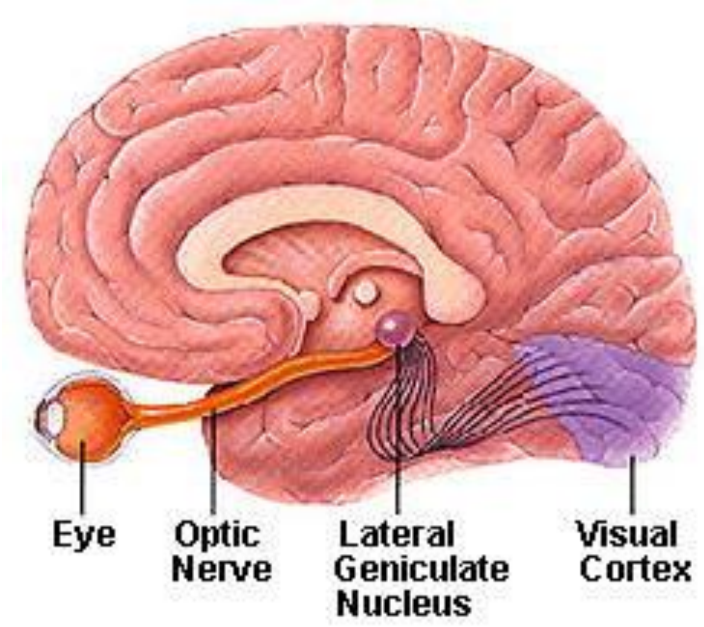
LIFE3082 Sensational Neuroscience

Primary Visual Pathway

Tobias Bast, School of Psychology, University of Nottingham



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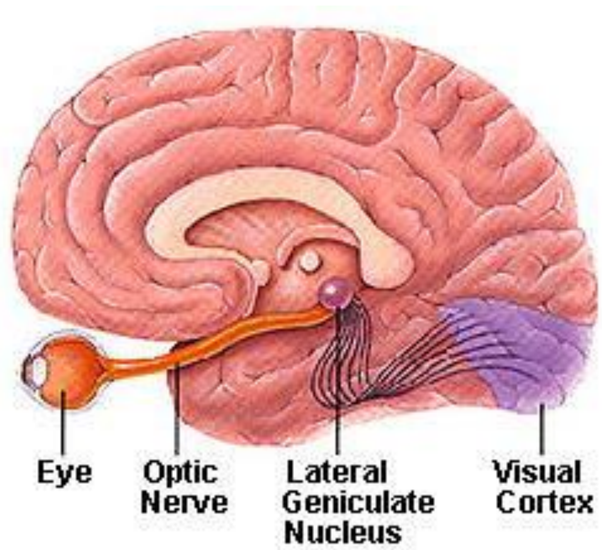
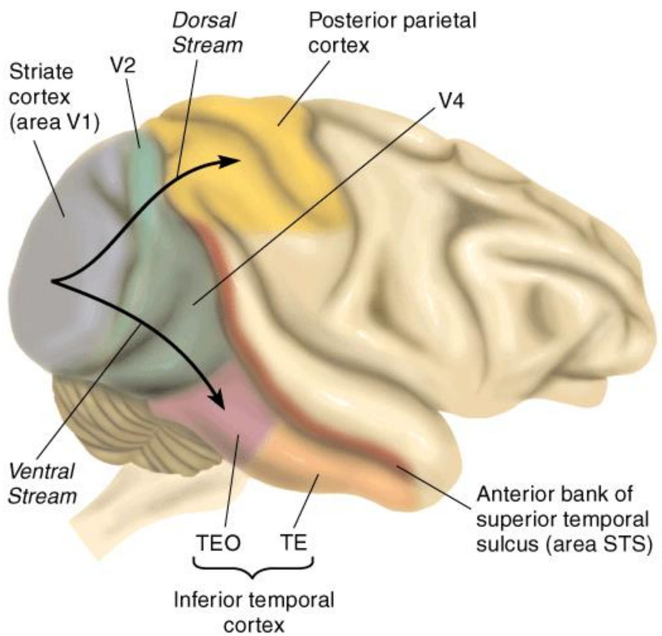
Today's lecture



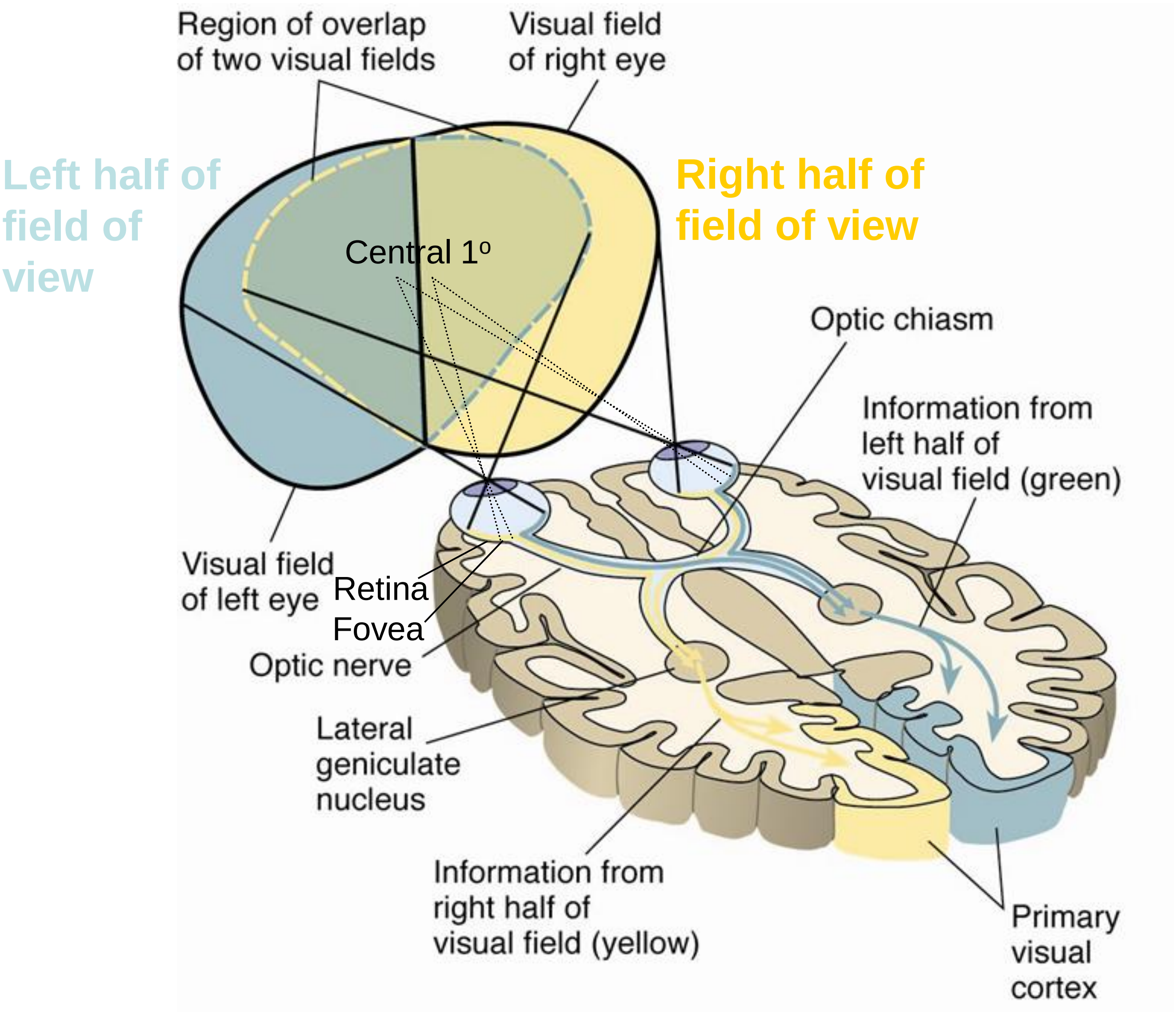
Initial stages of visual information processing – from retina to V1 (primary visual pathway)

Next lecture

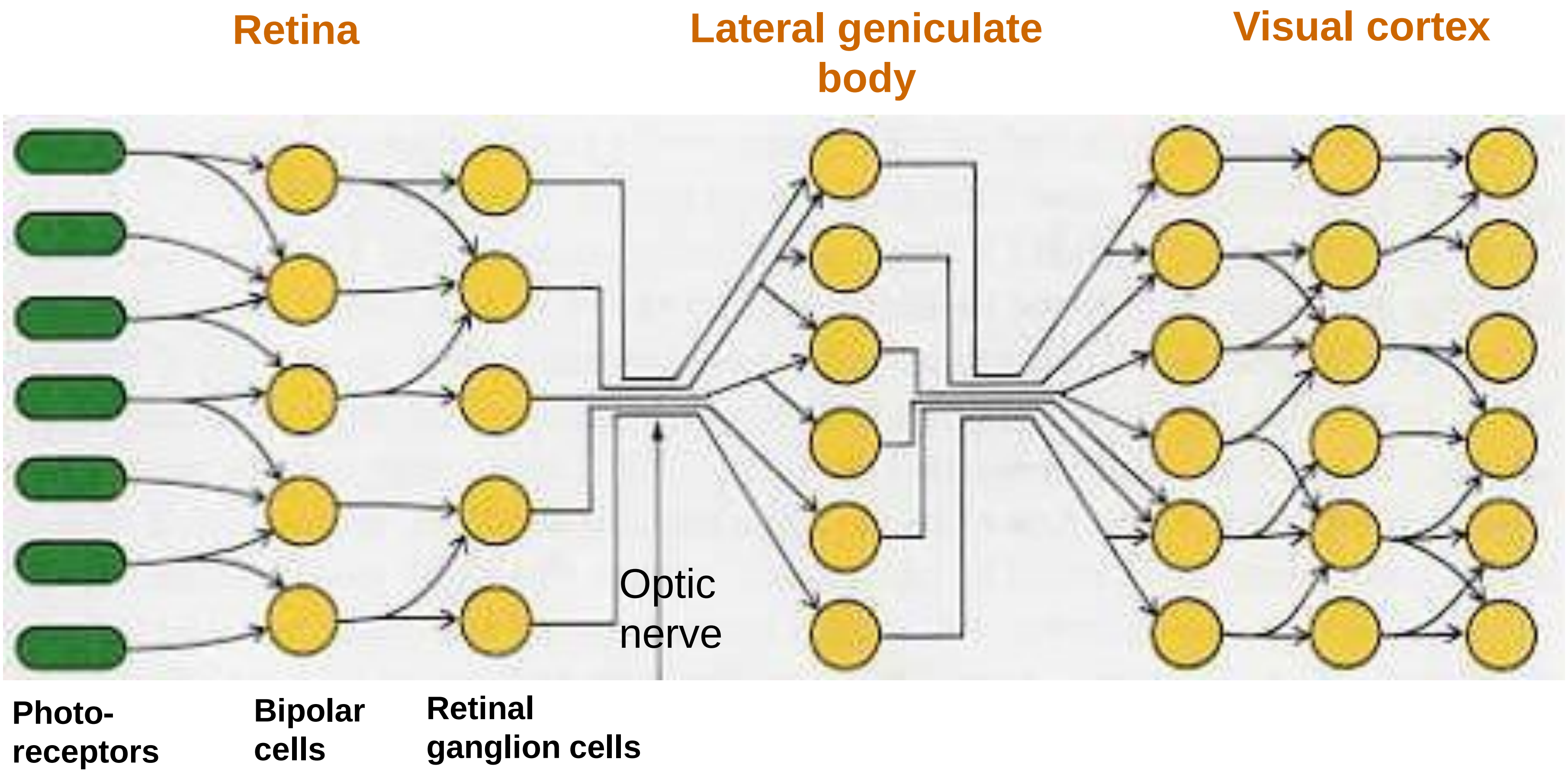


Visual perception, memory, etc. – beyond V1 (focus on occipito-temporal pathway)

Primary visual pathway from eyes to primary visual cortex (striate cortex, V1) in the occipital lobe



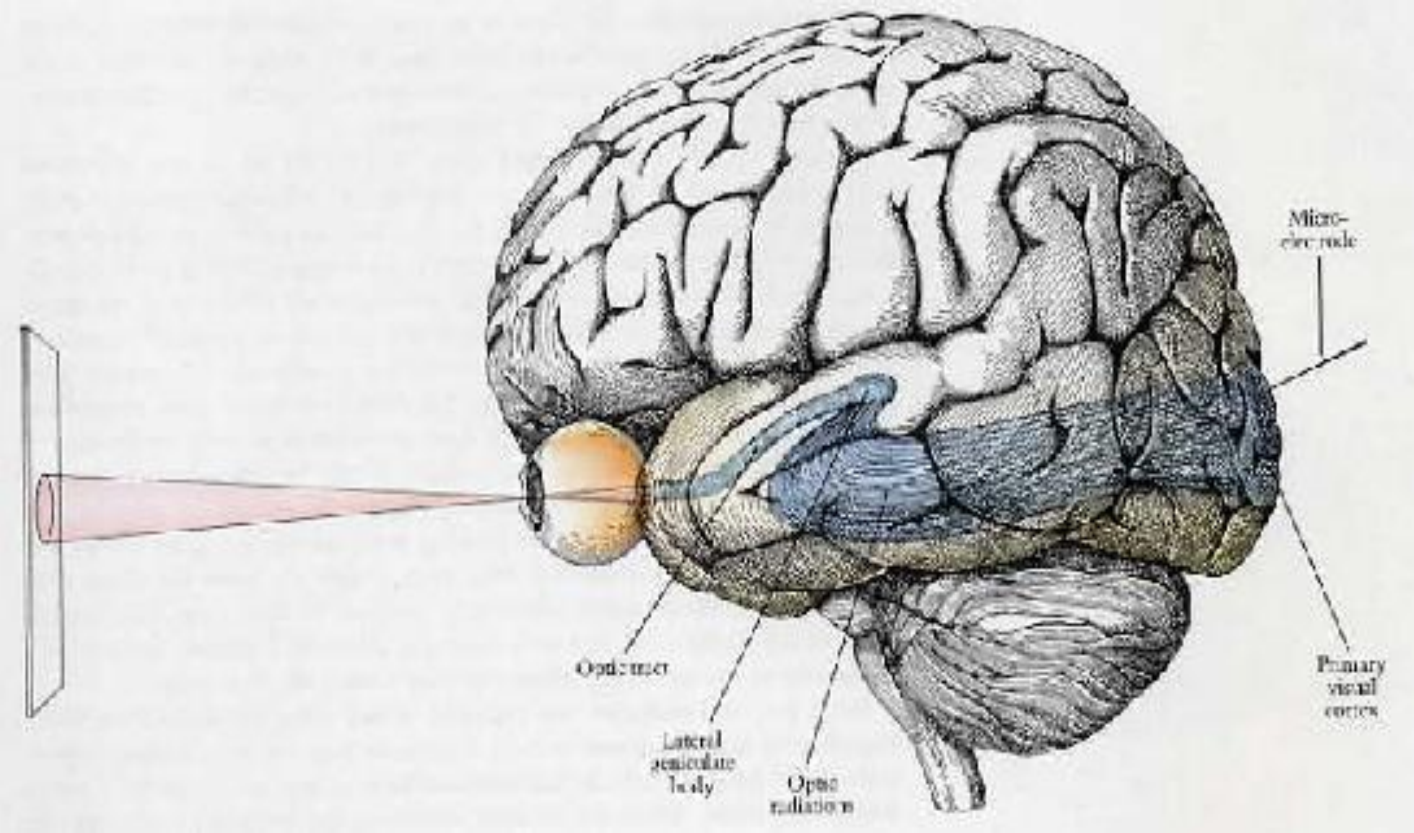
Information-processing stages in primary visual pathway



Experimental strategy to reveal mechanisms of visual perception

By studying the different neuronal responses at different stages of the visual pathway, one may gain understanding of the different stages of visual information processing that mediate visual perception.

Experimental set-up to record visual responses of neurons along the visual pathway



Seminal contributions to our understanding of visual information processing

The neurobiology group in the Department of Pharmacology at Harvard Medical School, 1963, the group that later formed the Department of Neurobiology.

David Hubel

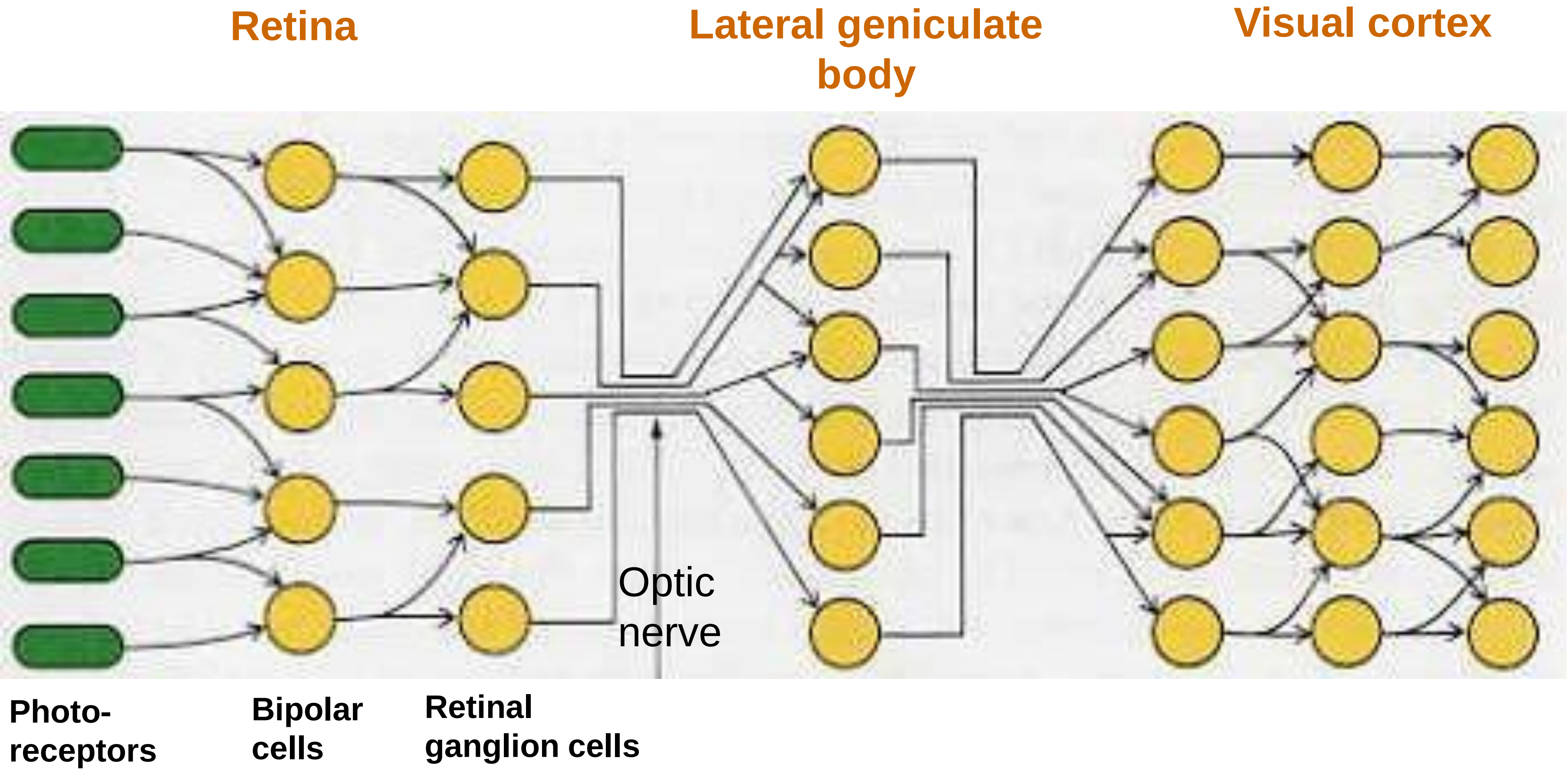
Thorsten Wiesel

Nobel Prize in Physiology or Medicine 1981

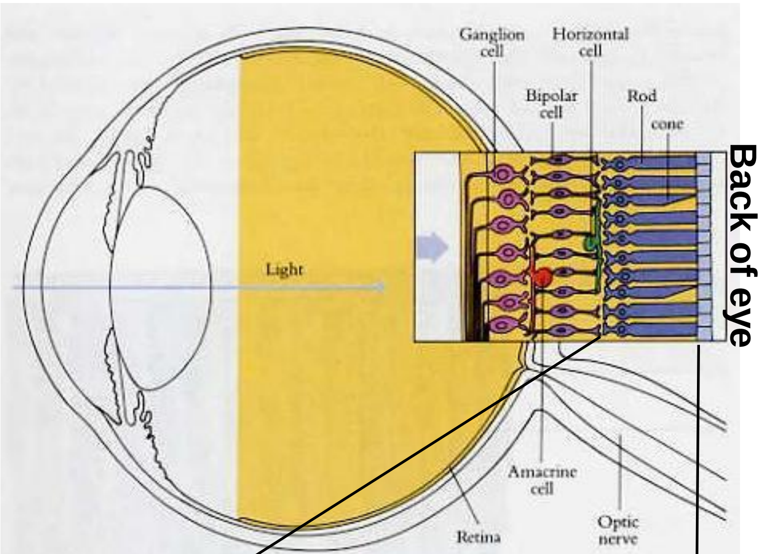
For discoveries concerning information processing in the visual system

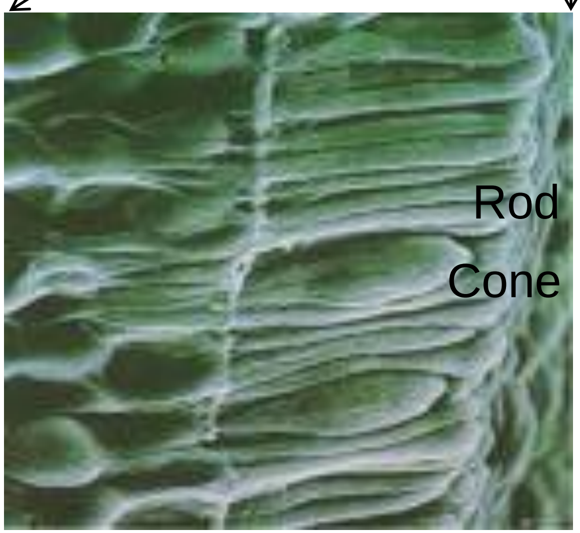
http://nobelprize.org/nobel_prizes/medicine/laureates/1981/index.html

Information-processing stages in primary visual pathway



Photoreceptors





- Rods

-More abundant (ca. 120 million in human retina)
-No colour (i.e., wave length) discrimination
-Sensitive in low light levels
-Higher density in periphery (don't look *directly* at dim stars)
-Track high-rate changes (see flicker of 60Hz monitor from corner of your eyes)

- Cones

-Less abundant (ca. 6 million in human retina)
-3 types discriminate different wavelengths (S,M,L)
-Less sensitive to low light
-Higher concentration in fovea
-Cannot follow rapid changes (can't see 60-Hz flicker when directly looking at monitor)

Photoreceptors and bipolar cells vary their **voltage** as they are stimulated (analogue signal), whereas all subsequent cells vary spike rate (all-or-nothing, digital signal).

Photoreceptor detection of light is translated into excitation or inhibition of retinal ganglion cells via bipolar cells.

Life without cones or rods:

a) Without cones we could only see in shades of black and white.

b) Without rods we could only see in shades of black and white.

c) Without cones we would have more trouble seeing things in the dawn.

d) a) and c) are correct.

Receptive fields of visual neurons

•The portion of the retina/visual field in which visual stimulation will evoke a change in the firing rate of a given visual neuron.

•Substructure of a receptive field: A description of how visual stimuli need to be presented in the receptive field of a visual neuron in order to evoke firing-rate changes.

Retinal ganglion neurons

•Receive input from multiple photoreceptors (via bipolar cells)

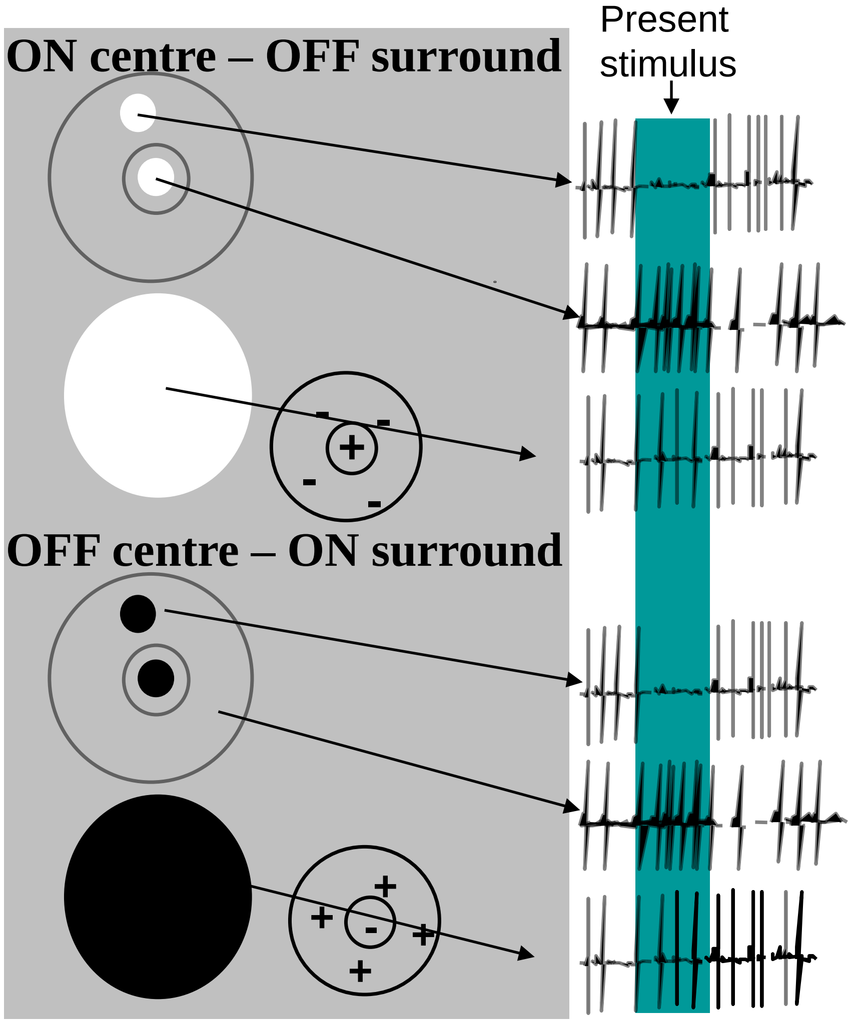
•ON-OFF Centre-Surround receptive fields

-Light presented in 'ON' regions excites cell, and light in 'OFF' regions inhibits cell

-ON and OFF regions are organised in 'centre-surround' fashion

-Response **rate** of cell is based on the sum of stimulation in ON region minus stimulation in OFF region

➡ Enhancement of contrast and boundaries



Neurons in the lateral geniculate body respond to visual stimuli in similar ways to retinal ganglion cells.

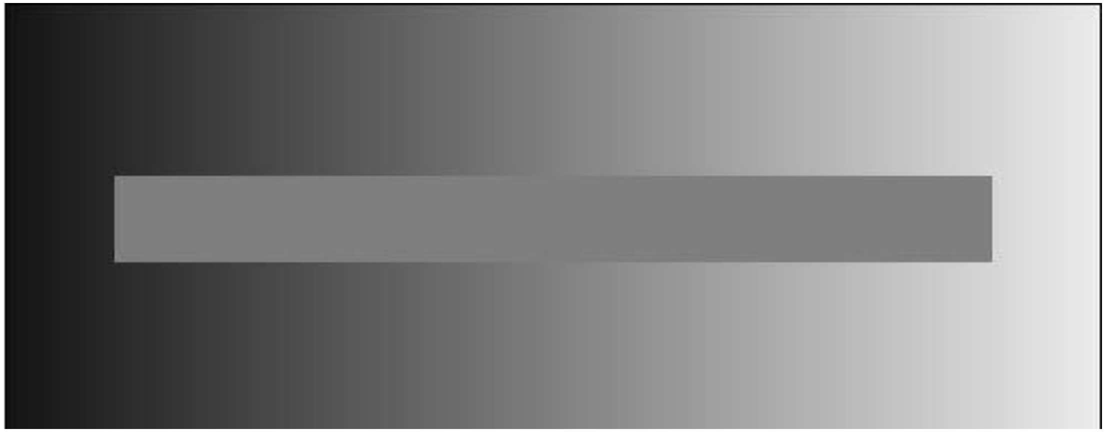
Functional significance of centre-surround fields

- The world has lots of things that stay constant, and we don't need to keep responding to them – what counts most are changes and boundaries. So, responding only to changes and boundaries (edges) is **efficient**.

- The luminance of features is represented relative to their surround.

This helps **preserve appearance of objects regardless of light levels in the environment** (newspaper looks basically the same in a dark room and in sunlight, despite hugely different levels of overall reflected light).

However, it can also result in illusions:



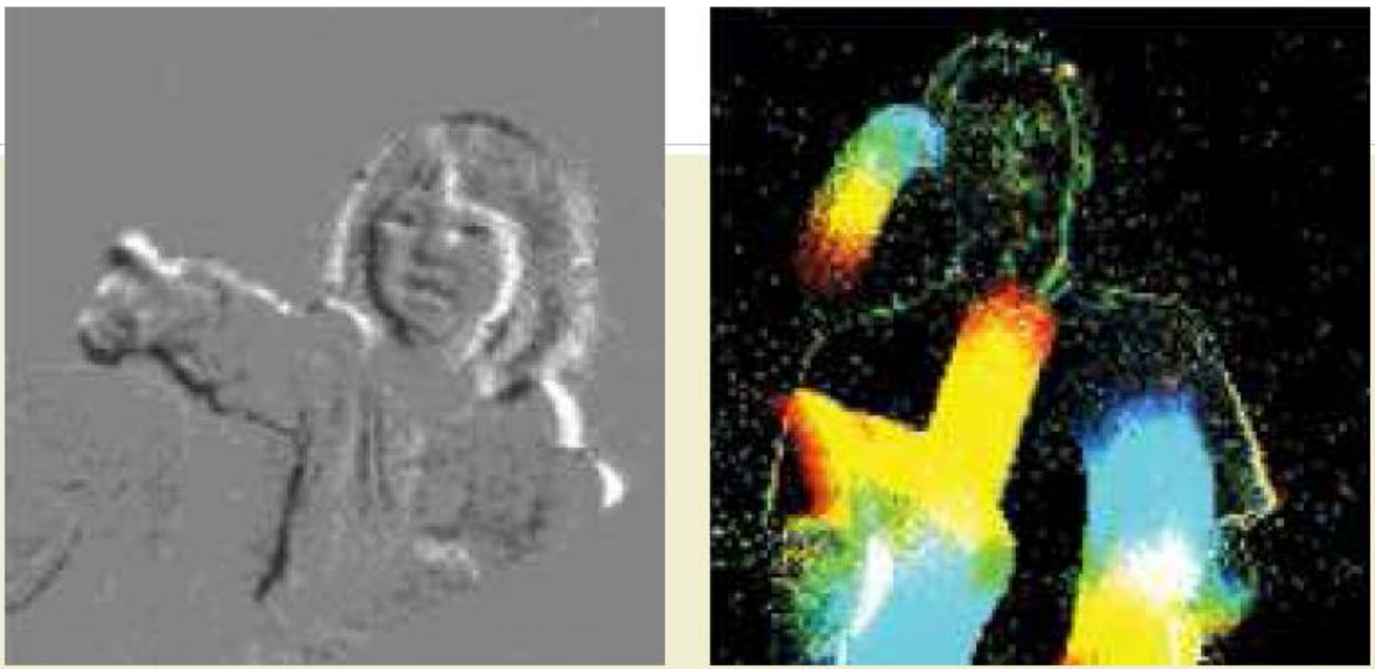
The Retina Inspires a New Kind of Camera

Technology emerges from studying the speed and efficiency of the brain's visual processing

Terry Sejnowski is an investigator with the Howard Hughes Medical Institute and is Francis Crick Professor at the Salk Institute for Biological Studies, where he directs the Computational Neurobiology Laboratory.

Tobi Delbruck is co-leader of the sensors group at the Institute of Neuroinformatics at the University of Zurich.

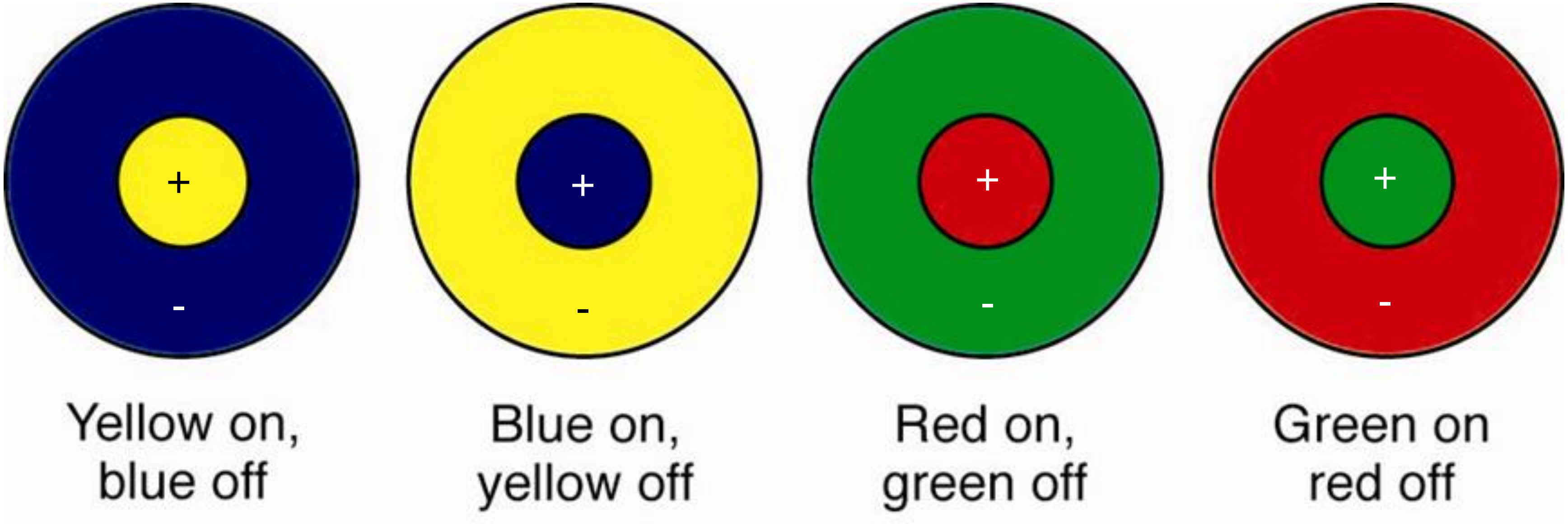
Scientific American, October 2012



See a video demonstrating the eye camera at: ScientificAmerican.com/oct2012/dvs
Paper by Sejnowski & Delbruck (2012, Scientific American 307(4): 54–59):
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4763947/

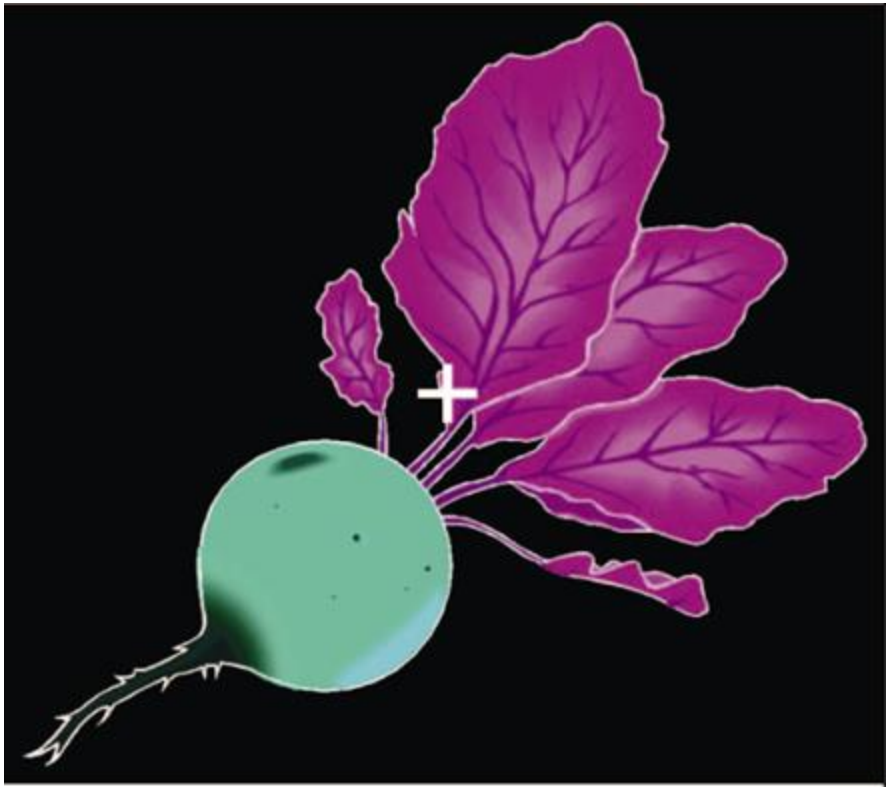
Colour sensitivity of retinal ganglion and LGN neurons

- **Retinal ganglion and LGN cells receive inputs from cones (that are differentially sensitive to different wavelengths) and are sensitive to colour**
- **Colour-sensitive retinal ganglion and LGN neurons have receptive fields that show centre-surround colour opponency**

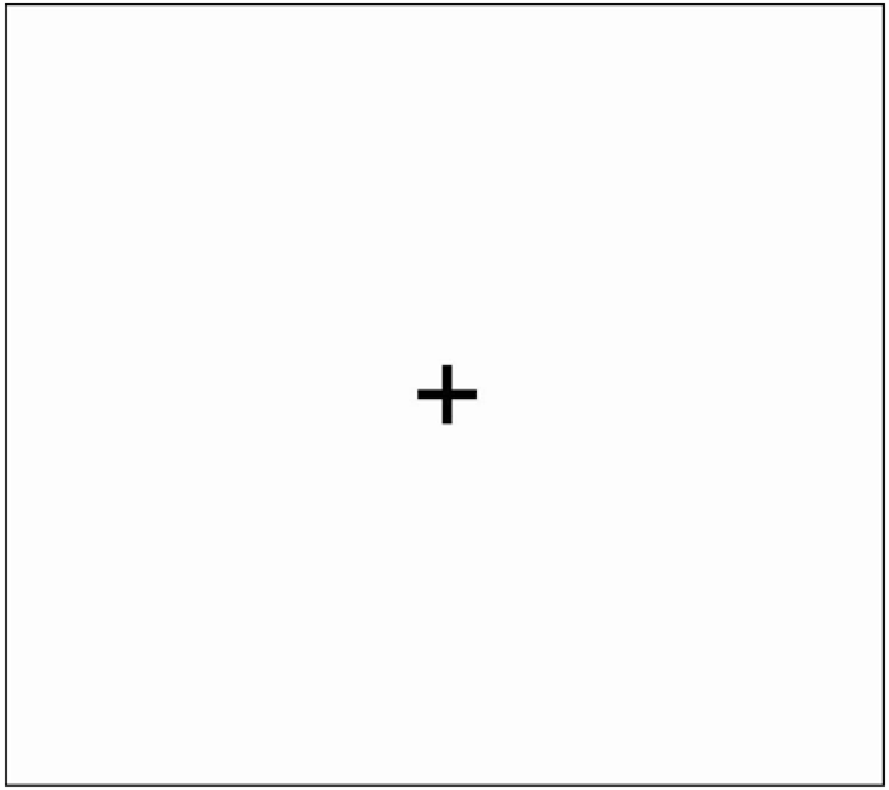


Functional significance of colour-opponency not clear.

However, colour opponency, together with firing-rate adaptation (rebound effects), in retinal ganglion cells can explain negative afterimages.



Negative afterimage



Life without centre-surround receptive fields:

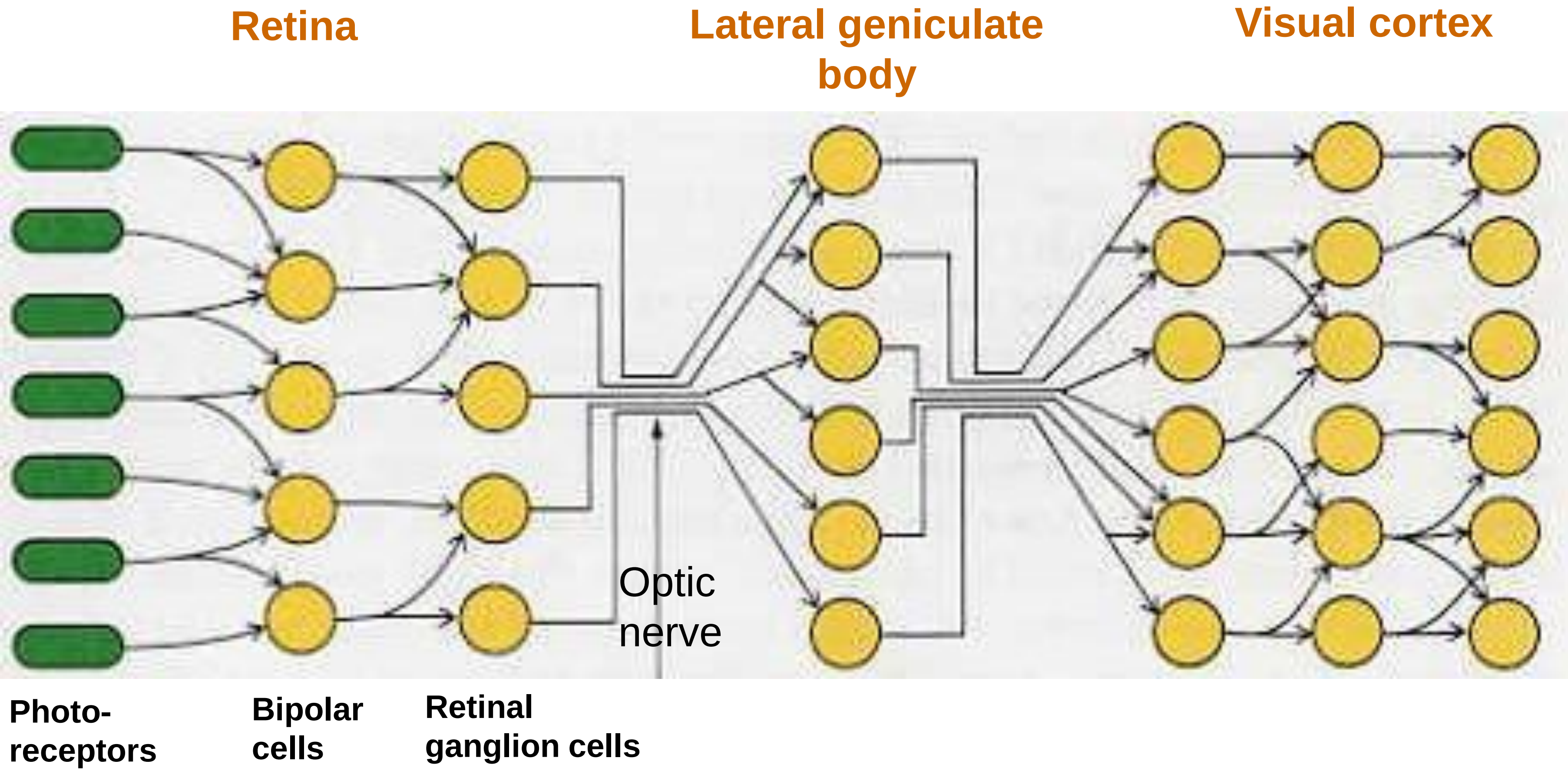
a) Without an on-off centre-surround organisation of the receptive fields in some neurons of primary visual pathway we'd struggle more to detect contrasts and edges.

b) We could not distinguish black and white.

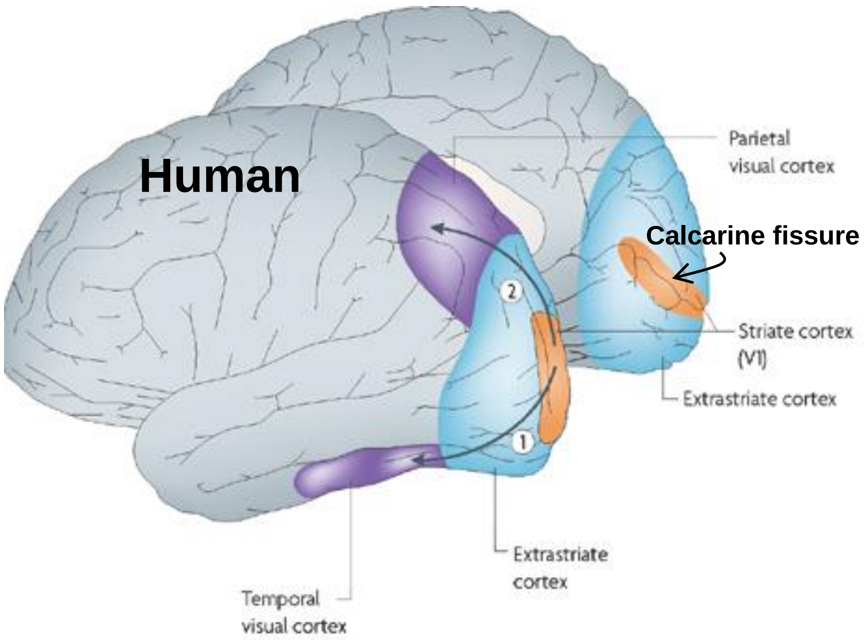
c) We would have more difficulties to recognize objects if light levels in the environment change.

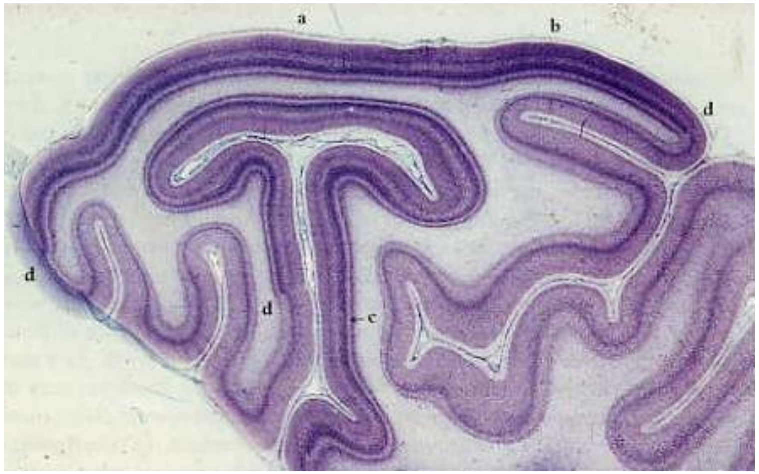
d) a) and c) are correct.

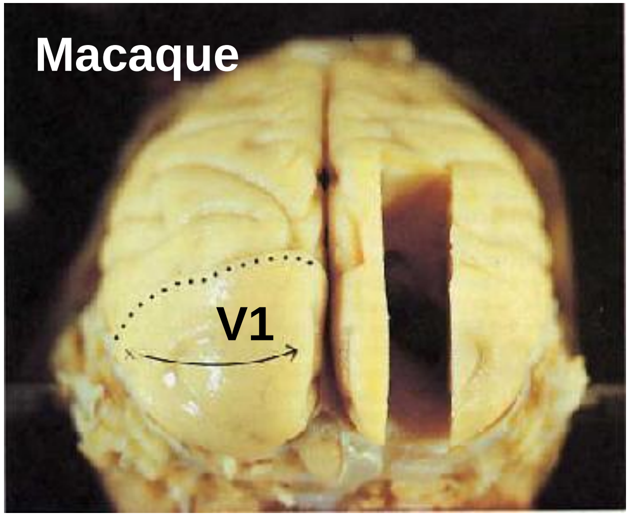
Information-processing stages in primary visual pathway

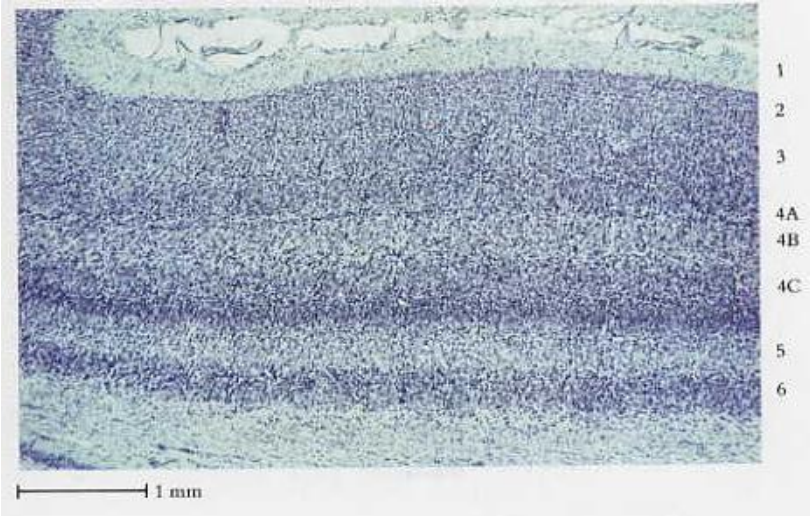


Primary visual cortex (striate cortex, V1)

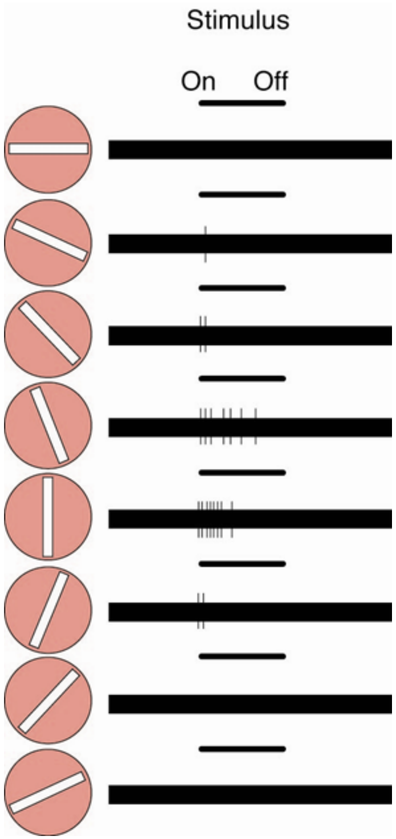








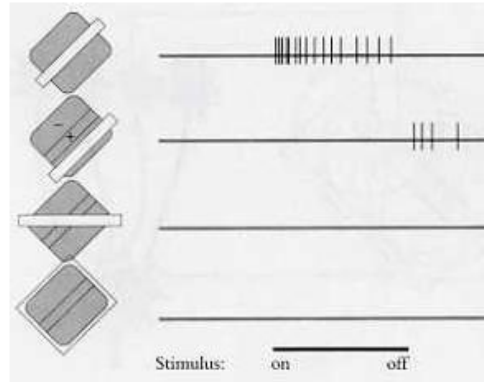
Orientation-selective cells in V1

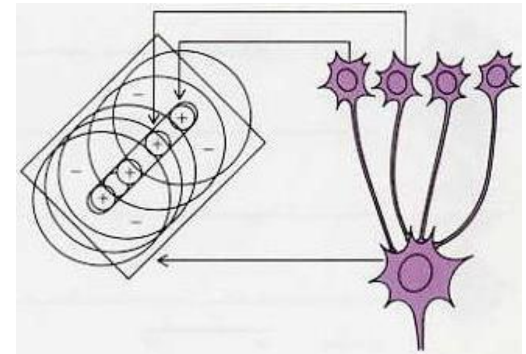


•Most V1 neurons respond to elongated stimuli with specific orientation.

•Two main types of orientation-sensitive V1 neurons

Simple cells

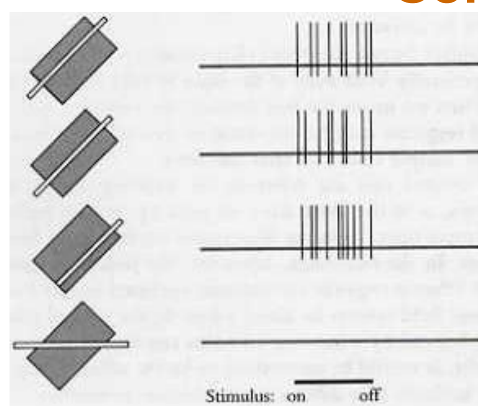


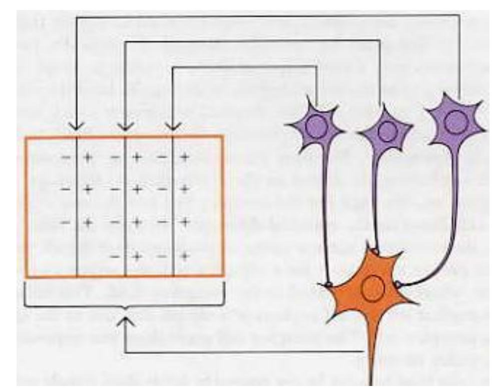


-Fields have inhibitory and excitatory regions.

-Can be thought of as combining inputs from ON and OFF cells.

Complex cells



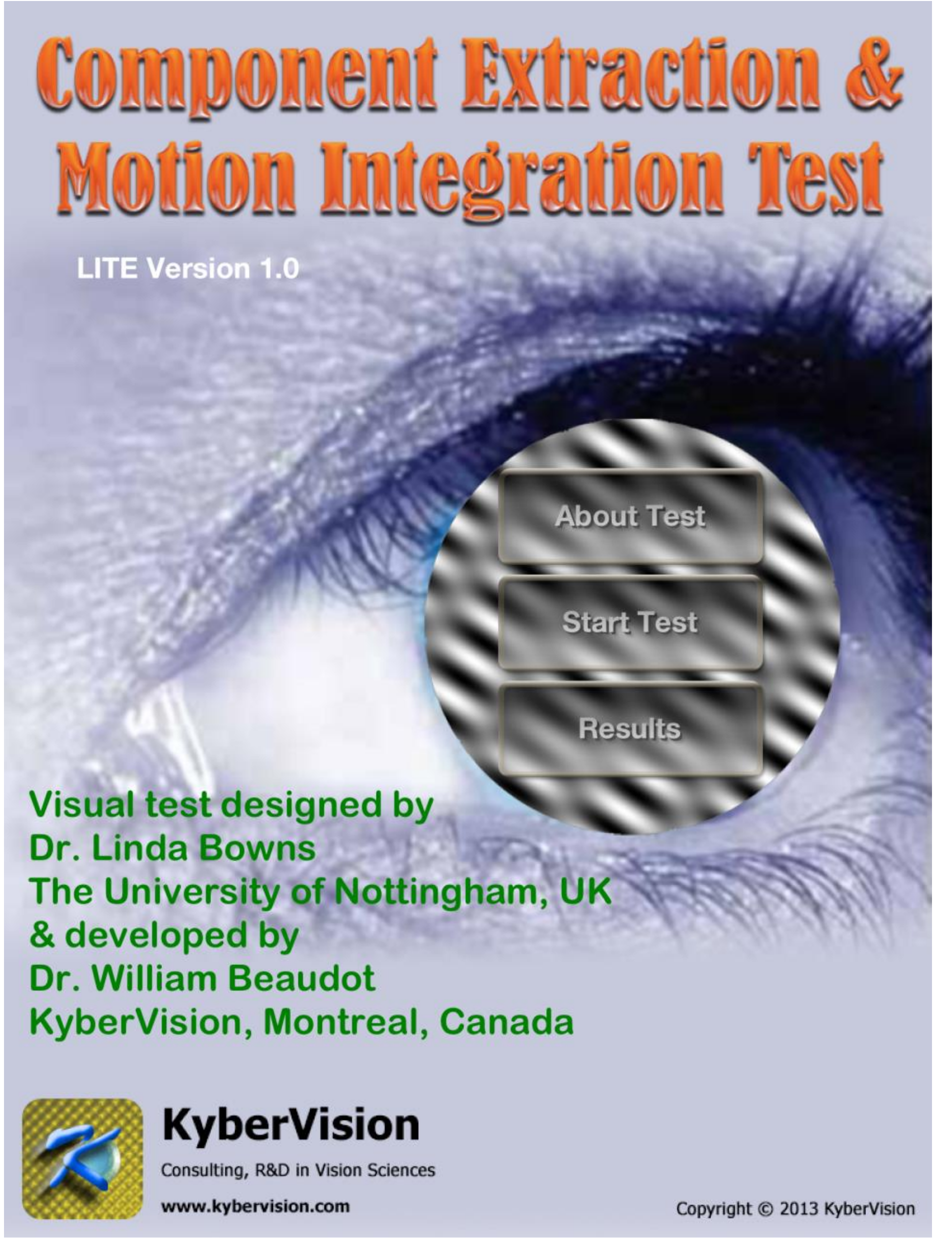


-Fields have no discrete ON and OFF regions.

-Best response to moving stimuli (reflecting response adaptation).

-Can be thought of as combining inputs from simple cells.

Stimulate your simple and complex cells in V1

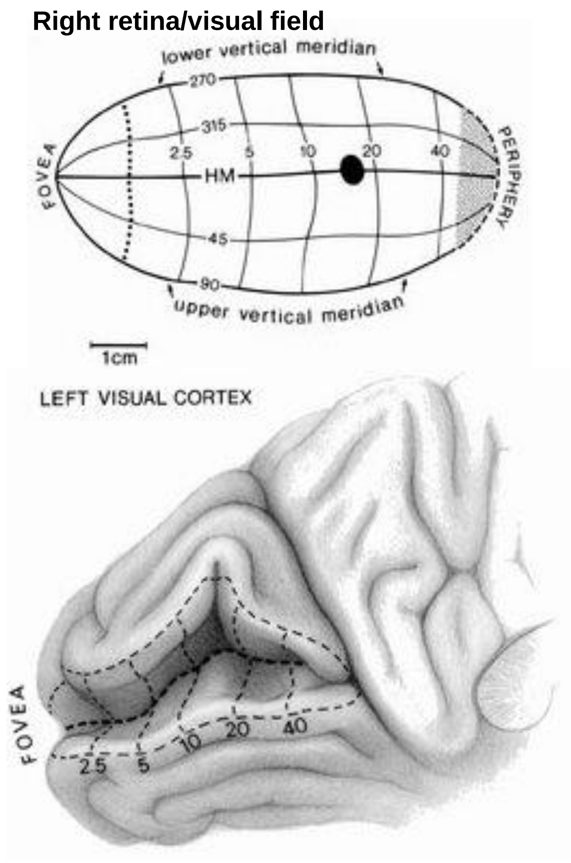


Download CEMIT Lite from the App Store.

Maps and modules in V1

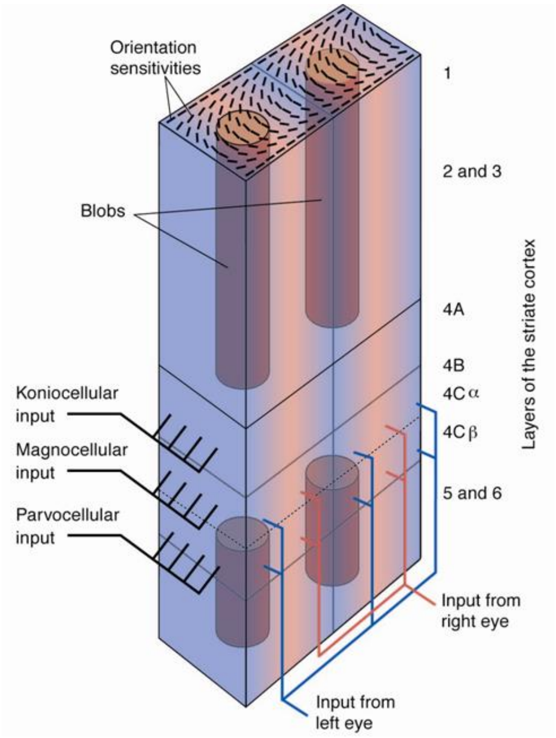
Retino-topic map

Orderly mapping of retina/visual field onto visual cortex



Modules

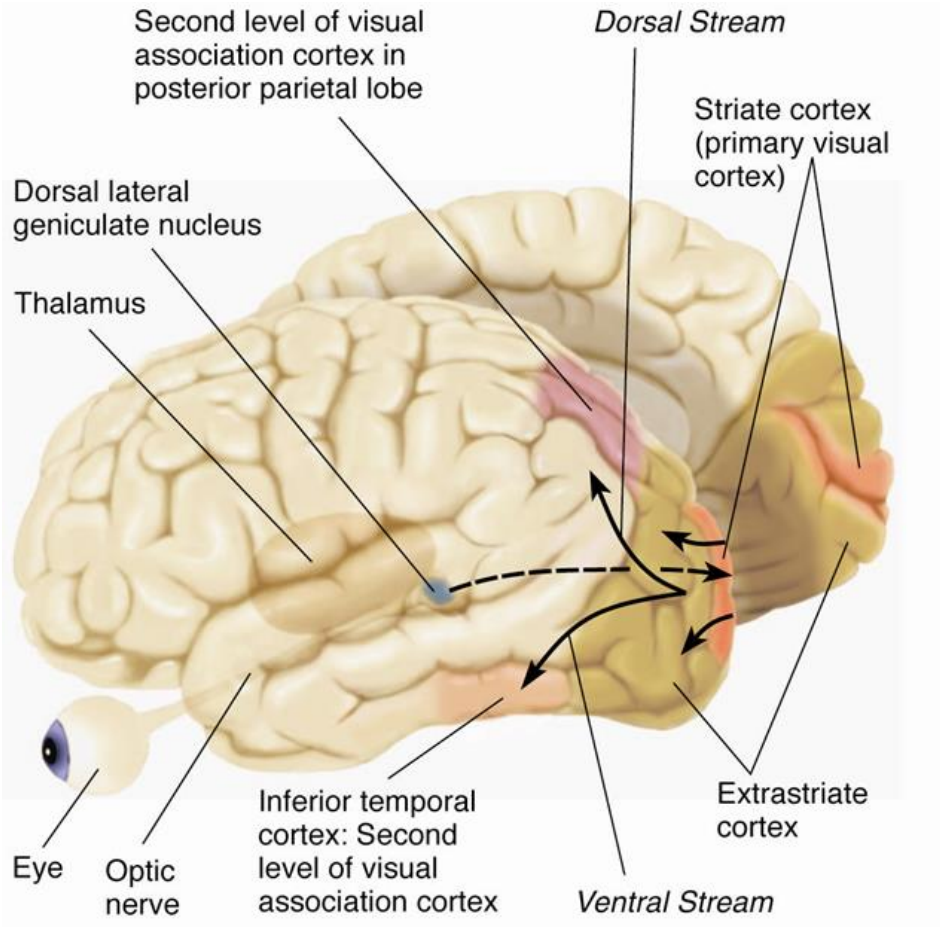
V1 is divided into small columnar modules that combine neurons sensitive to different aspects of stimuli presented in a small part of the visual field.



Further processing of visual information

•To result in **perception** and **memory** of the 'holistic' visual properties of whole objects and visuals scenes, the visual information from the modules in V1 needs to be combined and further processed.

•This processing takes place in the visual association cortices (V2-V5, inferior temporal cortex, posterior parietal cortex) and other regions.



NEXT LECTURE!!

Blindsight

•Subjects with lesions to primary visual cortex and apparent ‘blindness’ can show appropriate responses to visual stimuli of which they are not ‘conscious’.

•Examples of such ‘blindsight’ include: ‘looking’ (i.e., moving the eyes) or pointing toward visual stimuli; detection of movement; etc.

• ‘Blindsight’ highlights that, apart from the primary visual pathway that is critical for conscious vision, there are additional visual pathways.

Recent study suggests that direct LGN projections to extrastriate cortex are critical for blindsight (Schmid et al., 2010, Nature 466:373-377).

•‘Blindsight’ also highlights that the brain can perform visual information processing which can guide subjects’ behaviour without their conscious awareness.

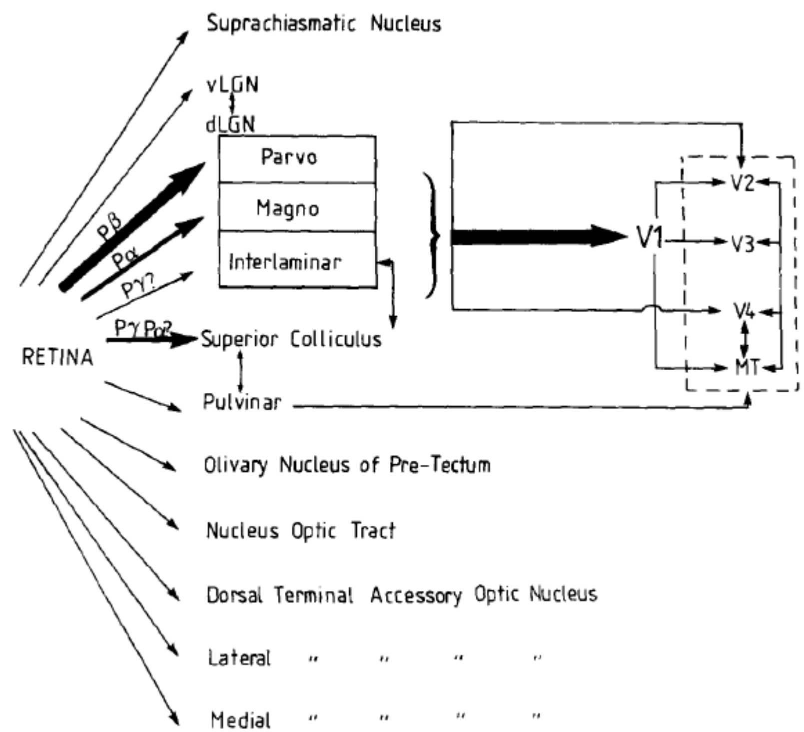


Fig. 1. *The known pathways from the eye into the brain, together with the initial cortical projections. The scheme excludes the extensive further connections between the initial cortical visual areas and the many further visual areas. The thicker arrows indicate the heaviest and most studied projections. The classes of retinal ganglion cells projecting to most of the brainstem targets are unknown.*

Cowey & Stoerig (1991) The neurobiology of blindsight. *Trends Neurosci.* 14:140-145.

Primary visual pathway – Selected Reading

***Textbook chapter*:**

Carlson NR (any recent edition) The physiology of behavior. Chapter 6, *Vision*.

Bear MF, Connors BW, Paradiso MA (any recent edition) Neuroscience – exploring the brain. Chapters 9 and 10.

Excellent book (many figures used in lecture come from this book)**:**

Hubel D (1995) Eye, brain, and vision. Scientific American Library/Scientific American Books. (Available in George Green Library).

***Review article*:**

Hubel D, Wiesel T (1998) Early explorations of the visual cortex. *Neuron* 20:401-420.

Primary visual pathway – Some revision questions

•Which brain regions make up the primary visual pathway?

•What is a visual receptive field, what is its substructure?

•Can you outline key stages of visual information processing along the primary visual pathway, characterizing the properties of neurons at different stages by describing the neurons' visual receptive fields?

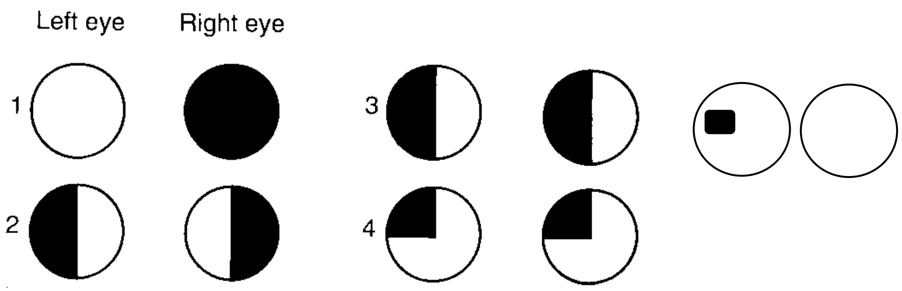
•Can you give a physiological explanation of negative afterimages?

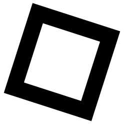
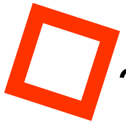
•What is 'Blindsight' and what are the conceptual implications of this phenomenon?

Primary visual pathway – Some questions to think about

•How could you explain these selective visual field defects (that can occur in neurological patients) based on a diagram of the visual pathway?
Try it yourself first, for solutions google ‘visual field defects, images’.

(eyes are tested one after the other, with one eye shut)



•Which processing stages could lead to the perception of  or  ?

•Do we “see” the world as it is?