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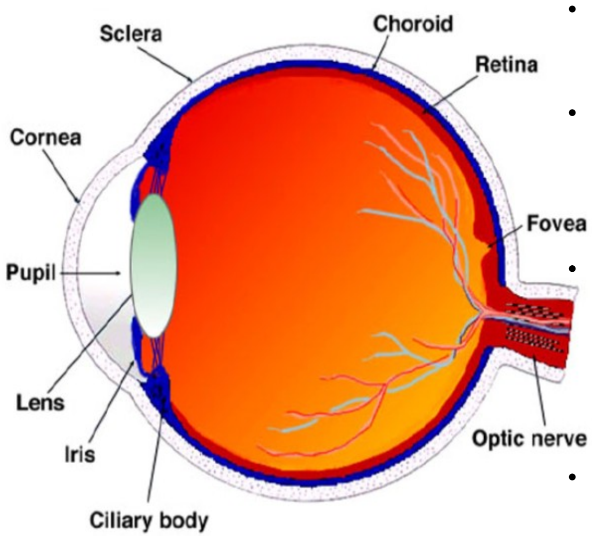
The Eye



- Cornea performs the initial bulk of the refraction (at fixed focus)
- Lens performs further refraction and can be stretched to change its shape and hence change focal length
- Iris allows the eye to regulate the amount of light that can enter in order to both protect from over stimulation, and improve focus (as with the pinhole camera).
- Optic nerve: 1 million nerve fibers transmit information sensed by eye to the brain.

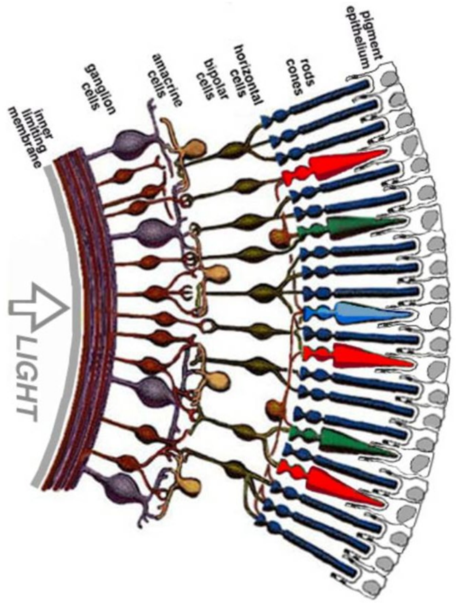
The Retina

The retina contains light sensitive **photoreceptors** (approx 130 million).

These photoreceptors are farthest from the light. But intervening cells are transparent

Photoreceptors **transduce** light to electrical signals (voltage changes).

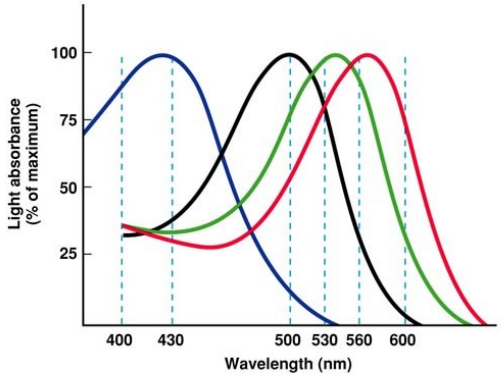
Transduction = the transformation of one form of energy to another.



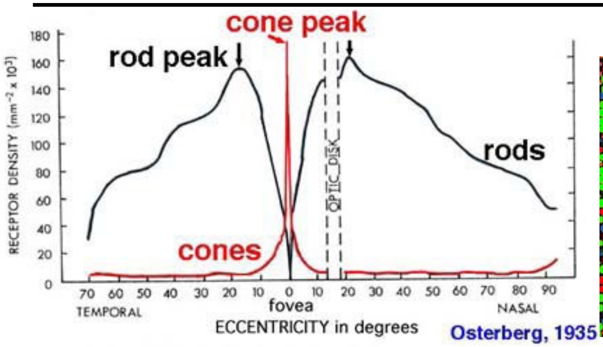
Photoreceptor types

Human eyes have 2 classes of photoreceptor:
- **Rods**:
  - high sensitivity (can operate in dim light)
- **Cones**:
  - low sensitivity (require bright light)
  - 3 sub-types that are sensitive to different wavelengths

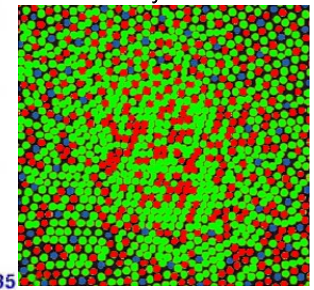
Hence cones provide colour information:
- blue: short-wavelength cones
  - peak sensitivity ~420nm
- green: medium-wavelength cones
  - peak sensitivity ~540nm
- red: long-wavelength cones
  - peak sensitivity ~570nm



Distribution of photoreceptors



cone density near fovea

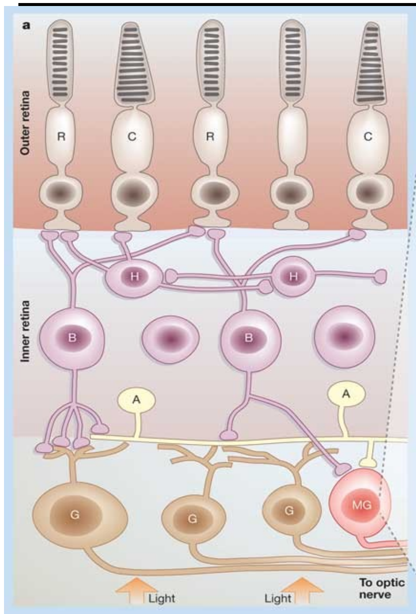


Photoreceptor types are not evenly distributed across the retina.

- **blind spot**: no photoreceptors (location where optic nerve leaves eye)
- **fovea**: no rods, high density of cones #(blue) << #(red) <= #(green)
- **periphery**: high concentration of rods, few cones

more rods overall

Retinal processing



Ganglion cells produce the output of the retina (the axons of all ganglion cells combine to form the optic nerve).

Each eye has approx. 1 million ganglion cells and 100million photoreceptors.

One ganglion cell collects input from multiple photoreceptors:

- Large convergence in periphery
- Smaller convergence in fovea

Another reason for the lower acuity in periphery compared to fovea

Foveal vs peripheral vision

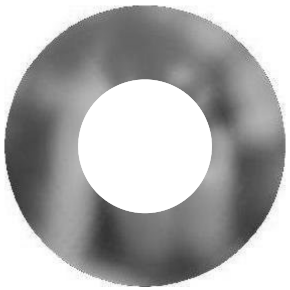
The fovea is small region of high resolution containing mostly cones

Fovea:

- high resolution (acuity) – due to high density of photoreceptors
- colour – due to photoreceptors being cones
- low sensitivity – due to response characteristics of cones

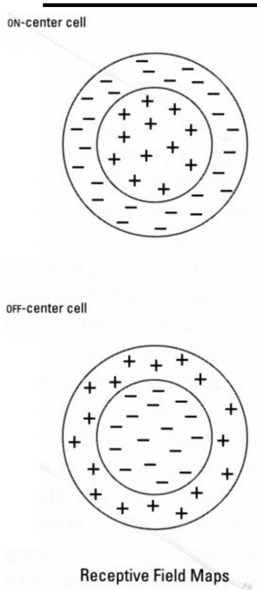
Periphery:

- low resolution (acuity) – due to low density of photoreceptors
- monochrome – due to photoreceptors being rods
- high sensitivity – due to response characteristics of rods



Far more of the brain is devoted to processing information from the fovea than from the periphery.

Ganglion cell responses



Ganglion cells have centre-surround **receptive fields**.

Receptive Field (RF) = area of visual space (i.e. area of retina) from which a neuron receives input. Or more generally, the properties of a visual stimulus that produces a response from a neuron.

Two types of ganglion cell:

On-centre, off-surround:

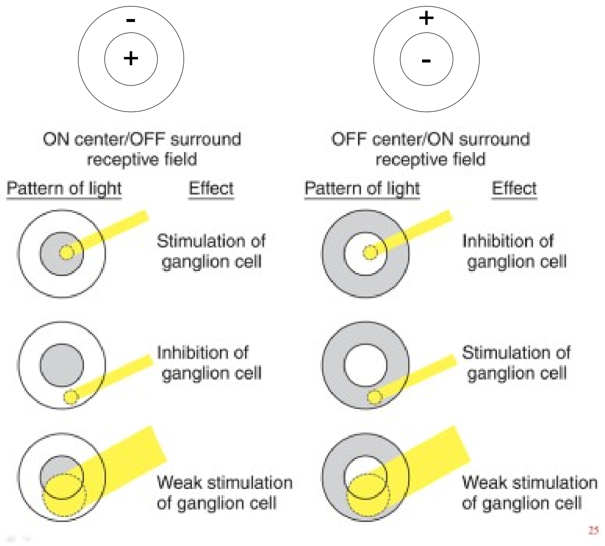
- active if central stimulus is brighter than background

Off-centre, on-surround:

- active if central stimulus is darker than background

Behaviour is generated by ganglion cell being excited (or inhibited) by photoreceptors in the centre of its receptive field and being inhibited (or excited) by photoreceptors surrounding its receptive field.

Centre-surround RF function



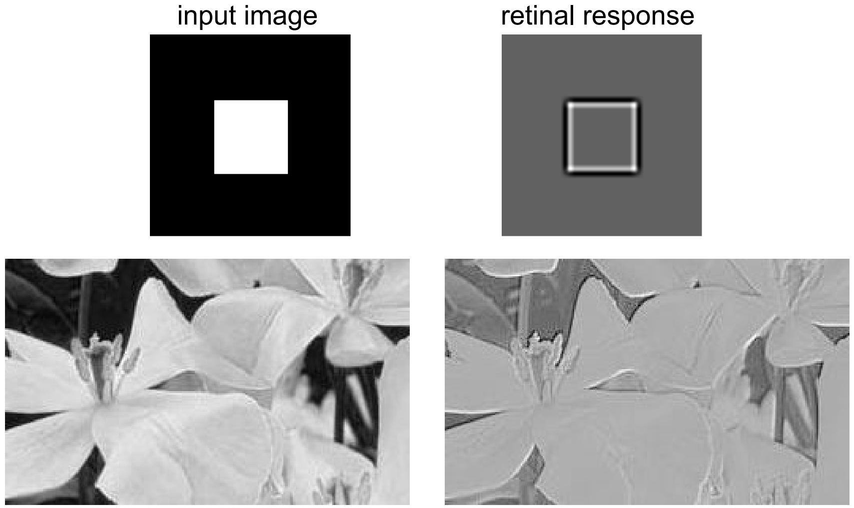
Functional consequences:

→ accentuates edges

→ invariance to ambient light

→ efficient coding

Centre-surround RF: edge enhancement

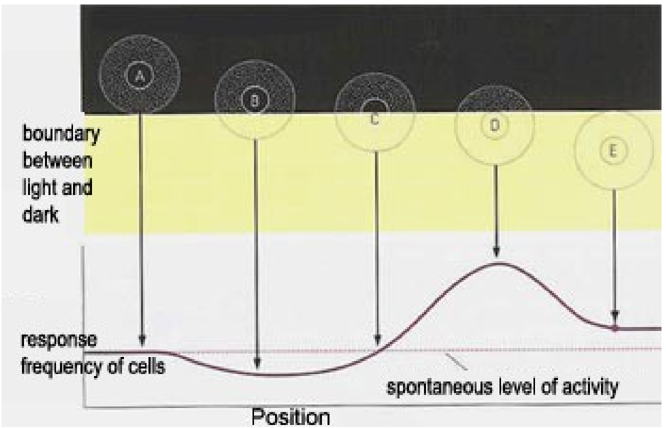


centre-surround cells respond weakly where input is uniform, and strongly where input changes. Hence, strong response near edges.

Centre-surround RF: edge enhancement

A and E: on plane surface input to centre and surround cancels (output at resting – spontaneous - state, greater than zero)

B and D: at contrast discontinuity input to centre and surround unequal (output increased or decreased)

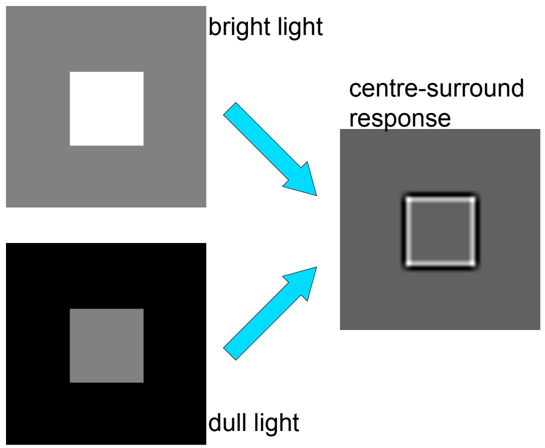


Centre-surround RF: invariance to lighting

Ambient lighting conditions, i.e. the **Illuminance** (E), are generally irrelevant for most perceptual tasks.
e.g. an object should look the same in bright light and dull light.

Centre-surround RFs measure the change in intensity (contrast) between adjacent locations.

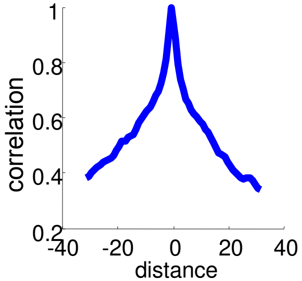
This contrast remains constant independent of lighting conditions.



Centre-surround RF: efficient coding

Cells with RFs that fall on plane surfaces are only weakly active
Cells with RFs that fall on areas where contrast is changing are strongly active

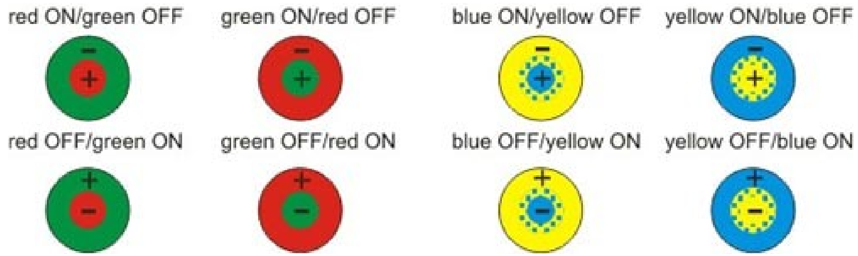
Natural images have strong spatial correlation (i.e. little intensity change over short distances)



By only signalling where intensity changes, centre-surround RFs:

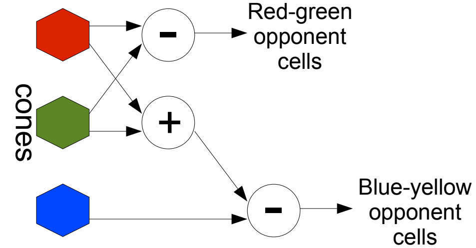
- minimises neural activity (efficient in terms of energy consumption)
- minimises bandwidth (efficient in terms of information coding) often referred to as "redundancy reduction" or "decorrelation" or "predictive coding"

Centre-surround RFs: colour opponent cells



A number of different colour combinations occur in the human retina giving rise to an number of different types of colour-opponent cell.

"yellow" is produced by averaging the outputs of red and green cones.

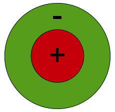


Centre-surround RFs: colour opponent cells

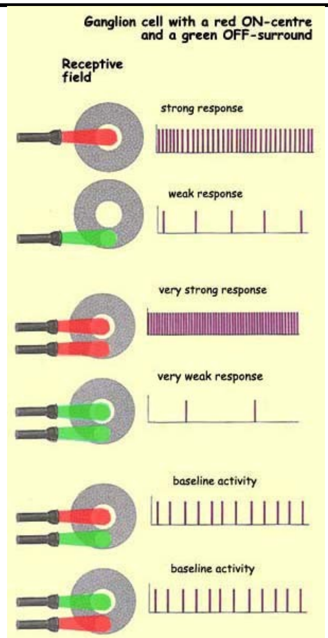
Ganglion cells combine inputs from both rods and cones in a centre-surround configuration.

Input from cones produces colour opponent cells.

e.g. a red on-centre, green off-surround (or red ON/green OFF)



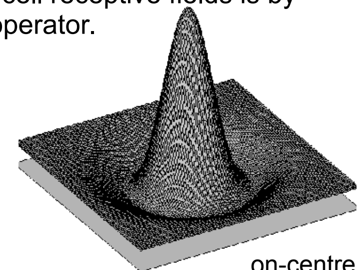
responds most strongly to red light falling within its RFs

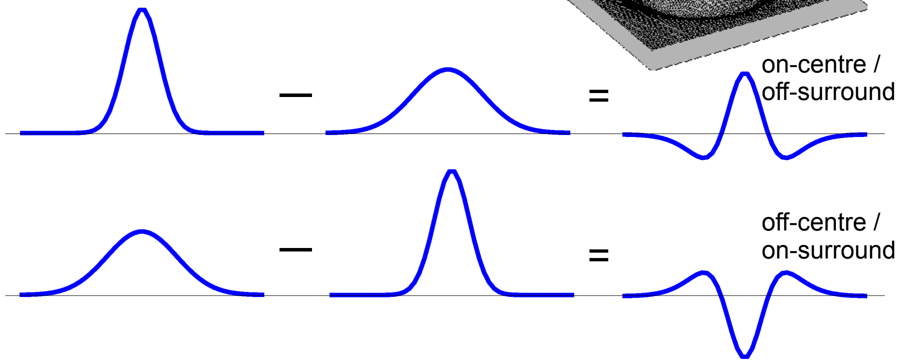


Modelling centre-surround RFs

The standard way of modelling ganglion cell receptive fields is by using a Difference of Gaussians (DoG) operator.

The DoG operator, is also used in computer vision (see later lecture).





Summary

Image formation is described by the pinhole (perspective) camera model

A point in 3D world projects to a point in 2D image dependent on extrinsic camera parameters, projection operator, intrinsic camera parameters

A lens is required to collect sufficient light to make an image that is both in focus and bright

Light reflected from an object is transduced into a electronic signal by a sensor (CCD array, retinal rods and cones)

The image is sampled at discrete locations (pixels), sampling is uniform in a camera, non-uniform in the retina (periphery vs fovea)

Following image formation the image needs to be analysed:

- in biological vision system 1^{st} stage of analysis is performed by centre-surround cells
- in artificial vision systems .... (next week)