University of BRISTOL

# Vision

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# Learning Objectives

To appreciate the anatomy of the mammalian visual system

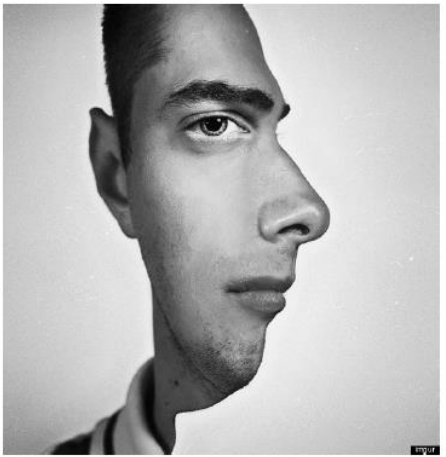
To understand the receptive field properties along the visual hierarchy

To be able to describe the retinal microcircuit

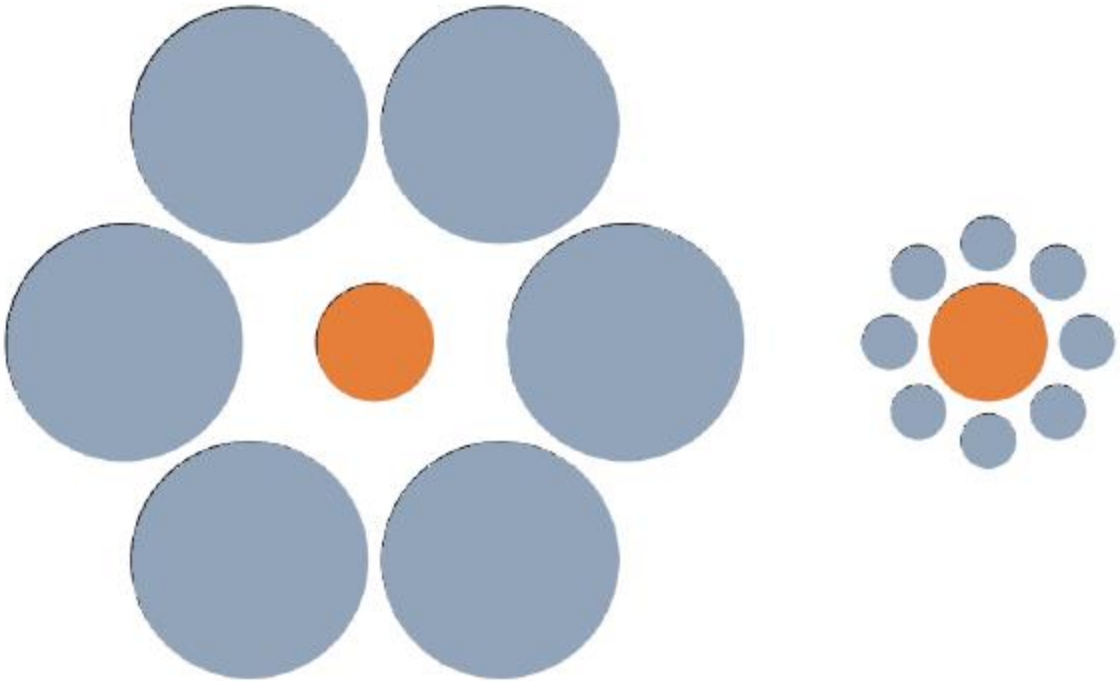
# Visual illusions

Statue in the Bankfield museum

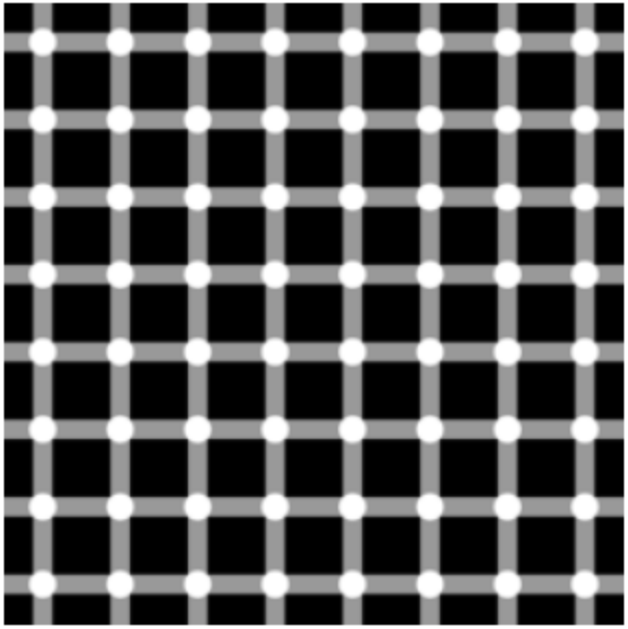
face profile illusion



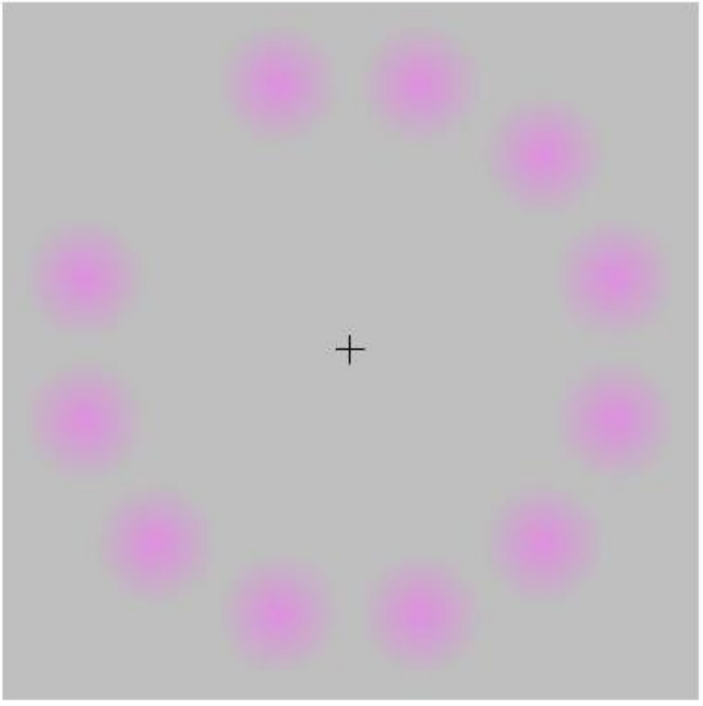
# Ebbinghaus illusion



# Hermann grid illusion



# Lilac chaser



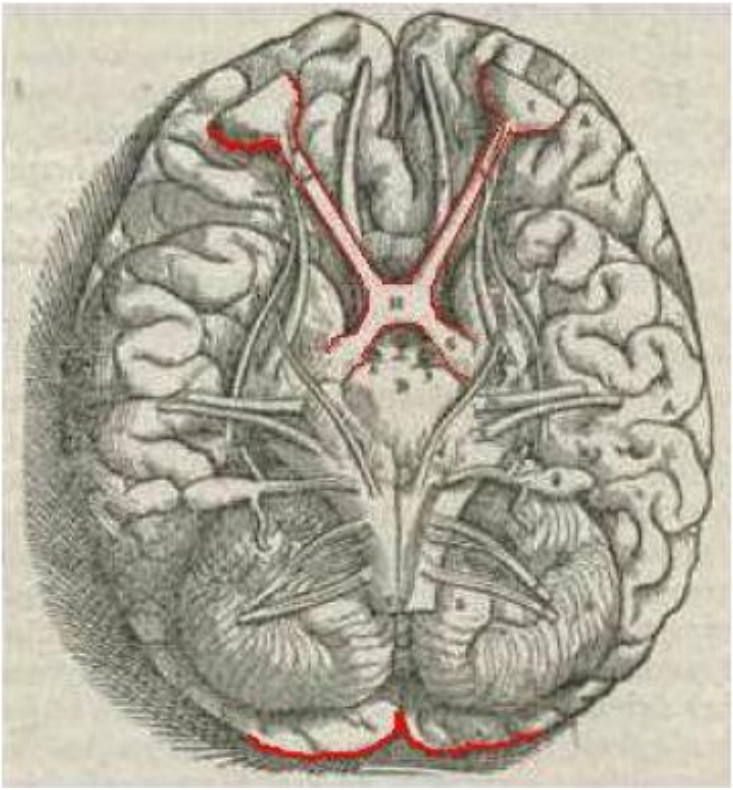
# Learning Objectives

In this diagram to the right, the red marks the retina, the optic nerves, the thalamus where the optic nerves cross and the visual cortex (V1).

One notable aspect is that **different sides of the brain** deal with **different sides of the visual field**

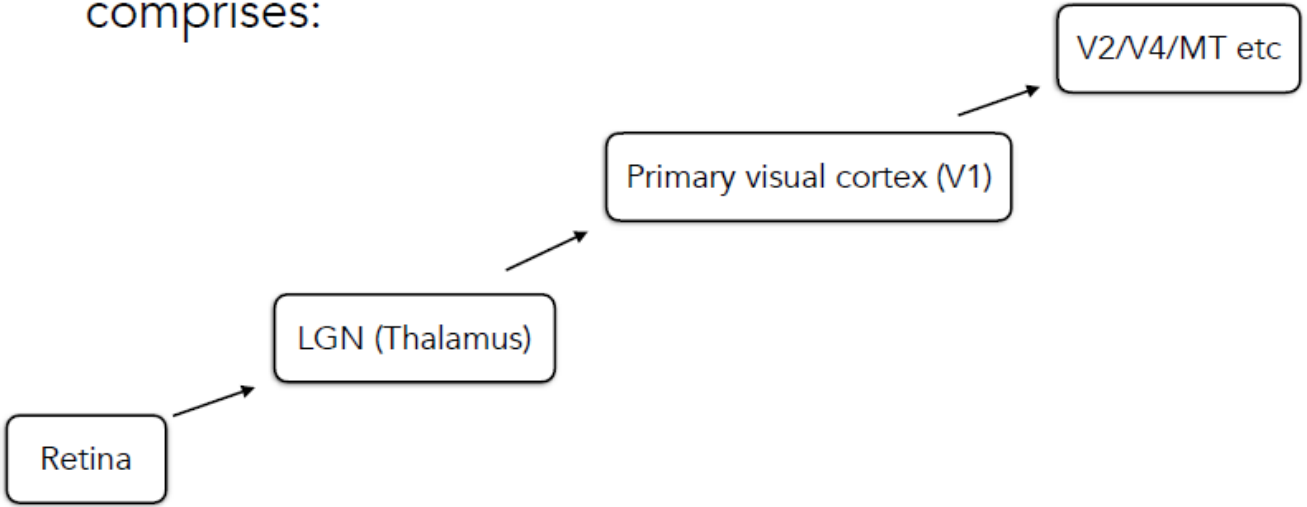
Signals from the left sides of the retina of both eyes go to the right side of the brain

- signals from the right sides so to the left side.



# Visual System

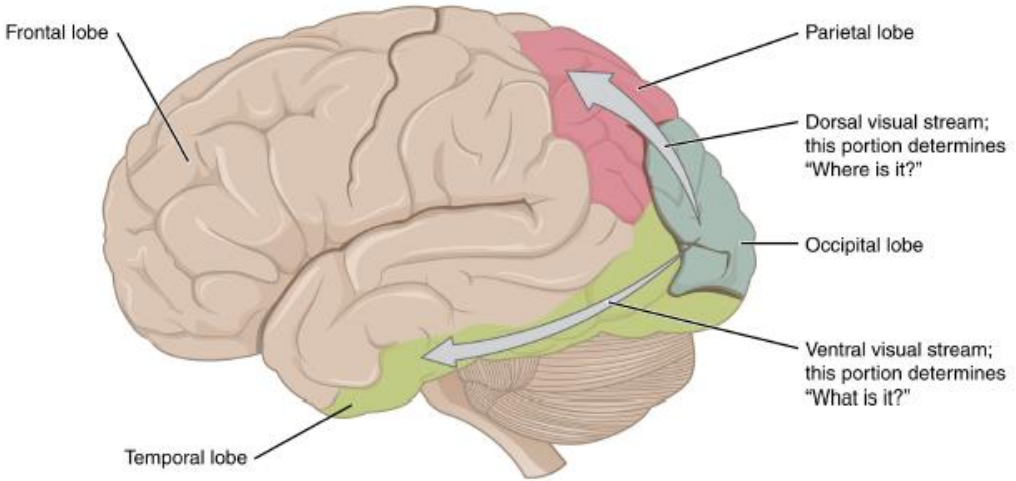
- As a first approximation, the visual system comprises:




- However, reality is much more complicated (tens of visual regions, heterogeneity within regions, feedback connections down the hierarchy)

# ‘What’ versus ‘where’ pathways

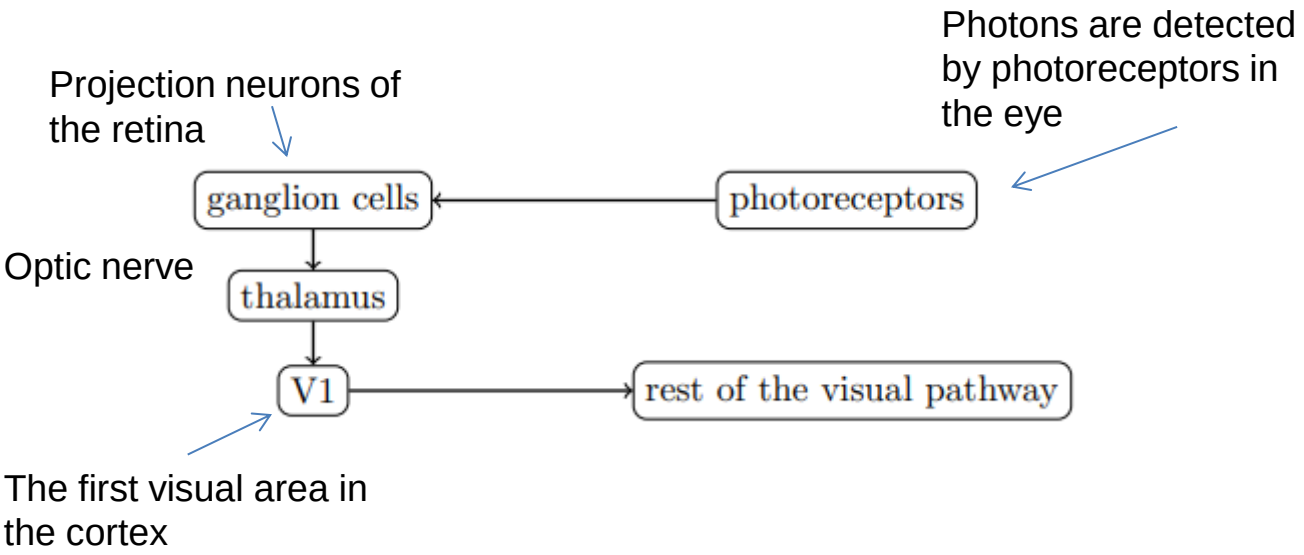
- The “two-streams” hypothesis suggests that the human brain splits visual information into two anatomically separate pathways.
- The “what” or ventral stream codes for object identity.
- The “where” or dorsal stream codes variables useful for action guidance.



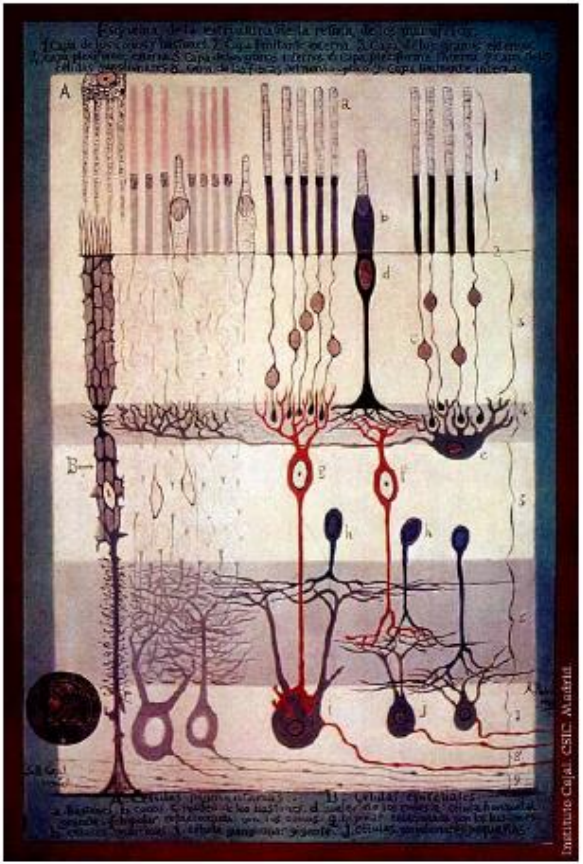

https://commons.wikimedia.org/wiki/File:1424_Visual_Streams.jpg

# The Visual Pathway

Here is a very rough diagram of the visual pathway:



# The Retina

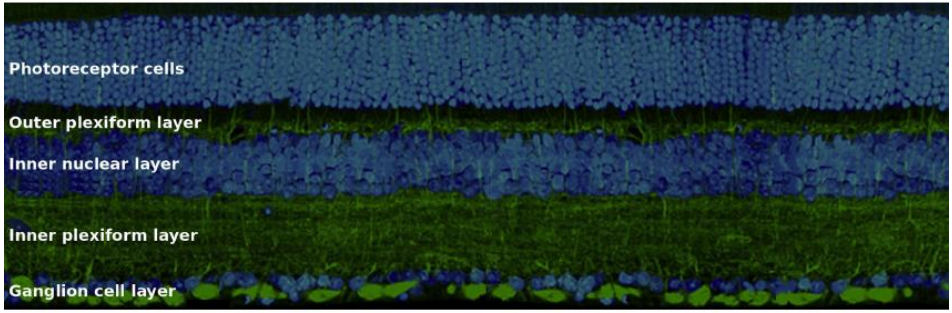


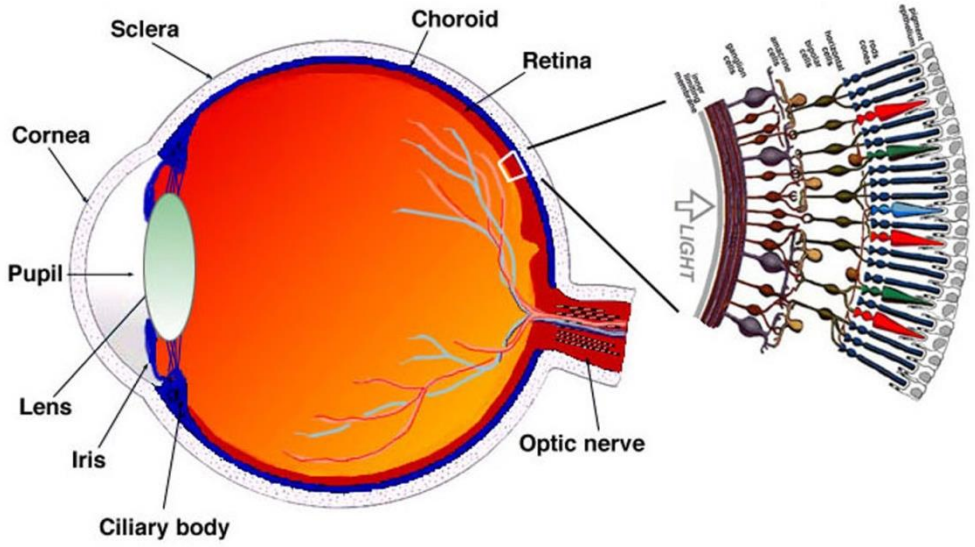

A drawing of the retina by Ramon y Cajal

Light is detected at the retina

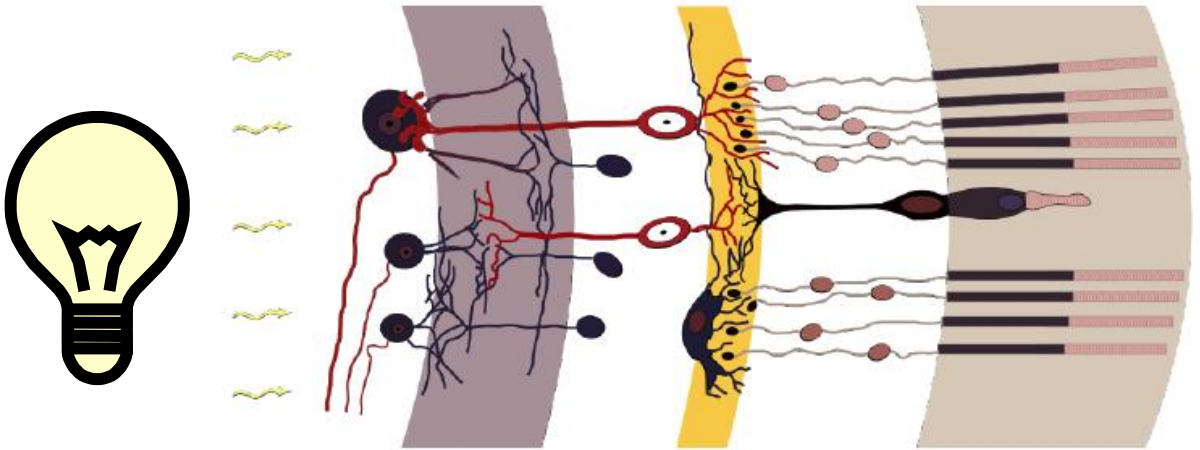
Light enters your eye (from the bottom of this drawing) and passes through several transparent nerve layers to reach the back of the retina where the rods and cones are located (at the top of this drawing)

# The Retina


Photoreceptor cells
Outer plexiform layer
Inner nuclear layer
Inner plexiform layer
Ganglion cell layer


Sclera
Choroid
Retina
Cornea
Pupil
Lens
Iris
Ciliary body
Optic nerve
LIGHT

# The Retina



A chemical change in the rods and cones send a signal back, first to the bipolar and horizontal cells (middle yellow layer), then to the amacrine cells and ganglion cells (left-most purple layer), then to the optic nerve fibres.

# The Retina

Light is detected at the retina

The retina is a surprising organ because it is backwards compared to how you'd expect it to be organized

- retinal layer with **light detectors is at the back instead of front**

In the retina, light is detected in specialized cells called photoreceptors

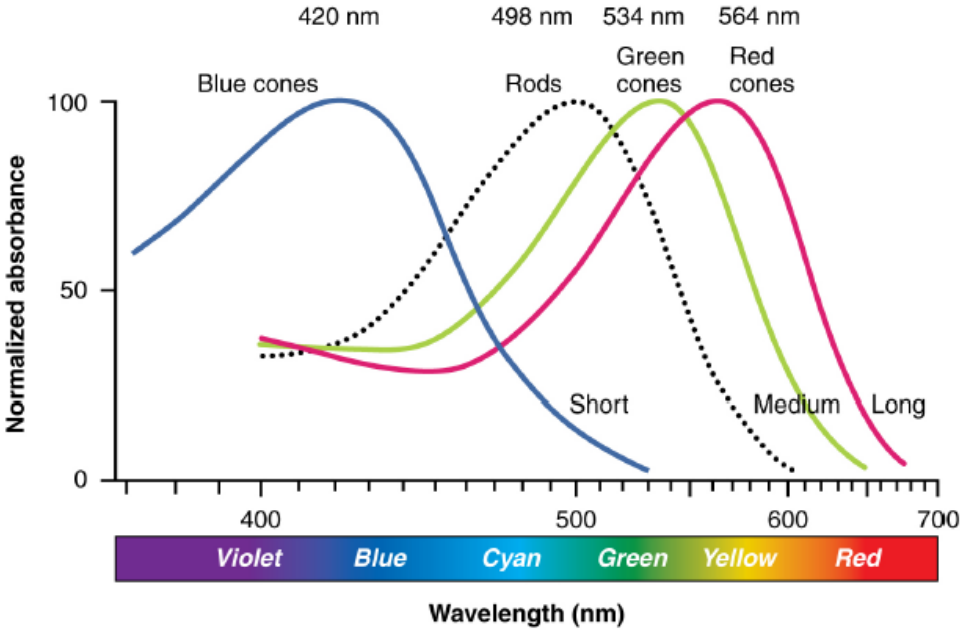
- these don't spike, but they do convert light into electrical activity.

There are two types of photoreceptors, the **rods, which are important for vision in low light**, and the **cones, which are responsible for colour vision** and important for vision in normal lighting conditions

The electrical activity of the photoreceptors is passed forward through bipolar cells to ganglion cells. Visual signals are processed in bipolar and ganglion layers of the retina

Ganglion cells aggregate activity from photoreptors, and other cells, and their axons form the optic nerve, carrying information to the thalamus

# Colour sensitivity in the retina




https://en.wikipedia.org/wiki/Photoreceptor_cell#/media/File:1416_Color_Sensitivity.jpg

[Bowmaker and Dartnall, *J Physiol* (1990)]

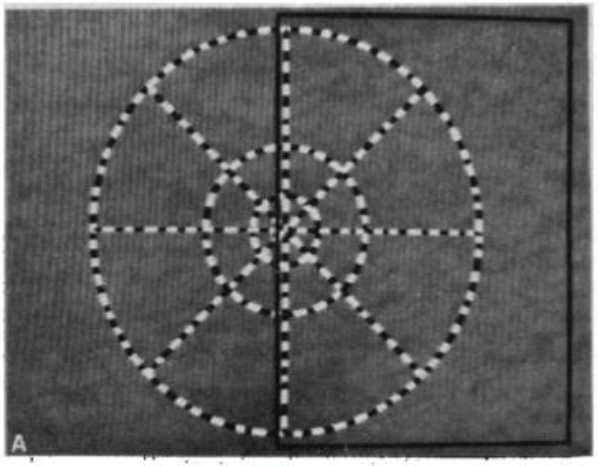
Cone cells are necessary for colour vision.

There are three types of cone cells, each with responses tuned to different wavelengths of light, corresponding to red, green and blue

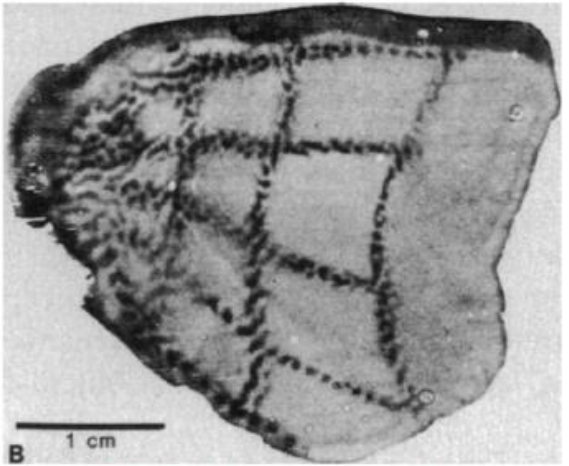
Perceived colour is based on the relative level of excitation of the different cones.

# Retinal Topography

- Anatomically neighbouring neurons tend to respond to neighbouring parts of the visual field.
- This retinotopy is preserved along the visual hierarchy.




Stimulus




Visual cortex response pattern

[Tootell et al., *Science* (1982)]

# The visual hierarchy

Visual information is processed in stages in the cortex with the information being passed forward

As objects are recognized the information fans out and is integrated with other signals

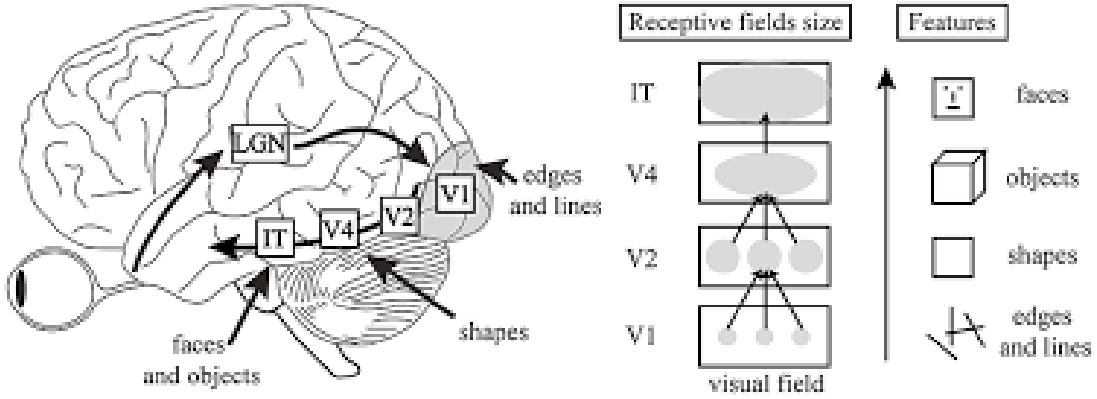
- from memory, from other sensory modalities and other aspects of our cognition

# The visual hierarchy

There are 6 layers of the visual cortex.

First, the visual signals start as raw outputs of points in the rod and cone cells

Then the nerve layers identify simple shapes, such as bright points surrounded by dark points, edges, and movement



# Coding along the visual hierarchy

Receptive fields tend to change from level to level up the visual processing hierarchy.
They:

- Become larger.
- Become sensitive to complicated aspects of the visual stimulus.
- Become more multimodal (i.e. also depend on non-visual sensory signals).
- Become more sensitive to top-down, contextual information (e.g. task context, animal's behavioural state, attention)

# Receptive Fields

**Receptive fields**

- the subset of the stimulus space that gives the largest neuronal response

We saw that in V1 there are cells that have edge-like receptive fields

different cells respond to particular orientations in particular locations in the visual field

The edge-like receptive fields in V1 were first discovered by Hubel and Wiesel

-They used an electrode to record from V1 neurons in the cat and moved an edge-like stimulus around until they found the position that caused the highest ring rate, they observed that the ring rate depended on orientation as well as position

# Ganglion cell receptive fields

Ganglion cells in the retina are responsive to contrast patches

Different cells will respond to different locations within the visual field

The width of the receptive fields vary between cells

- ganglion cells processing information from the centre of the visual field have a receptive field about the same size as a full stop at reading distance
- those processing information from the periphery of the visual field have a receptive field that is about the size of a page

# Coding along the visual hierarchy

**Retinal ganglion cells / LGN: ON and OFF centre cells**

In on-cells an illuminated region surrounded by an unilluminated one causes firing

In off-cells, an unilluminated region surrounded by an illuminated region causes firing.

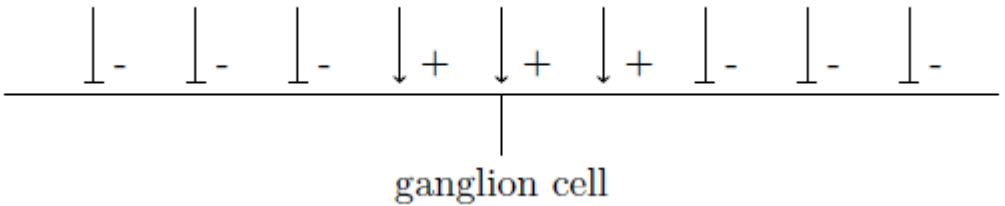
ON cell =   = OFF cell

On and off centre cells respond to small contrast patches

# Coding along the visual hierarchy

**Retinal ganglion cells / LGN: ON and OFF centre cells**

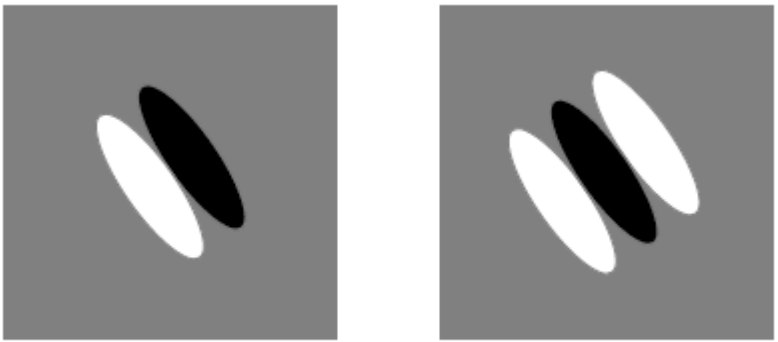
These on and off centre firing patterns are generated during development by excitatory and inhibitory synapses that feed forward onto retinal ganglion cells



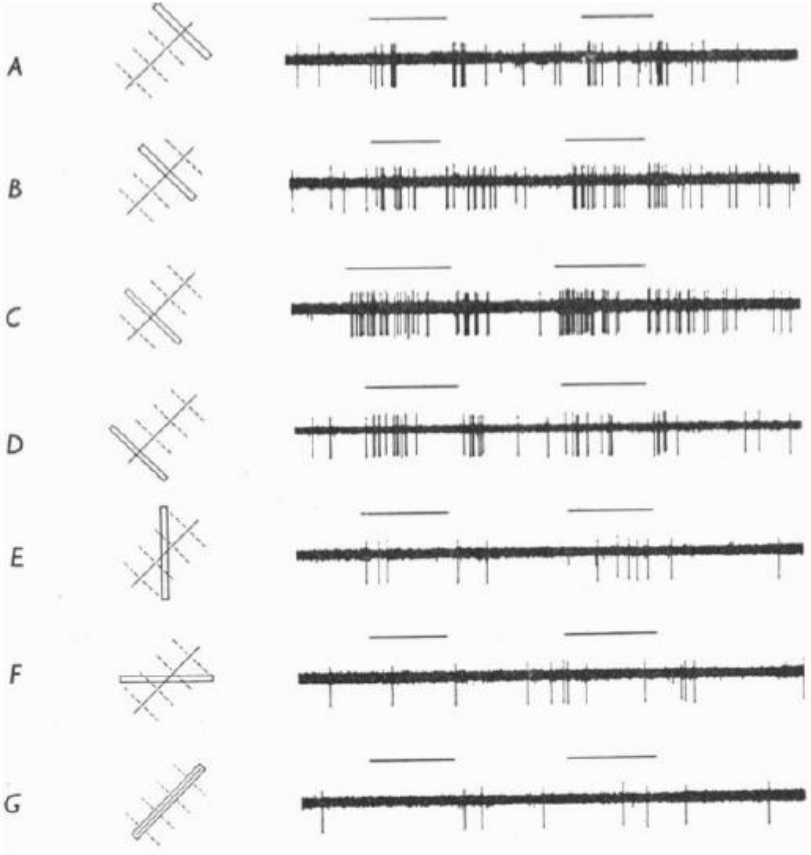
# Coding along the visual hierarchy

**V1**

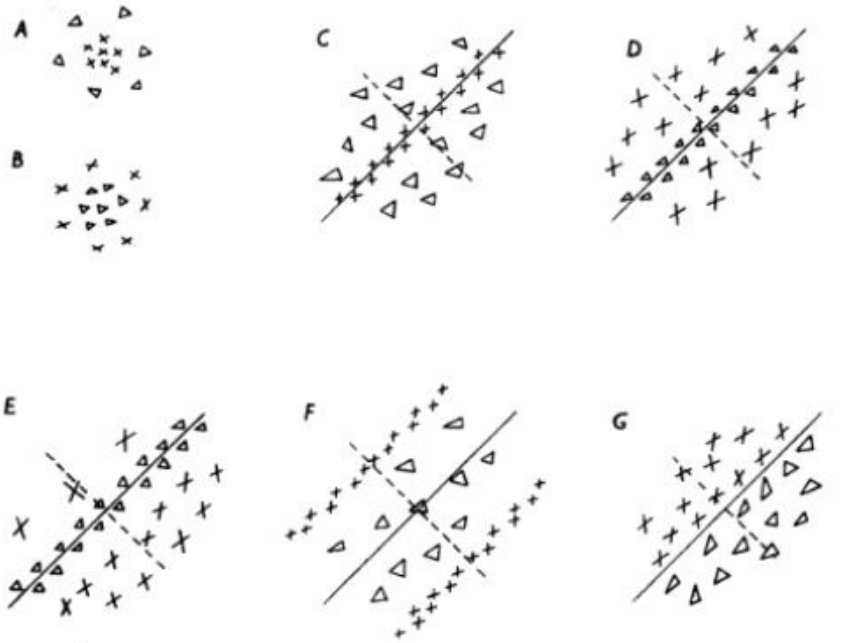
Simple cells in V1 respond to edges and the orientation of these edges



# Coding along the visual hierarchy



# Coding along the visual hierarchy




Text-fig. 2. Common arrangements of lateral geniculate and cortical receptive fields. *A*. 'On'-centre geniculate receptive field. *B*. 'Off'-centre geniculate receptive field. *C–G*. Various arrangements of simple cortical receptive fields. ×, areas giving excitatory responses ('on' responses); △, areas giving inhibitory responses ('off' responses). Receptive-field axes are shown by continuous lines through field centres; in the figure these are all oblique, but each arrangement occurs in all orientations.

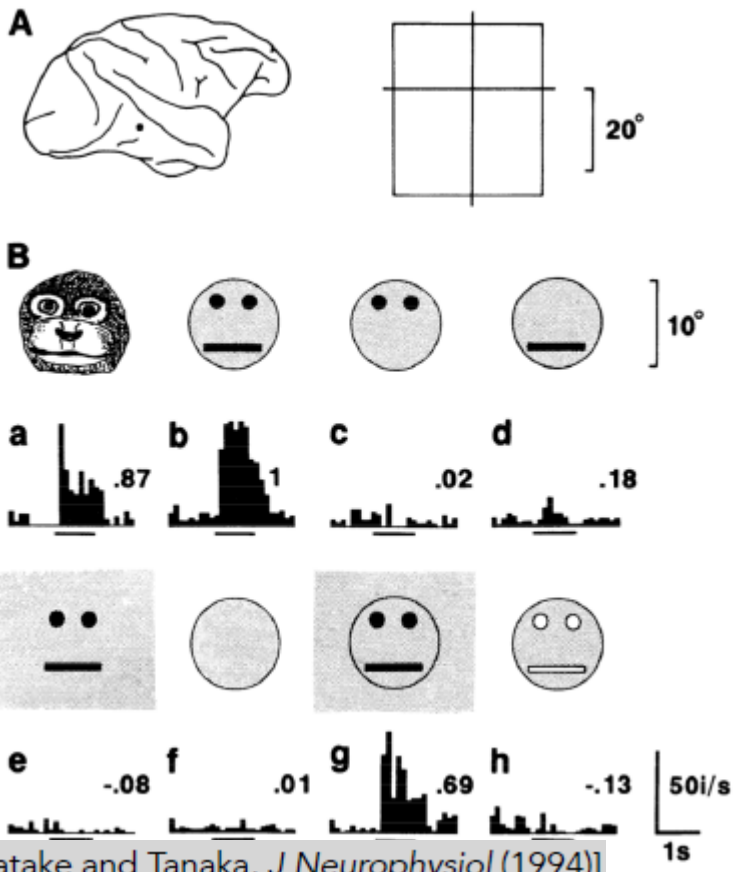
X = excitatory response

∆ = inhibitory response

What is the point in having these receptive fields?

Feature extraction??

# Coding along the visual hierarchy




[Kobatake and Tanaka, *J Neurophysiol* (1994)]

**Higher visual areas**

Higher visual areas are responsible for integrating information from lower areas

Allows you to recognise objects, pick out faces, integrate current visual scenes with memories…

How do you select features?

- this comes back to the idea of sparseness

# Conclusions

The visual system contains cells with different receptive fields

Retinal ganglion cells are sensitive to contrast patches:
- ON centre and OFF centre cells

V1 simple cells are sensitive to the orientation of edges

Visual information is processed in stages along the visual hierarchy in more and more complex ways