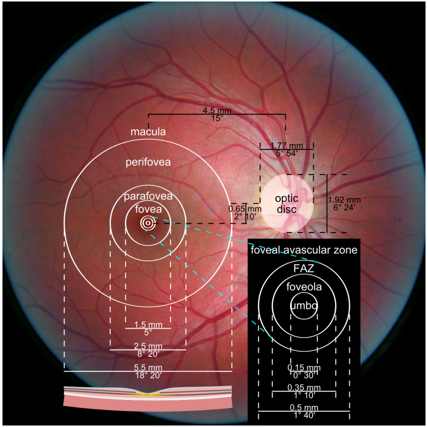
The Mach Band illusion results from retinal filters

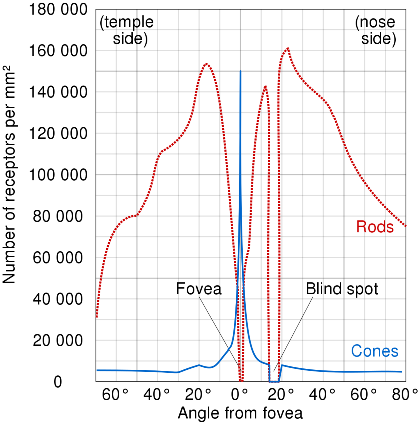


At the contrast changes, the DOG RF responds more strongly than in uniform areas,

Receptive Fields across Sensory Systems

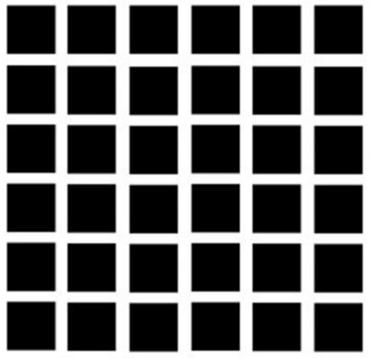
- Introduced by Sherrington (1906) to describe an area of the body surface where a stimulus could elicit a reflex
- The receptive field is a portion of sensory space that can elicit neuronal responses when stimulated.
- Examples: skin surface, frequency range or location of a sound, chemical properties of an odourant,
- Receptive fields have different sizes, such as small somatosensory RFs at the fingertips and large ones on the back.





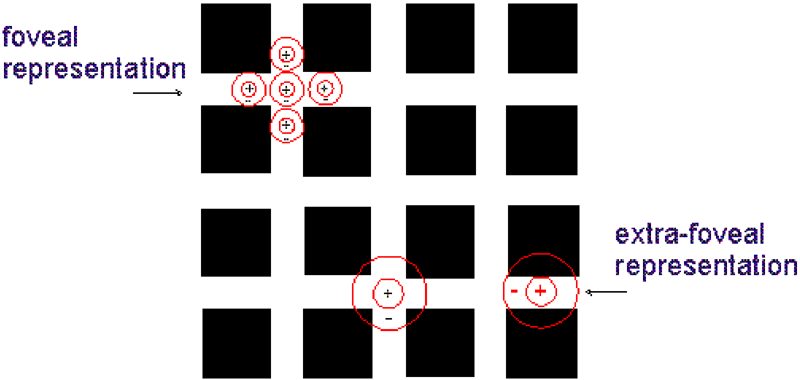
120 Million rods, 6 million cones. In the fovea, resolution is about 300 dpi.

The Hermann Grid illusion



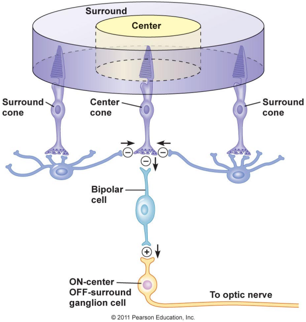
Dark blobs are visible at the intersections of the white lines, but only where you do not fixate.

The Hermann Grid illusion



Outside the fovea, large receptive fields cover lines and adjacent squares, and the response is modulated. In the fovea, RFs are very small, so this surround modulation does not happen.

Lateral inhibition



The surround is generated by lateral (=from the side) inhibition. This connectivity is common in sensory systems to enhance differences along one or multiple stimulus dimensions.

Summary

- The retina not only transforms stimuli into electrical activity, but also processes these inputs.
- The area of sensory space a neurons is responsive to is called the *receptive field*.
- Retina receptive fields are compressing the images before they are sent on to the cortex.
- Circuits in the retina use *lateral inhibition* to emphasise differences in spatial contrast in images (the same operation is also used to emphasise changes in time).