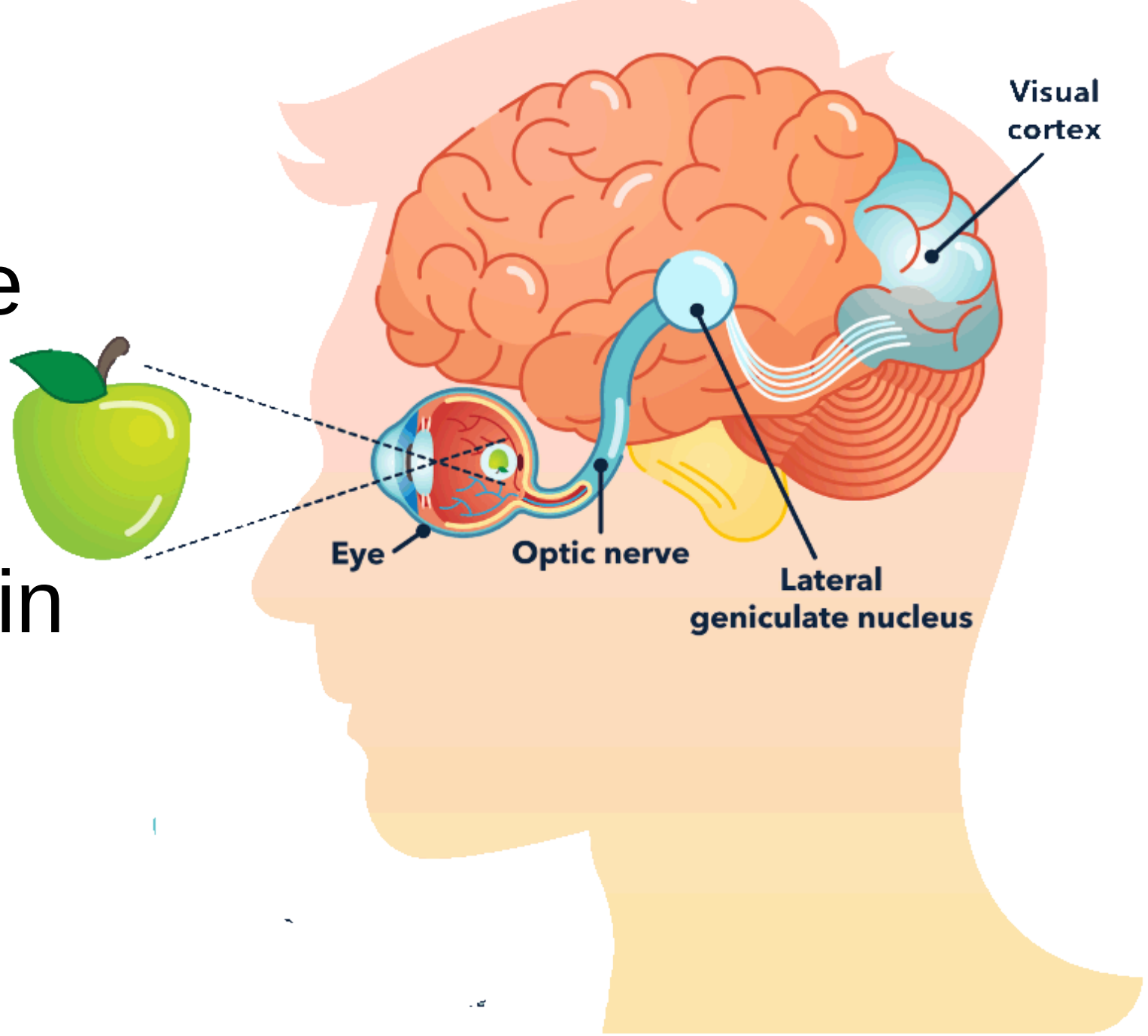
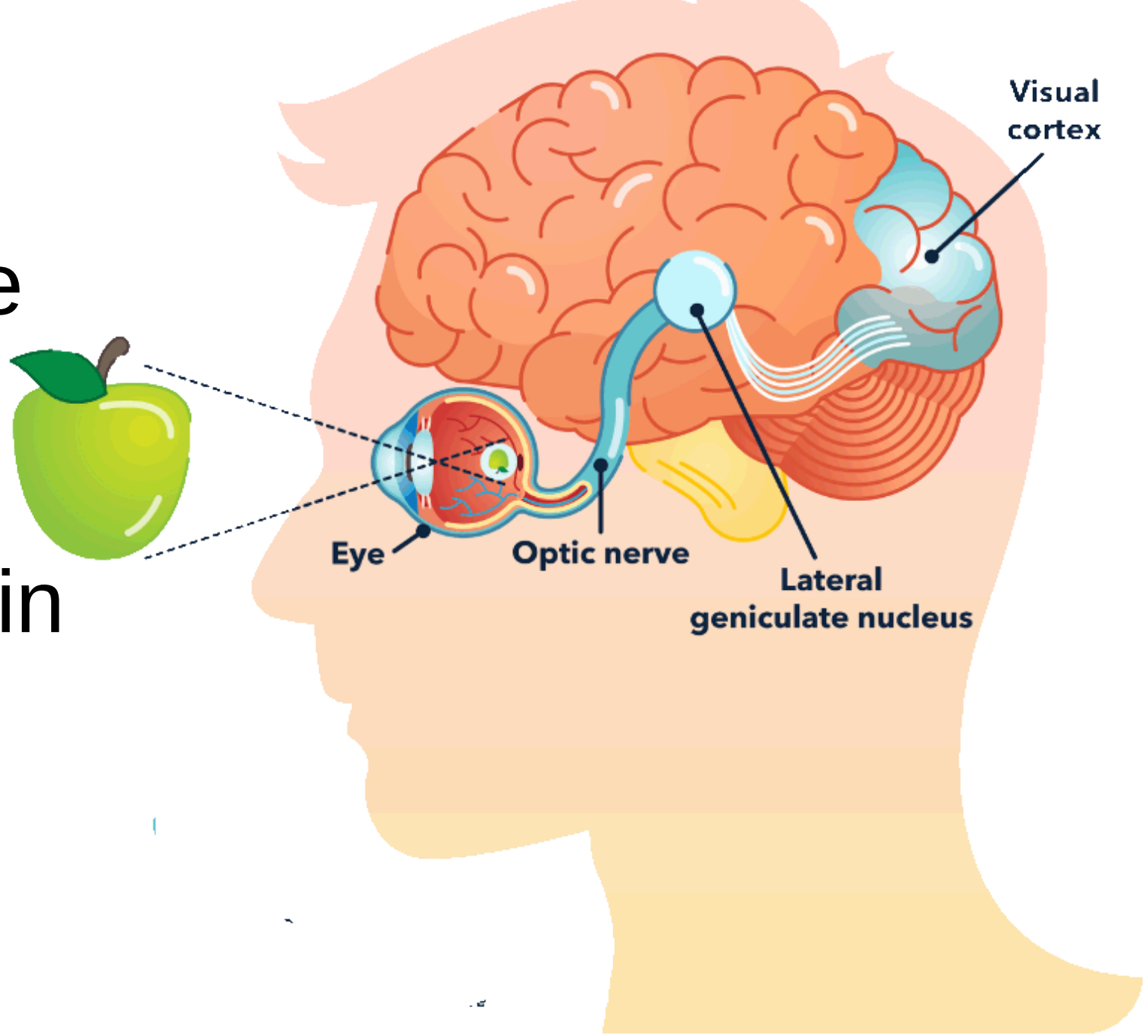
The Human Visual System

Jack Fein and Leathem Mehaffey

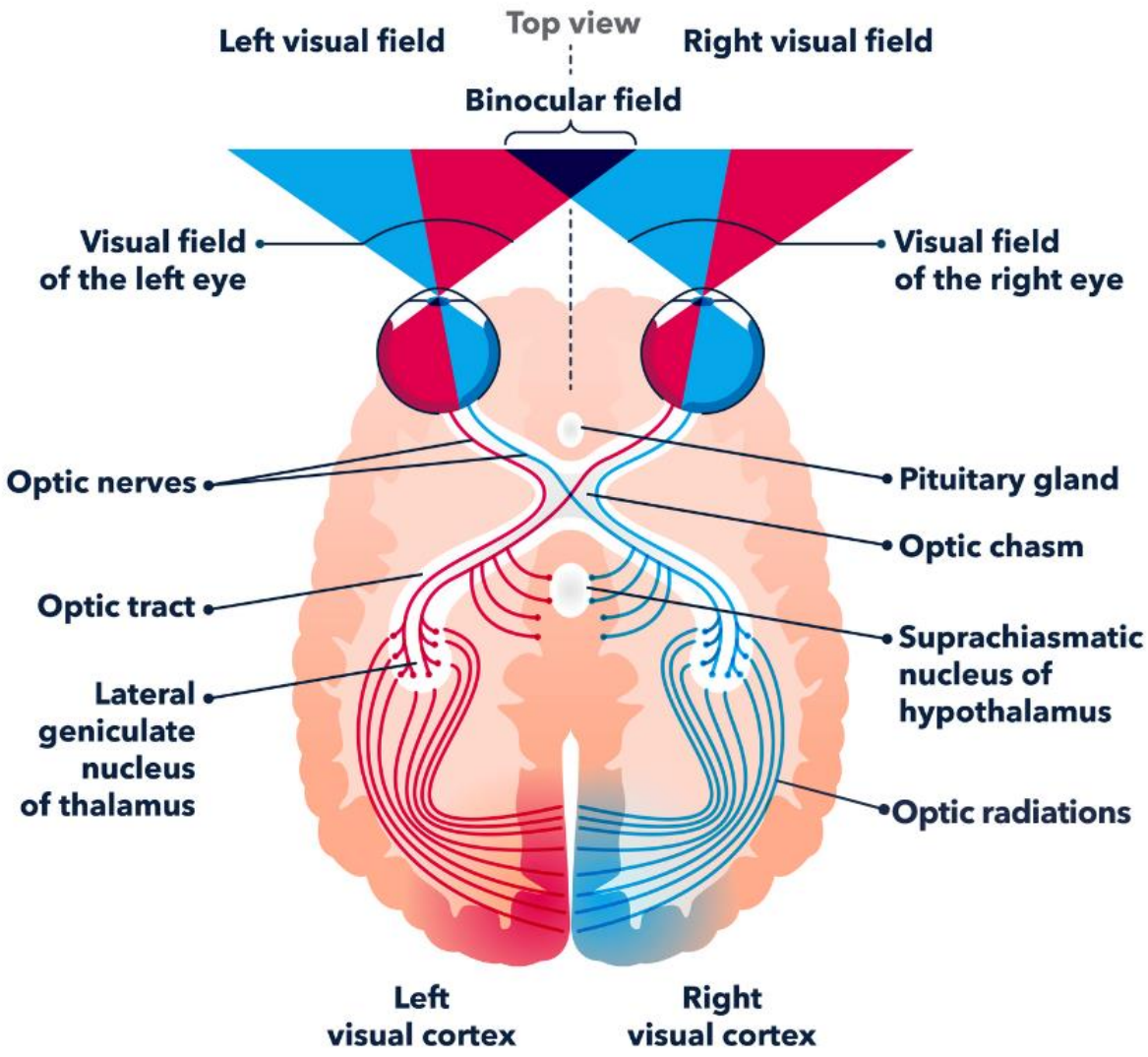
Beyond the Retina: Signal Processing in the Brain



Beyond the Retina: Signal Processing in the Brain



Extra-retinal Visual Pathways



Special note:
Retinotopic mapping.
Higher cells receive input from both eyes, but matching hemifields.

CVI NOW
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Retinal Ganglion Cells

- Three types project to the Lateral Geniculate Nucleus (LGN) of the thalamus and are involved in visual perception:
  - P-cells: parvocellular ganglion cells
    - About 80% of all retinal ganglion cells
  - M-cells: magnocellular ganglion cells
    - About 10% of all retinal ganglion cells
  - K-cells: koniocellular ganglion cells)
    - About 10% of all retinal ganglion cells

P-Cells

- project to the parvocellular layers of the lateral geniculate nucleus.
- small sizes of their dendritic trees and cell bodies.
- receive inputs from relatively few rods and cones (In many cases, they are connected to midget bipolars, which are linked to one cone each).
- slow conduction velocity, and respond to changes in color but respond only weakly to changes in contrast unless the change is great
- have simple center-surround receptive fields, where the center may be either ON or OFF while the surround is the opposite.

M-Cells

- project to the magnocellular layers of the lateral geniculate nucleus.
- large size dendritic trees and cell bodies.
- part of the magnocellular pathway.
- receive inputs from relatively many rods and cones.
- fast conduction velocity
- can respond to low-contrast stimuli, but are not very sensitive to changes in color
- have much larger receptive fields which are nonetheless also center-surround.
- Respond well to transient illumination

K-Cells

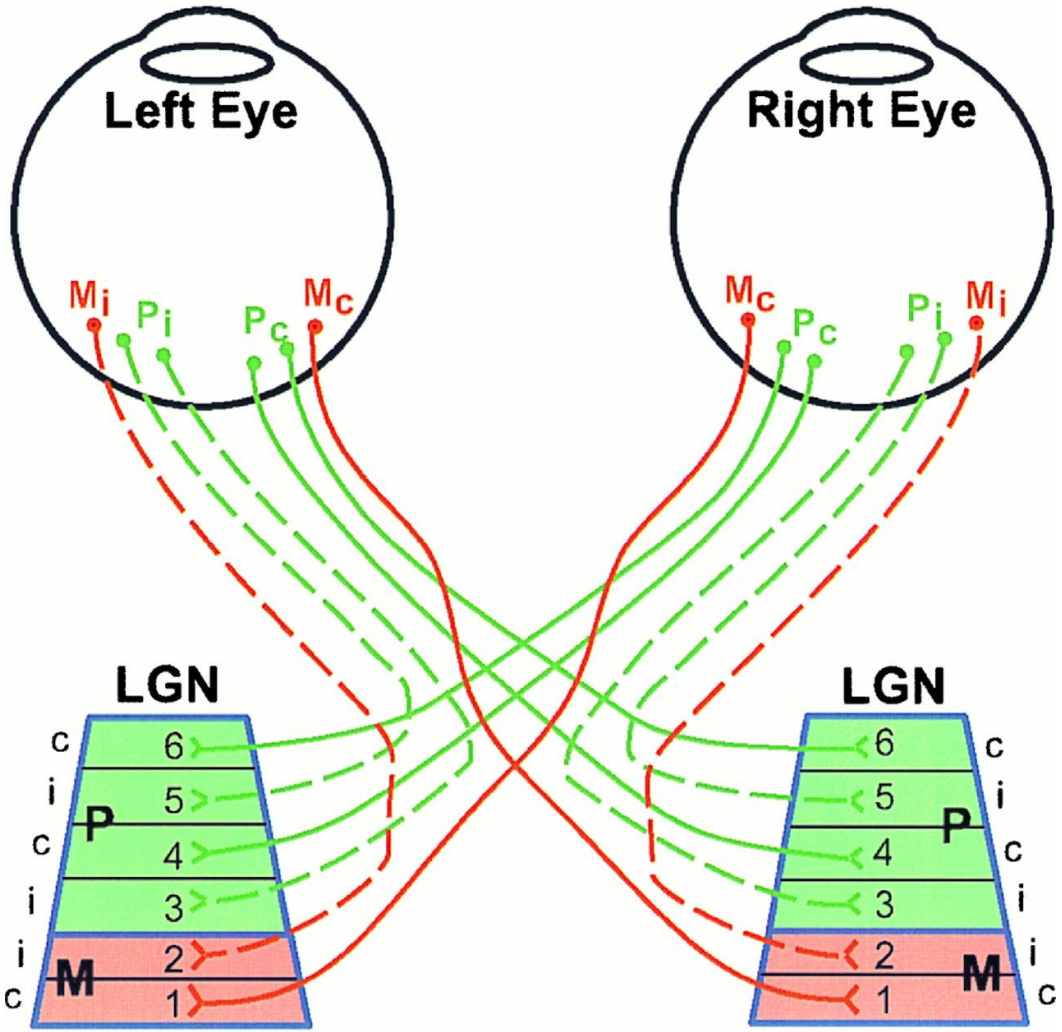
- project to the koniocellular layers of the lateral geniculate nucleus.
- Koniocellular means “cells as small as dust”; their small size made them hard to find.
- About 10% of all retinal ganglion cells are bistratified cells,
- go through the koniocellular pathway
- receive inputs from intermediate numbers of rods and cones.
- moderate spatial resolution, moderate conduction velocity, and can respond to moderate-contrast stimuli.
- may be involved in color vision
- very large receptive fields that only have centers (no surrounds) and are always ON to the blue cone and OFF to both the red and green cone.

Other types of ganglion cells (not in the direct visual pathway)

- Photosensitive ganglion cell
  - contain their own photopigment, melanopsin
  - respond directly to light even in the absence of rods and cones
  - project to, among other areas, the suprachiasmatic nucleus (SCN) via the retinohypothalamic tract for setting and maintaining circadian rhythms.
- Cells projecting to the Edinger-Westphal nucleus of the oculomotor nerve for control of the pupillary light reflex
- Cells projecting to the superior colliculus for eye movements (saccades)

Next Stop: The Lateral Geniculate Nucleus of the Thalamus

Schematic illustration of neuronal connections between the eyes and the LGN in the macaque monkey.



Meissirel C et al. PNAS 1997;94:5900-5905

Functions of the LGN

- Inputs
  - Ganglion cell axons from retina (ipsi- and contralateral)
    - Possible role in association or coordination of images
  - Cortex
    - Possible role in attention
  - Optic tectum (superior colliculus)
    - Possible role in saccadic suppression
- Outputs
  - Optic Radiation to primary visual cortex (striate cortex; V1)
    - Primary role in normal vision
  - Putative outputs to higher regions of visual cortex (V2 and V3)
    - Possible explanation for or role in “blind sight”

The Lateral Geniculate Nucleus

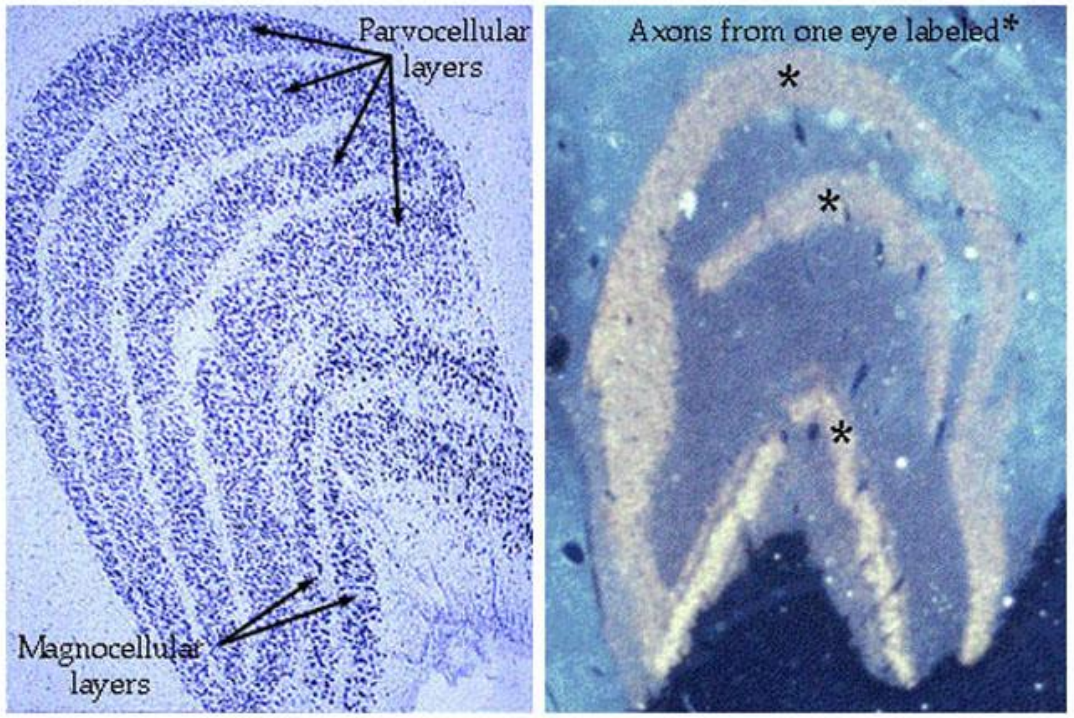


Figure 11. The projections of the small (P cells), and large (M cells) ganglion cells from the two eyes to parvocellular and magnocellular layers of the LGN respectively. Each eye projects to alternating layers as seen in the autoradiogram (right).

Each layer receives contains a complete map of the retina form only one eye (retinotopic mapping).

Alternate layers get input from alternating eyes.

LGN neurons show the same characteristics as the cells from which they receive input.

Sorting of Information in the LGN

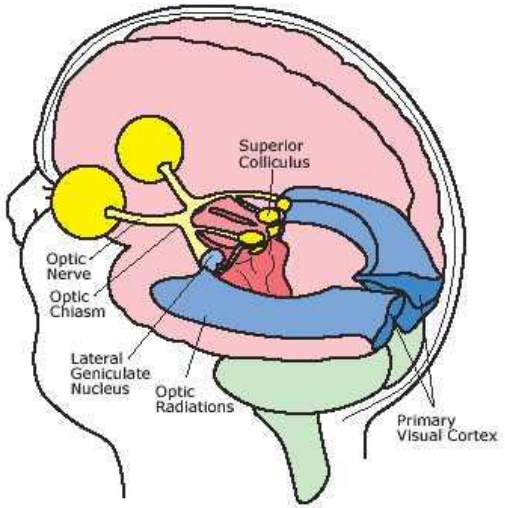
- There are two magnocellular layers (deepest layers)
  - The cells in these layers get input from retinal M cells.
- There are four Parvocellular layers above the M layers.
  - The cells in these layers get inputs from retinal P ganglion cells.
- Between the M and P layers are interspersed thin layers
  - The cells in these layers get input from K-type ganglion cells.

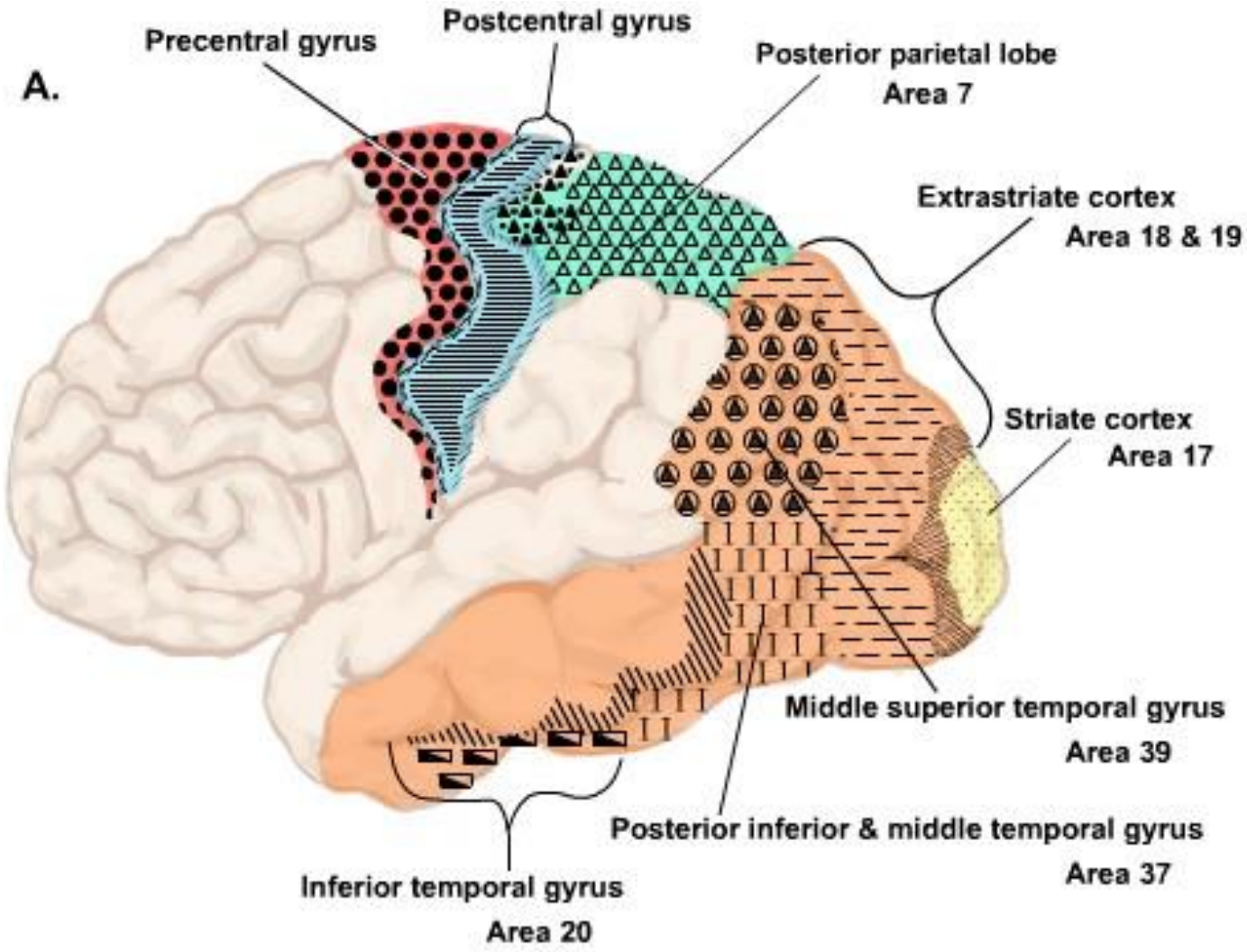
Processing in the LGN

- In summary, then, the LGN consists of alternating monocular layers of cells to allow for the interaction within these layers of specialized information (contrast, movement, color, etc.)
- Each layer then sends its information to specific areas (layers) in the visual cortex
- The LGN also receives input from multiple sources including striate cortex, the thalamic reticular nucleus (TRN), and the brainstem. The LGN therefore represents the first stage in the visual pathway at which cortical top-down feedback signals could affect information processing such as attention.

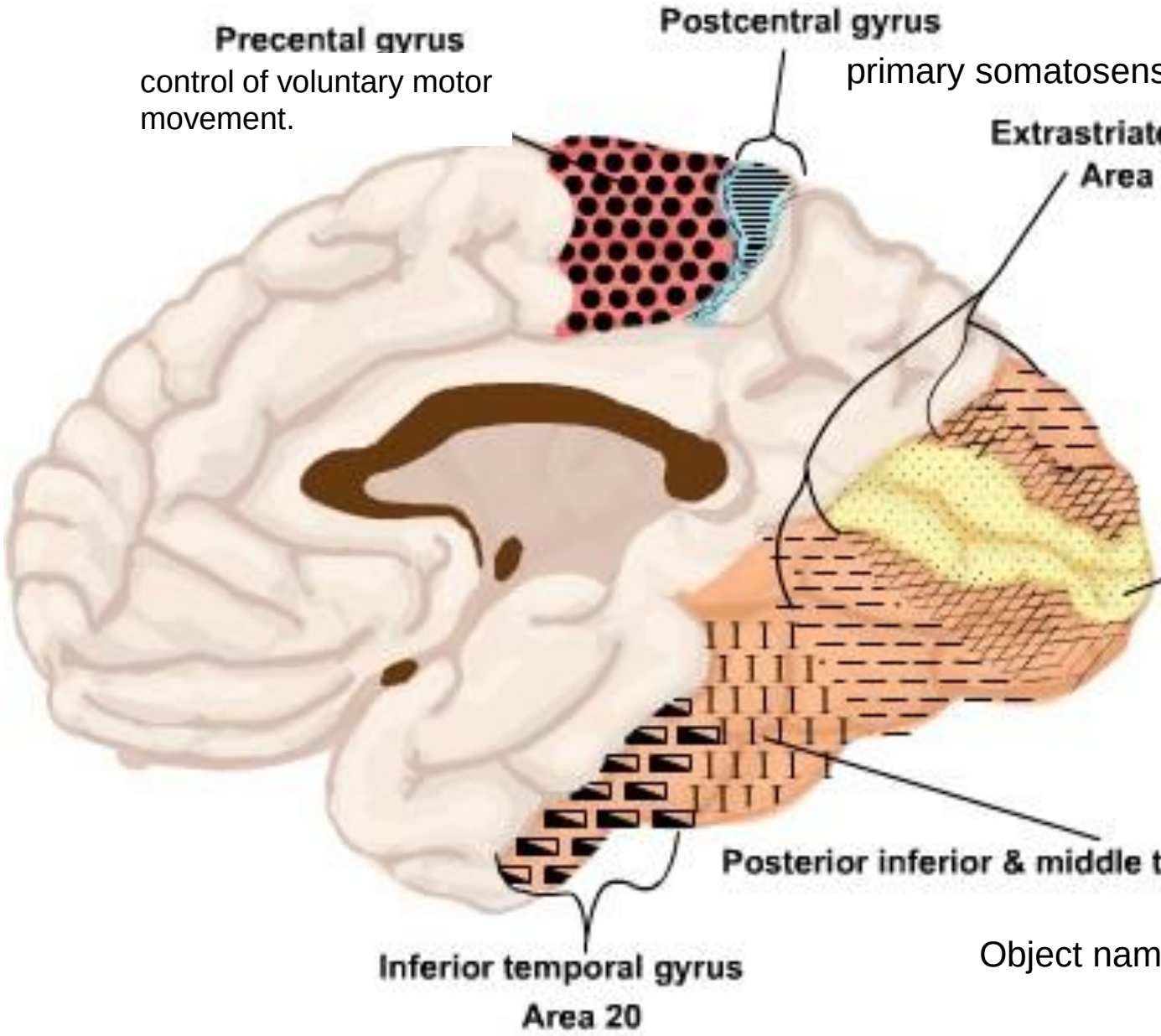
Next Stop: The Primary Visual Cortex

(Striate Cortex; Area V1 of Brodman)





Nearly the entire caudal half of the cerebral cortex is dedicated to processing visual information!



control of voluntary motor movement.

primary somatosensory cortex

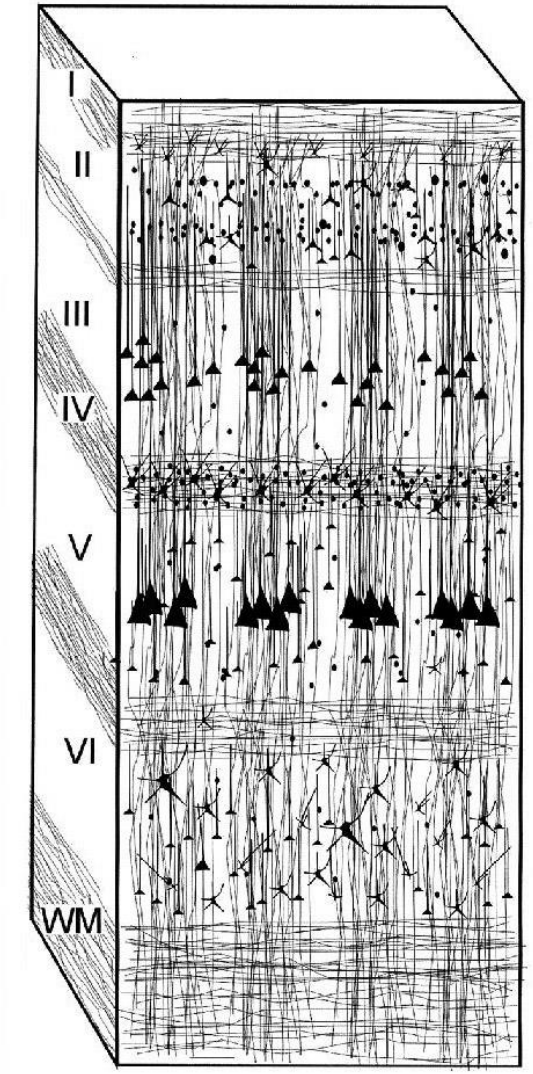
18: Visual Association Area
19: Associative visual cortex involved in the detection of light intensity, feature attention and pattern detection

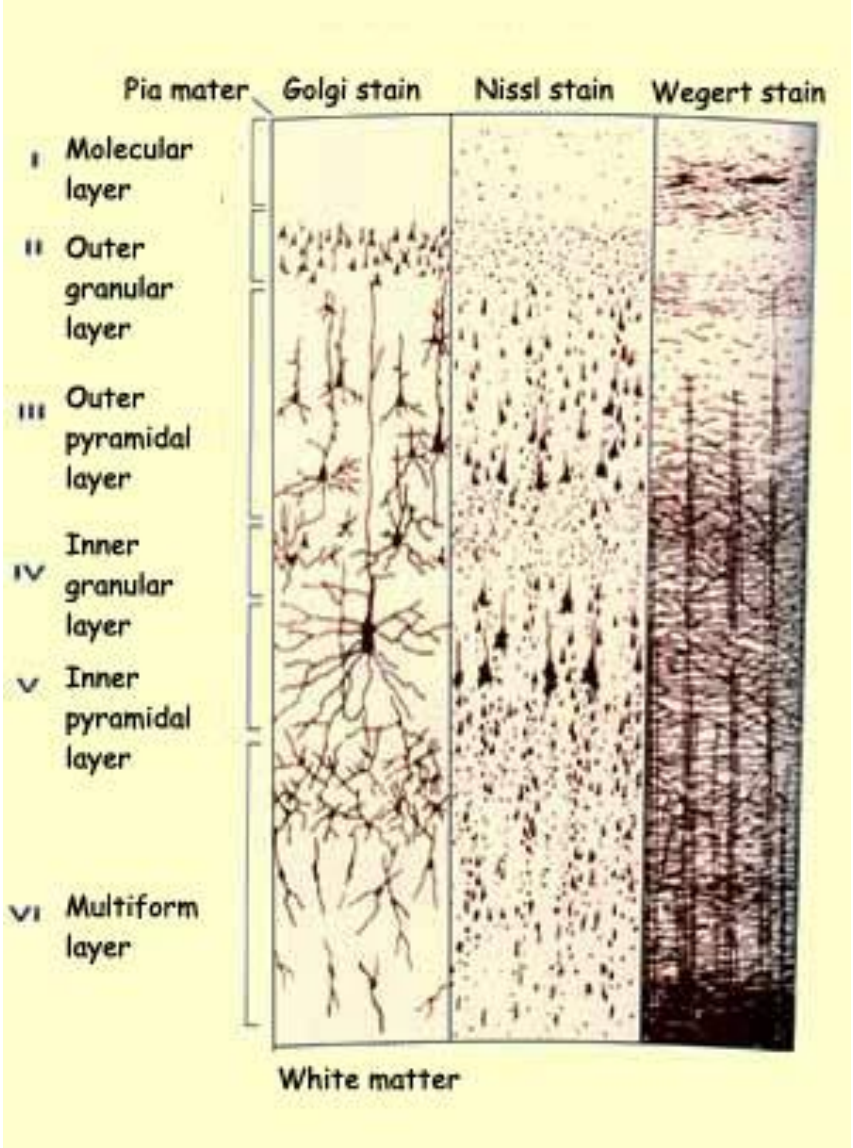
Primary Visual Cortex

Object naming and recognition memory

high-level visual processing and recognition memory.

Anatomy of the Striate Cortex





LGN to Striate Cortex

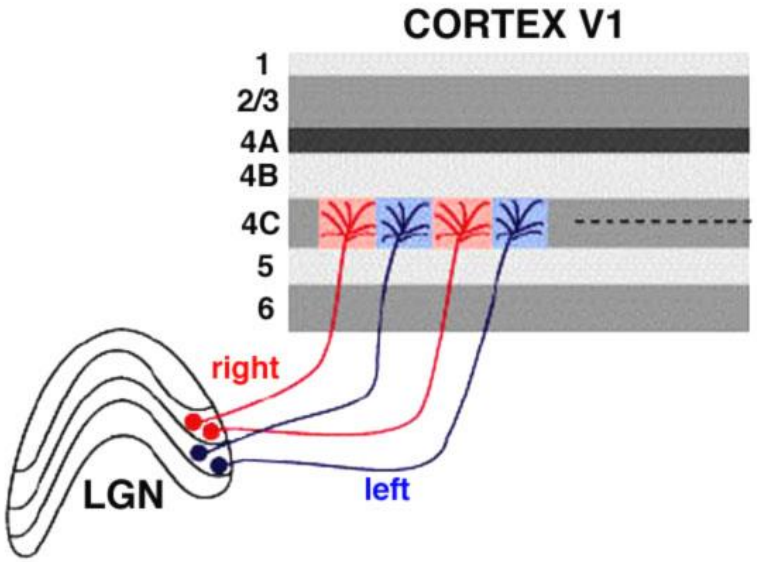


Figure 14. The signals from each eye are segregated within the LGN and go into different ocular dominance columns within area V1, layer 4C.

Axons from the LGN terminate in layer 4C of V1.

LGN P-cell axons terminate in the deeper part (4Cβ) Postsynaptic cells here send axons to VI layers 2 and 3. Axons from these layers go to V2;

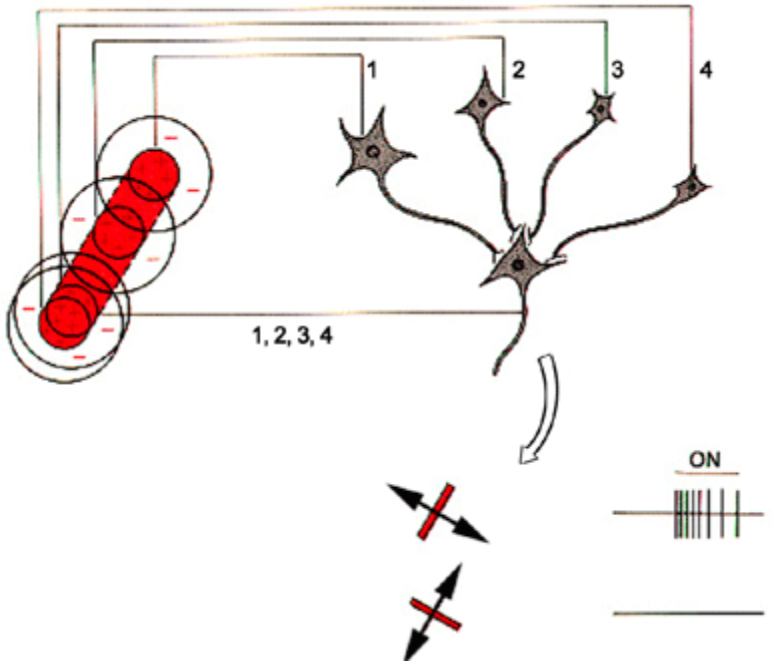
LGN M-cells terminate in V1 layer 4Cα. Postsynaptic neurons then send axons to layer 4B and to both V2 and V5.

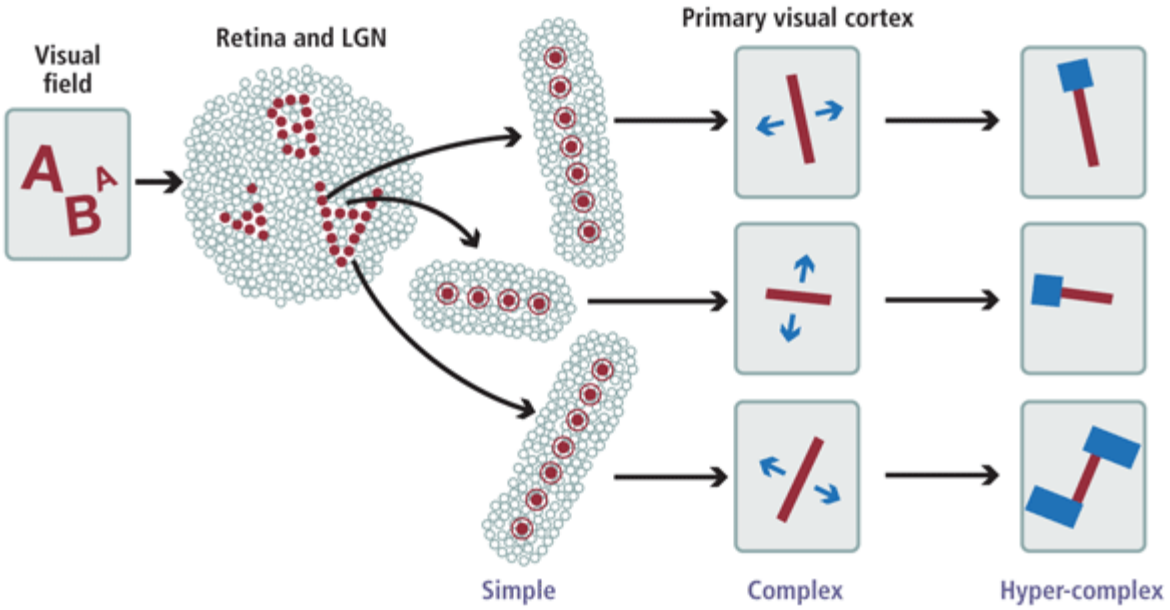
In both cases (P and M) the axons from a given (monocular) layer in the LGN terminate in adjacent columns in V1

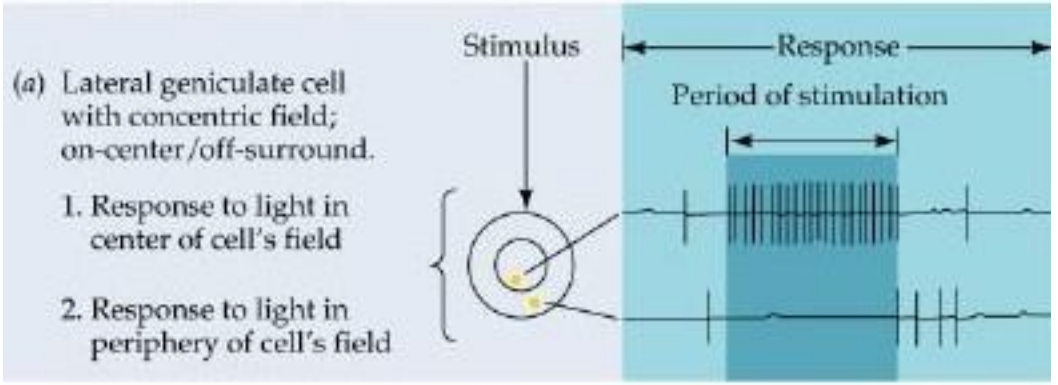
Signal Processing by the Striate Cortex

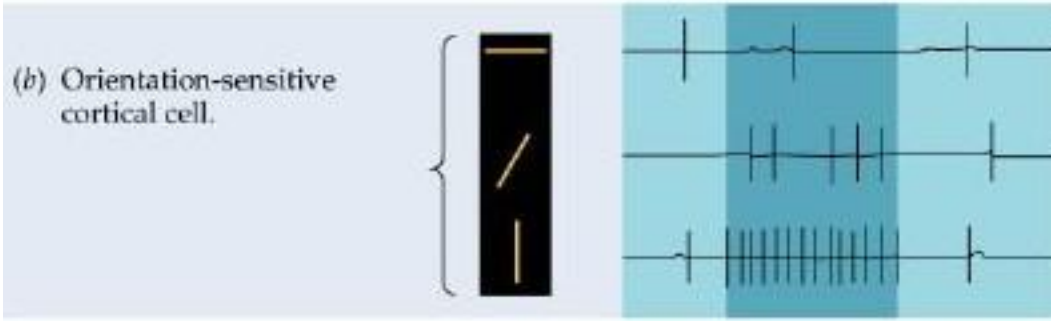
- In the striate cortex (V1) we find the first real processing of the raw signals from the LGN into more complex analysis:
  - New types of receptive fields
  - Binocular interactions

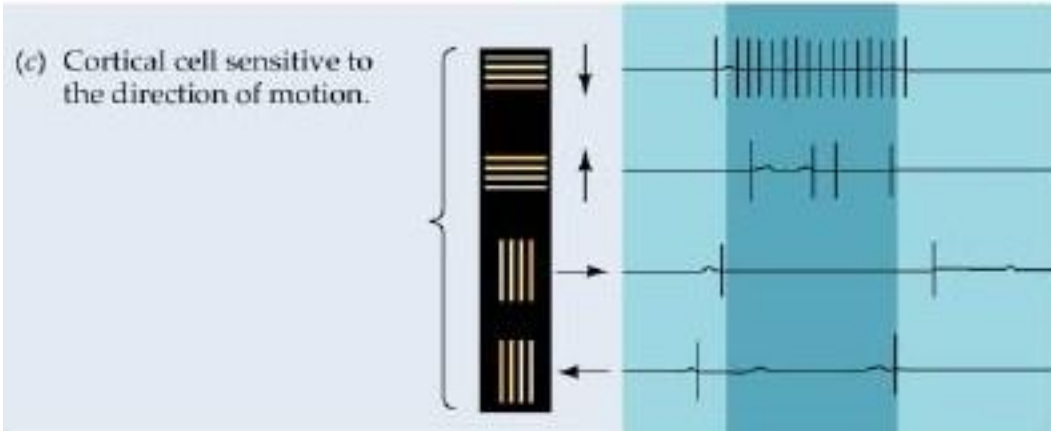
Cortical Cells







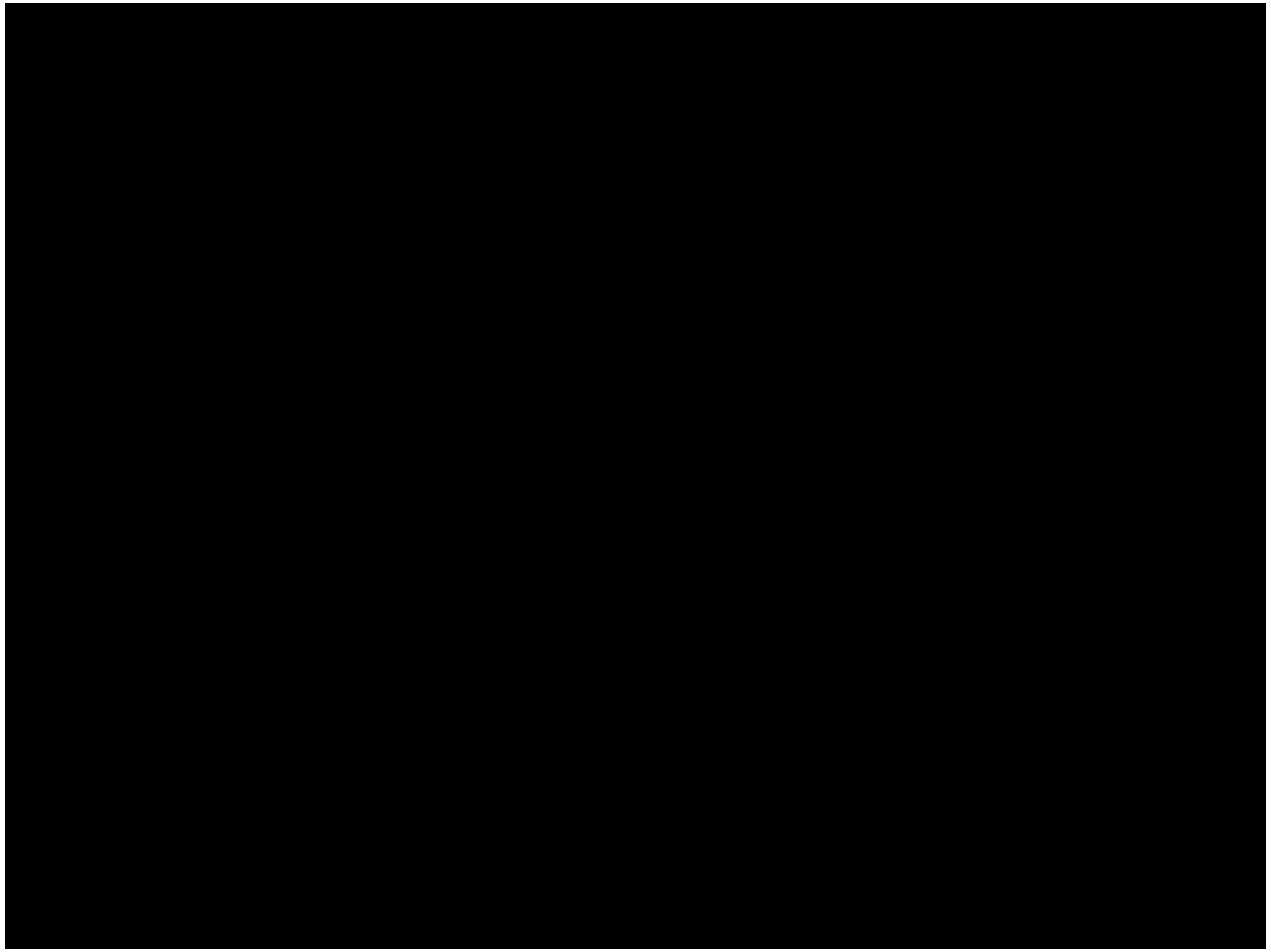




Receptive Fields in the Striate Cortex: Hubel and Wiesel's Pioneering Work*

*Shown here by Colin Blakemore

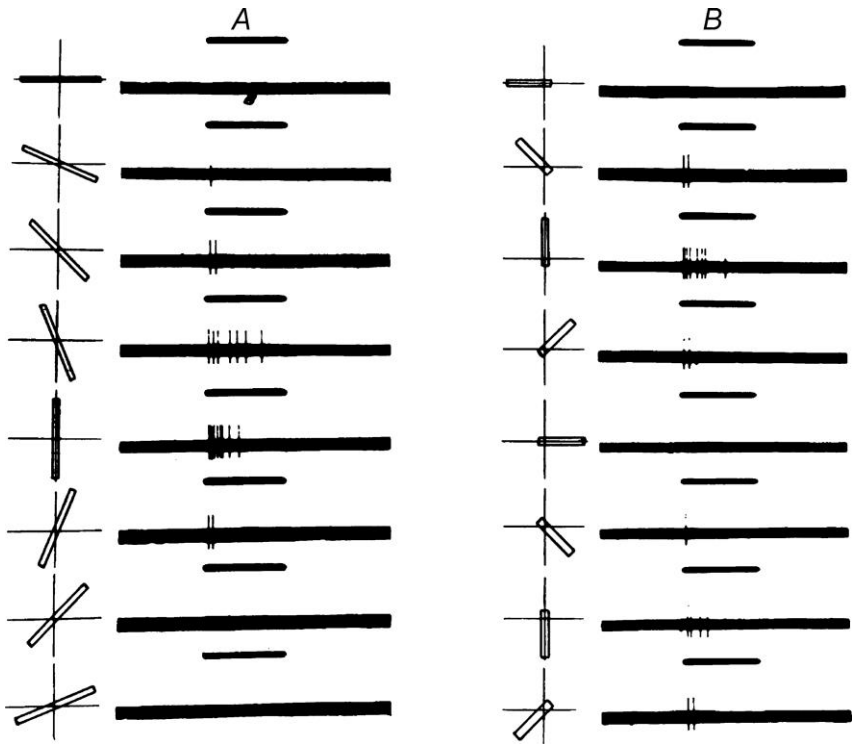
Some Hubel and Wiesel Experiments



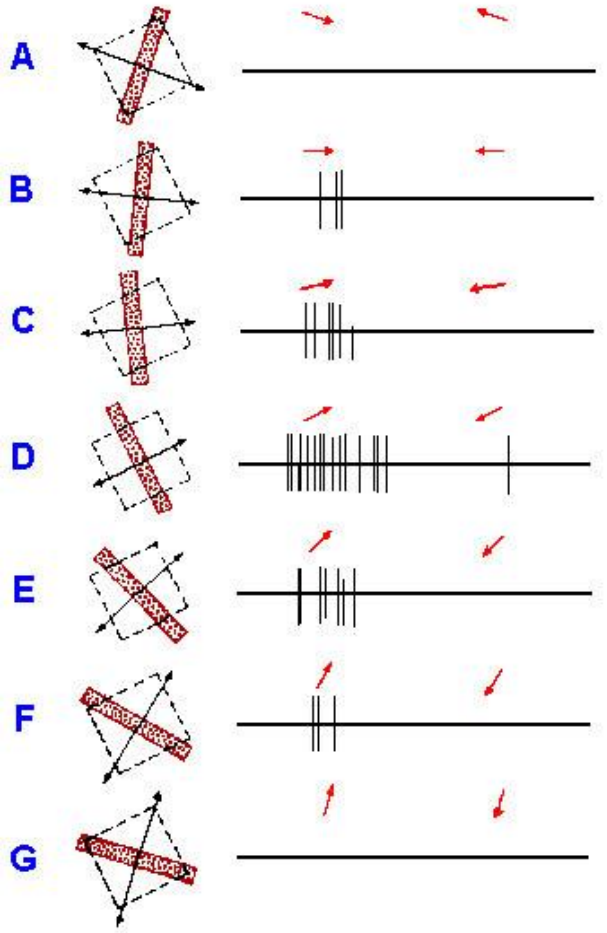
Receptive fields in Striate Cortex (V1)

- Unprocessed fields
  - Simple center/surround fields as found in retinal ganglion cells and the LGN
  - Found only in layer 4C (where LGN fibers terminate)
- “Simple” fields
  - Found mostly in layers 4 and 6
  - Optimal stimulus is a bar of light (or dark) of a certain width and a certain orientation at a particular location in the receptive field.
- “Complex” fields
  - Found in all layers, but most abundant in 2,3 and 5
  - Optimal stimulus is similar to simple fields, but the location within the field is unimportant.
  - Many are also directionally selective

Simple receptive fields I: orientation

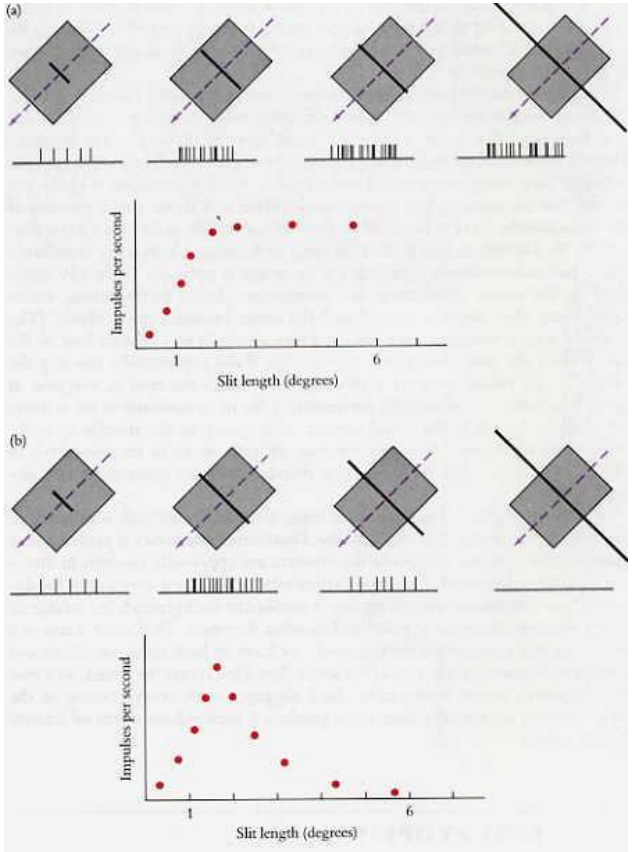


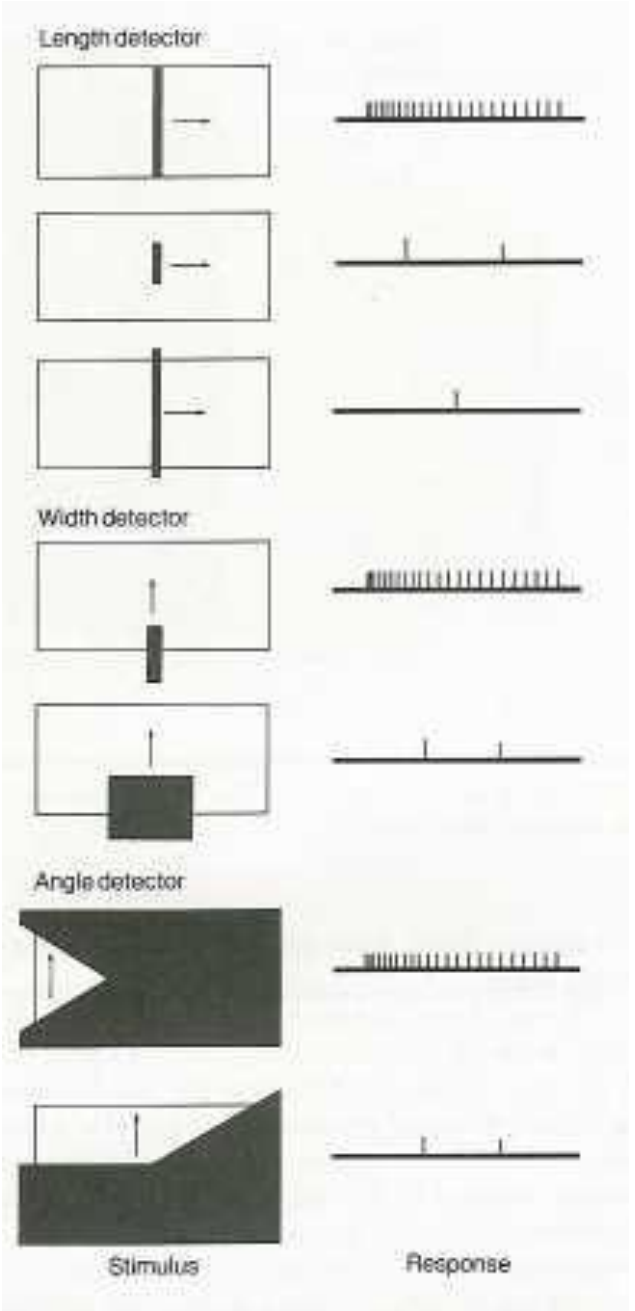
Orientation only



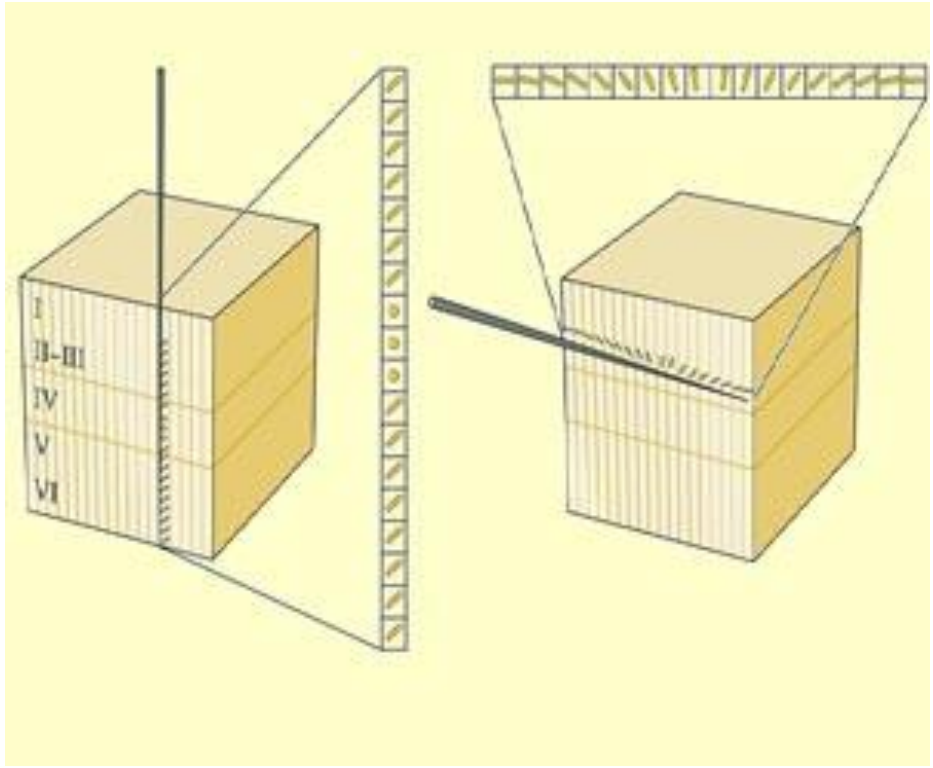
Orientation and direction

Complex receptive fields: end-stopped, width and angles

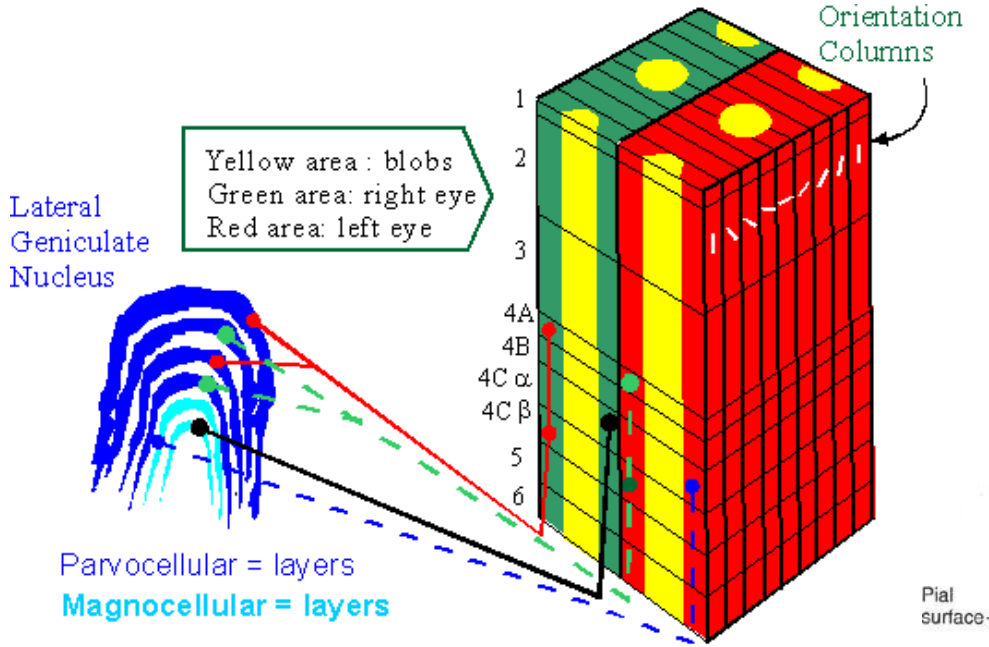


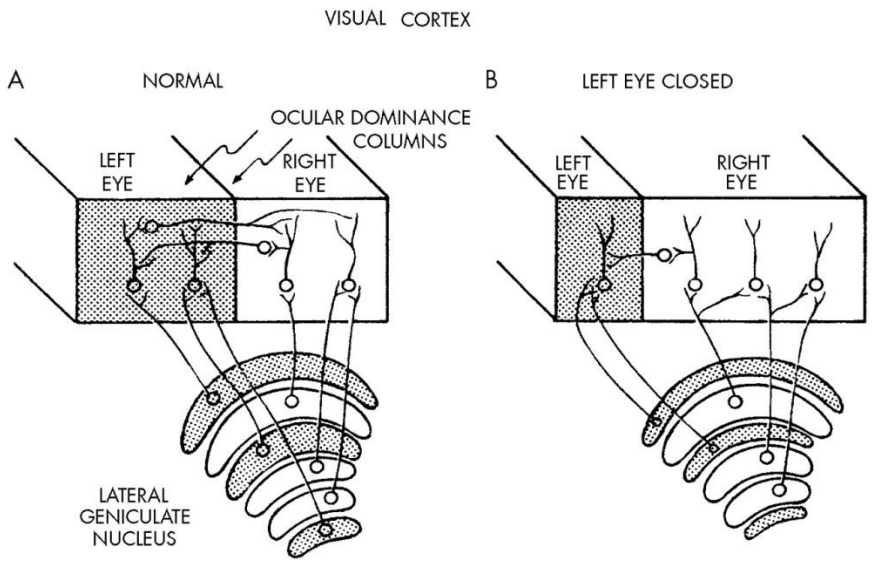


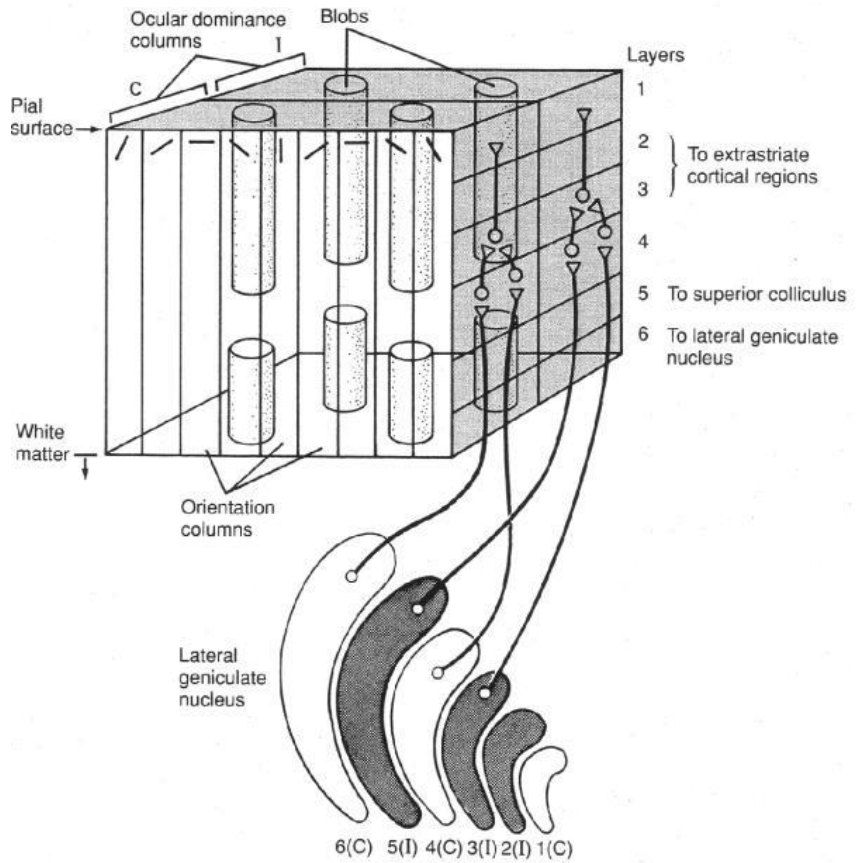
Organization of the Striate Cortex: orientation columns

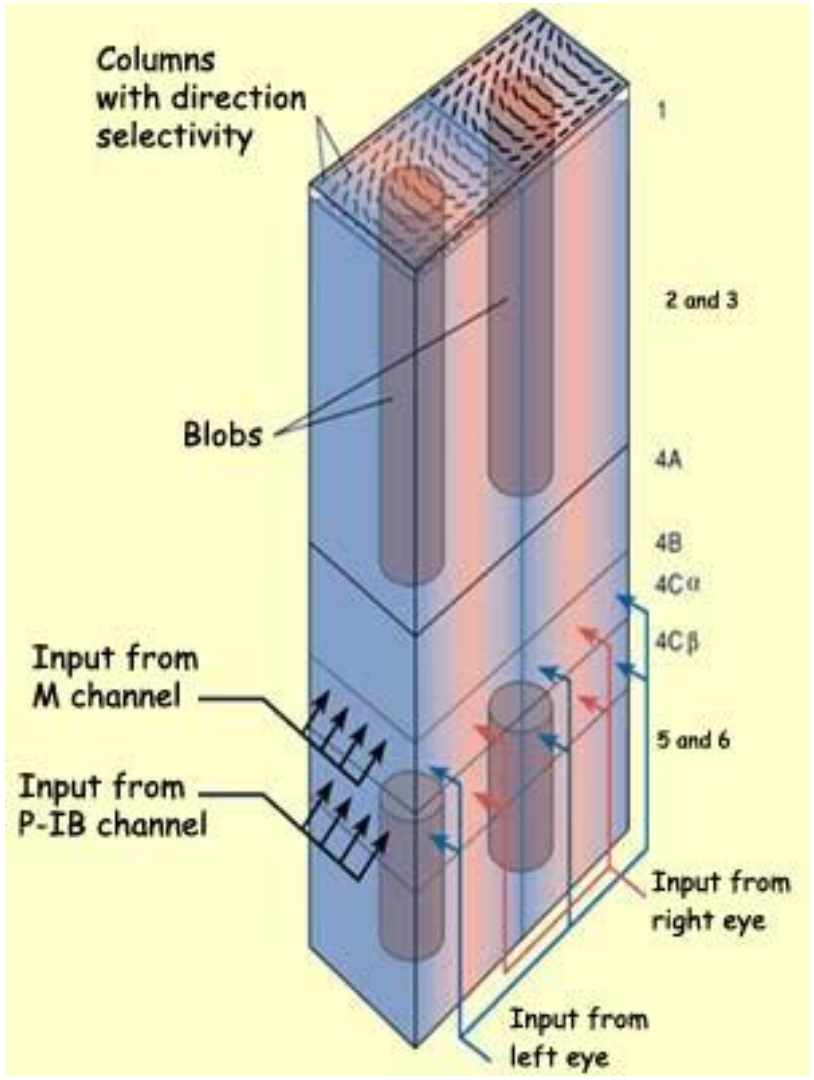


Ocular Dominance Columns









Blobs

Cytochrome oxidase staining reveals dark-staining columns 0.2mm in diameter and spaced at 0.5mm intervals that extend through layers 2 and 3 and to a lesser extent in 5 and 6.

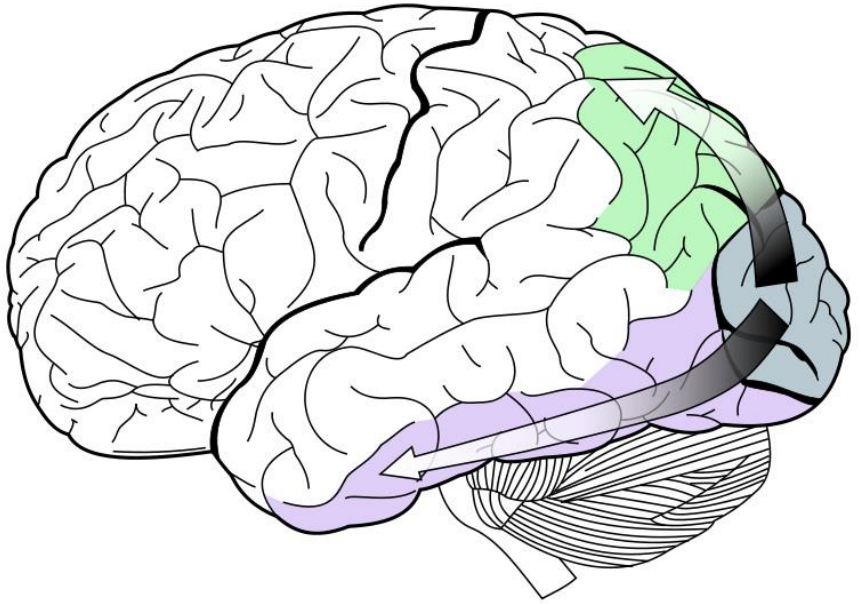
While interblob cells show little color preference but instead are sensitive to orientation and have small receptive fields, blob cells are the opposite: color sensitive (color-opponent center-surround fields), orientation-insensitive, large receptive fields.

Two main pathways

- Parvocellular Pathway:
  - Retinal P cells to LGN P cells to V1 layer 4Cβ
  - Then splits into two paths in the upper layers of V1:
    - P-I: goes via interblob cells; mediates high-acuity perception
    - P-B: goes via blob cells; mediates color vision
  - Ultimately the P pathway goes to the inferior temporal cortex which mediates object and pattern recognition (ventral or “what” pathway)
- Magnocellular Pathway:
  - Retinal M cells to LGN M cells to V1 layer 4Cα
  - Ultimately goes to posterior parietal cortex which processes spatial and motion information (Dorsal or “where” pathway)

What happens next

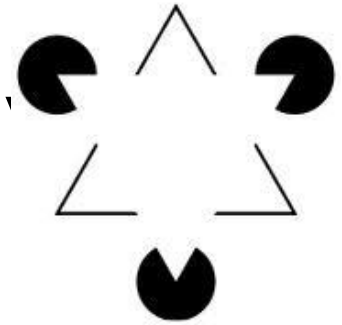
The stream from V1 divides into a dorsal and ventral component.



Dorsal (magnocellular) stream: V1 →V2 → V3 → V5 → posterior parietal cortex. Called the "Where Pathway". Associated with motion, representation of object locations, and control of the eyes and arms, especially when visual information is used to guide saccades or reaching.

Ventral (parvocellular) stream: V1 → V2 → V3 → V4, → inferior temporal cortex. Called the "What Pathway“, Associated with form recognition and object representation and with storage of long-term memory

Higher visual processing:



- Maps: single retinotopic map of LGN and V1 altered to form several different maps: orientation, interocular disparity and color.
- Receptive fields: more complex: orientation of illusory contours, binocular disparity, and whether the stimulus is part of the figure or the ground and multiple orientations at different subregions within a single receptive field.
- Other: V2 cells show a small amount of attentional modulation, are tuned for moderately complex patterns, and may be driven by multiple orientations at different subregions within a single receptive field.

Higher Processing: V3

- Divided into dorsal and ventral V3.
  - Dorsal V3 gets input from V1 and V2 and projects to V5 and the posterior parietal cortex (“where” pathway).
    - Neurons respond to coherent motion of large patterns covering extensive portions of the visual field.
  - Ventral V3 gets most inputs from V2, projects to V4 and the inferior temporal cortex (“what” pathway).
- Most cells in V3 are orientation specific, concerned with processing dynamic form.

Higher Processing: V4 (Ventral or “What” Stream)

- Gets inputs from V1 and V2; sends outputs to the posterior inferior temporal lobe
- V4 is the first area in the ventral stream to show strong attentional modulation (selective attention can change firing rates in V4 by about 20%).
- Tuned for orientation, spatial frequency, and color, but more complex than V1: tuned for object features of intermediate complexity, like simple geometric shapes.
- V4 exhibits long-term plasticity, encodes stimulus salience, and shows changes in the spatial profile of its receptive fields with attention.

Last stop on the ventral “what” pathway: The inferior temporal cortex:

- Crucial for object recognition
- Cells have large receptive fields, even crossing the midline of the visual field of each eye.
- Usually selective for the shape or color of the stimulus or both parameters and almost all units respond more to complex than simple shapes.
- Selectivity for shape is invariant over changes in stimulus size, contrast, color and exact location on the retina.
- A small percentage of units are selective for facial images. Some respond to emotional expression and some to direction of eye gaze. Cells selective for hands are also found.
- Activity of neurons can be modulated by attention.
- Neurons can show both short or long term memory for visual stimuli and their selectivity can be modified by experience.

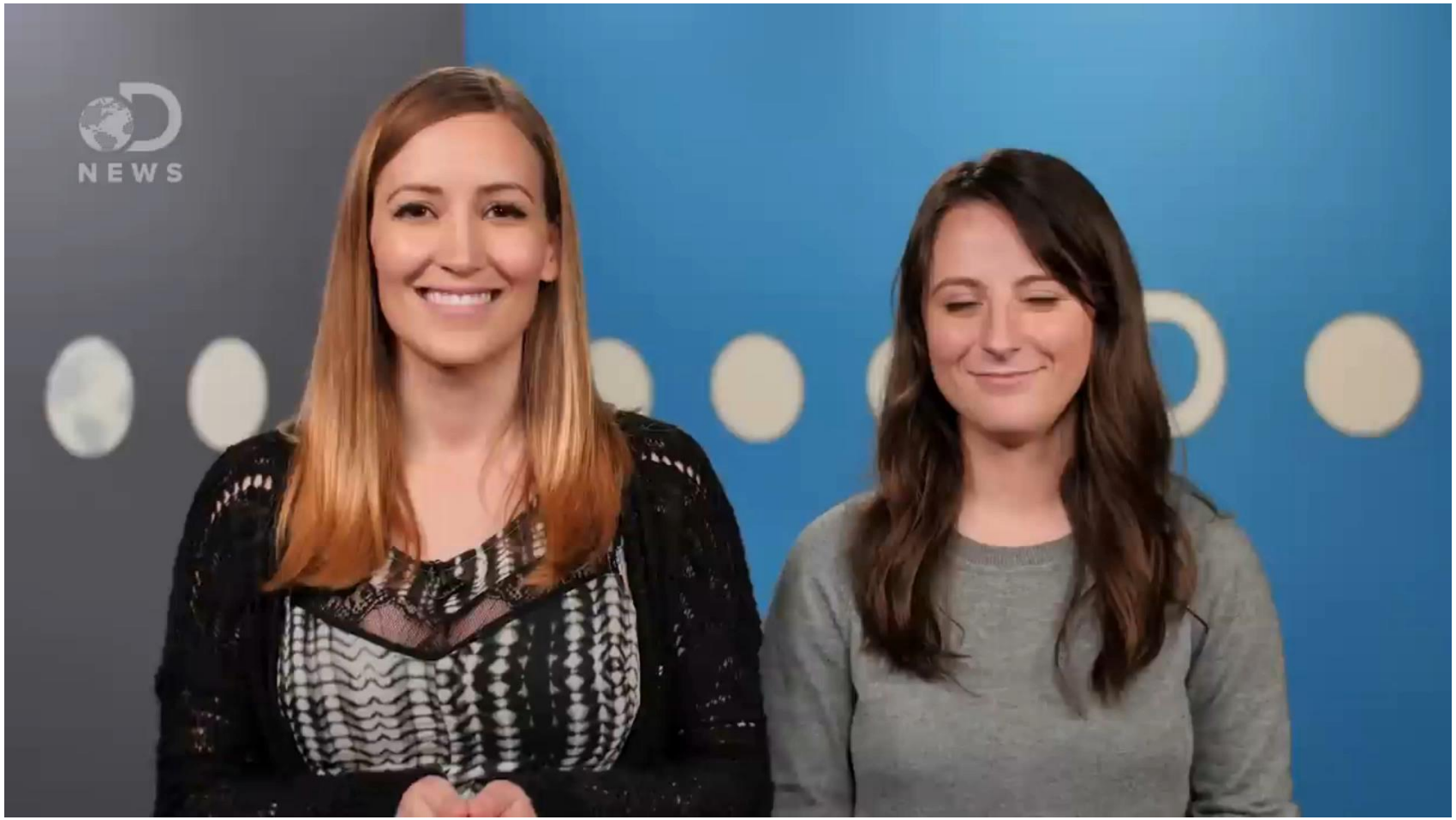
Lesions in the inferior temporal cortex

- Prosopagnosia (prosopo-, from the Greek for “face” or “person”): the inability to recognize and identify faces. Patients are often unable to identify familiar individuals by their facial characteristics, and in some cases cannot recognize a face at all. Nonetheless, such individuals are perfectly aware that some sort of visual stimulus is present and can describe particular aspects or elements of it without difficulty.

An example: L.H., a 40-year-old minister and social worker had sustained a severe head injury as the result of an automobile accident when he was 18. After recovery, L.H. could not recognize familiar faces, report that they were familiar, or answer questions about faces from memory. He was nonetheless able to lead a fairly normal and productive life. He could still identify other common objects, could discriminate subtle shape differences, and could recognize the sex, age, and even the “likability” of faces. Moreover, he could identify particular people by nonfacial cues such as voice, body shape, and gait.

Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001. Lesions of the Temporal Association Cortex: Deficits of Recognition.

The Highest of Processing in Humans: Facial Recognition




The End
Thanks for sticking with me!