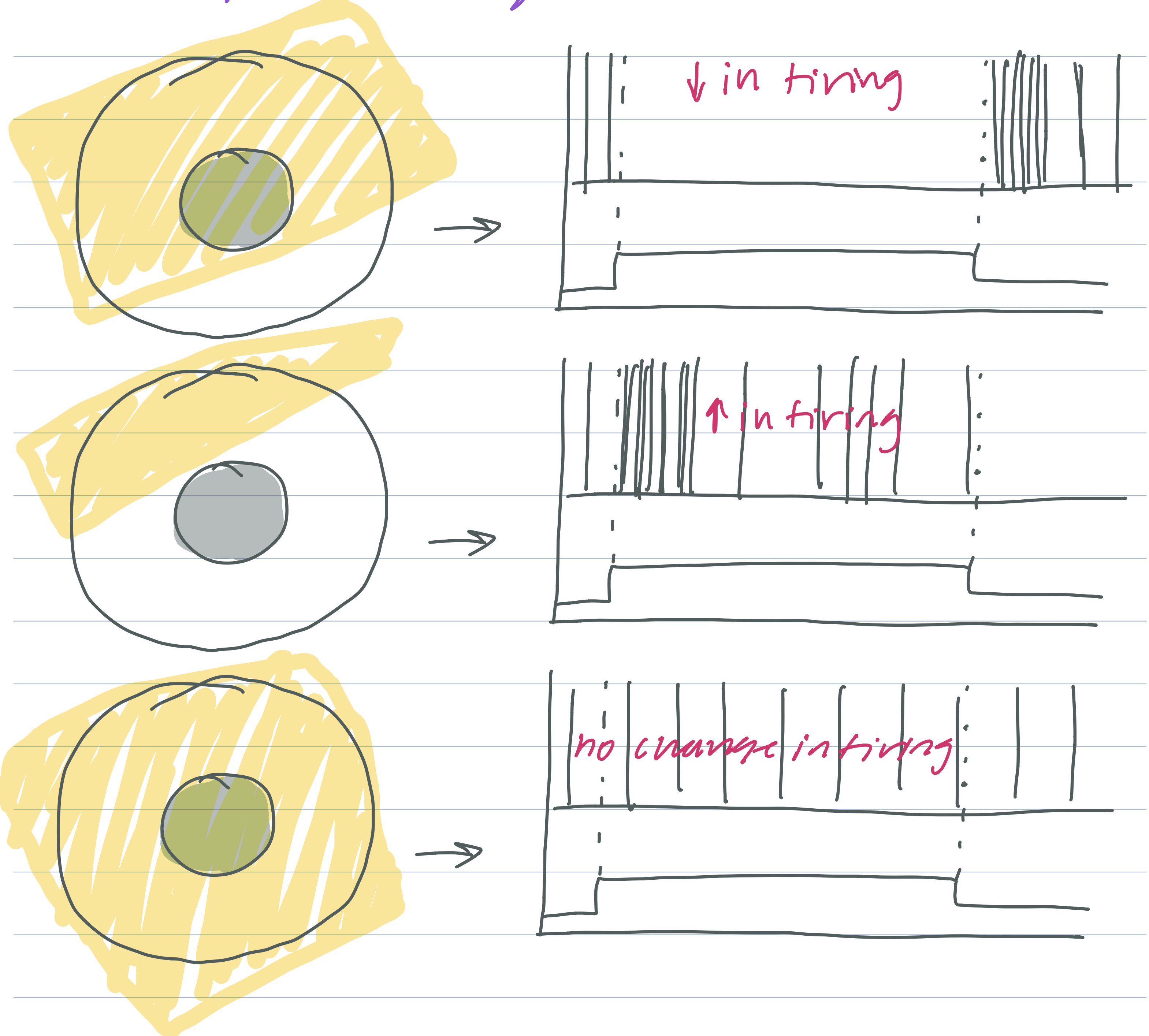
Neuro 80 Lecture 14 Oct 23 2015

What would match OFF-retinal ganglion cell response to light across center?



An obj on the very edge of left visual field is detected by

left nasal retina

Pituitary tumors disrupt optic chiasm. Causes visual impairments that include

loss of peripheral vision

MCB/Neuro 80 - Neurobiology of Behavior

Today's Topic:

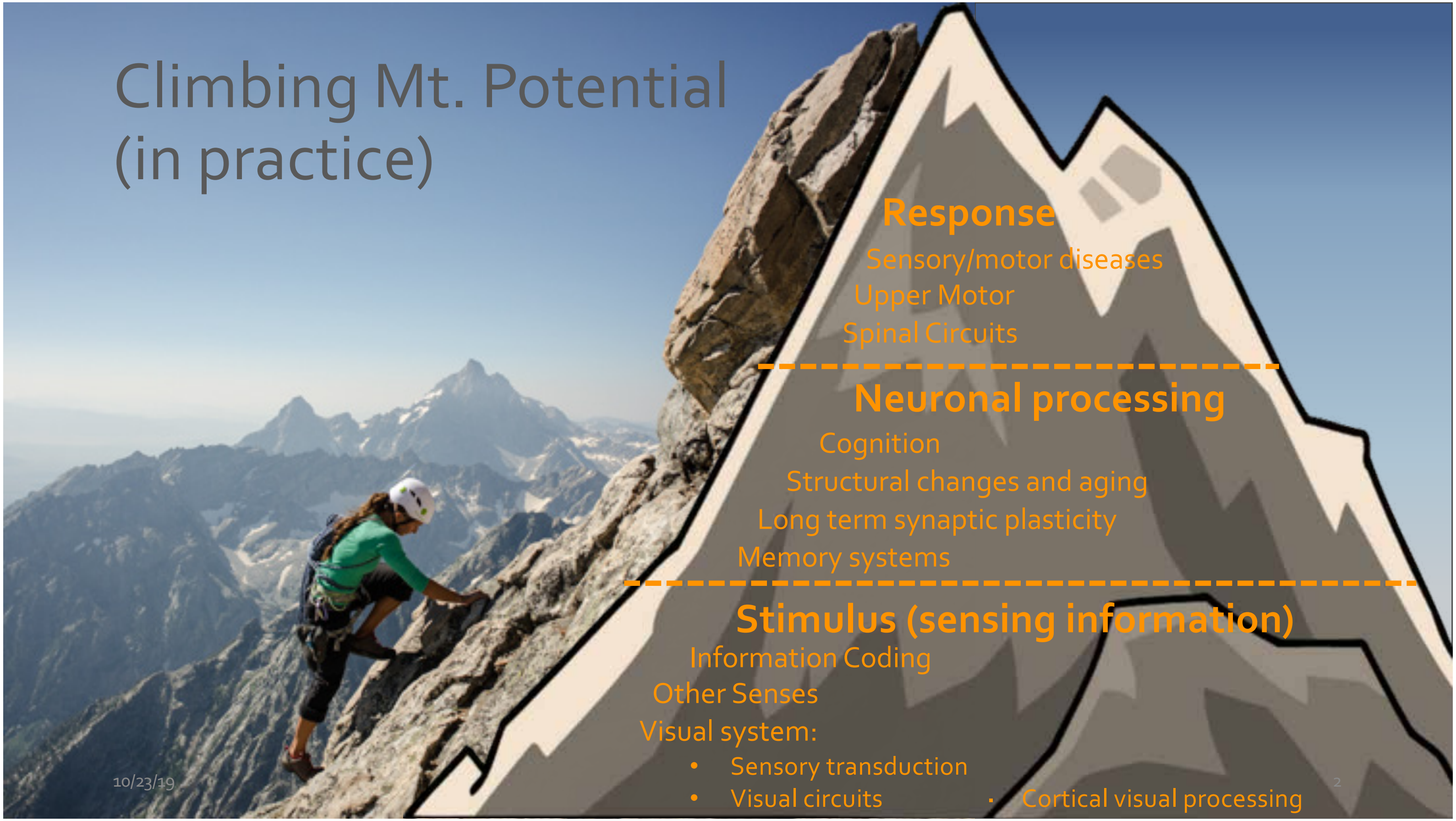
Vision 3 – the brain

Lecture 14

Optional reading: Purves et al., Neuroscience 6th pages 261-279

Lecture notes, review questions, office hour times available at:

https://canvas.harvard.edu/courses/59120


Climbing Mt. Potential
(in practice)
Response
Sensory/motor diseases
Upper Motor
Spinal Circuits
Neuronal processing
Cognition
Structural changes and aging
Long term synaptic plasticity
Memory systems
Stimulus (sensing information)
Information Coding
Other Senses
Visual system:
• Sensory transduction
• Visual circuits
• Cortical visual processing

Two important lessons from the retina

1) Hierarchical processing:

the receptive field properties get more complicated as the signal moves from photoreceptors to retinal ganglion cells.

2) Parallel processing:

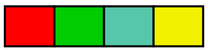
streams of information related to properties of the visual scene are dealt with simultaneously by different circuits

- These themes may continue as visual information leaves the retina and travels further into the brain

Properties of the visual world that our visual system encodes

• Position (vertical, horizontal and depth axes)

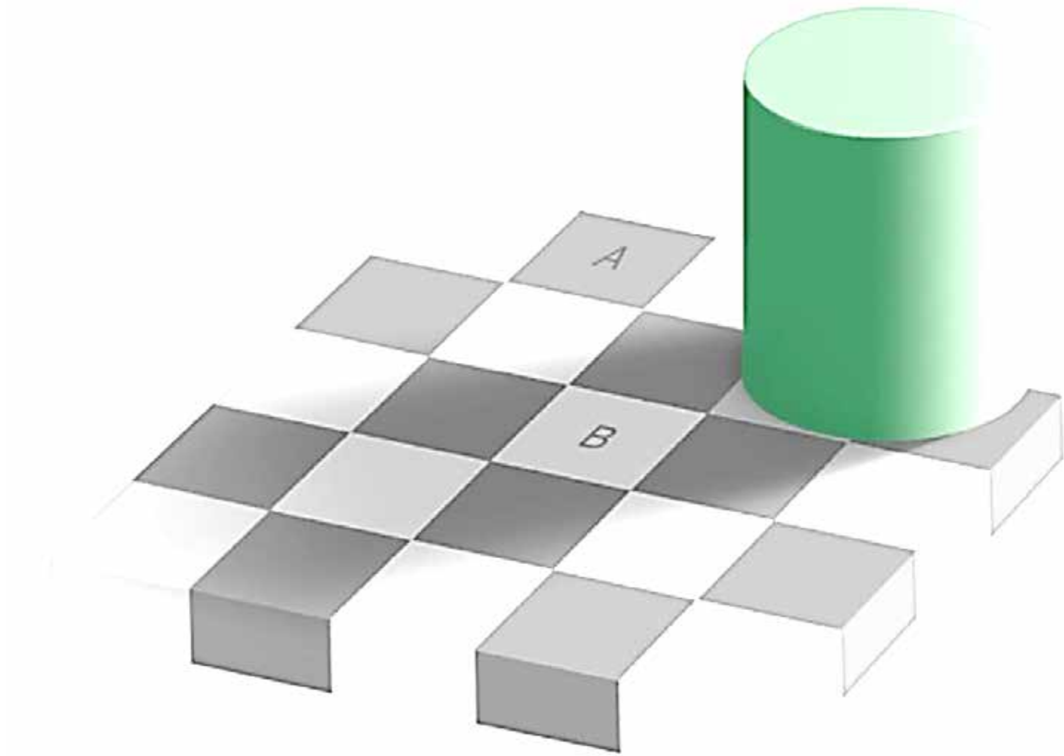
• Position (vertical, horizo

- Shape
- Color 
- Position (vertical, horizontal and depth axes)
- Movement
- What don’t we encode?

• Position (vertical, horizontal and depth axes)

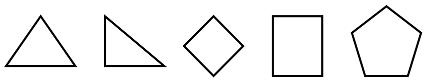
• Position (vertical, horizontal and depth axes)

We sense relative, not absolute, intensities



http://web.mit.edu/persci/people/adelson/checkershadow_downloads.html

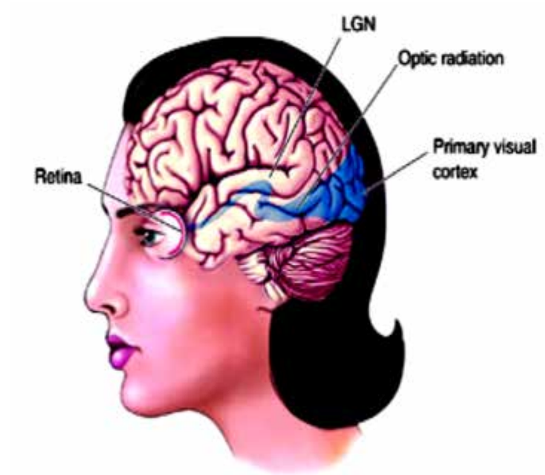
Properties of the visual world that our visual system encodes

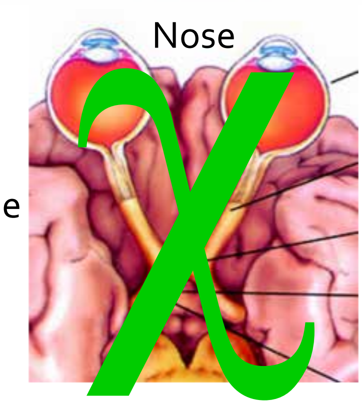
- Shape 
- Color 
- Position (vertical, horizontal and depth axes)
- Movement
- What don't we encode?

Light Intensity

Retinofugal projection

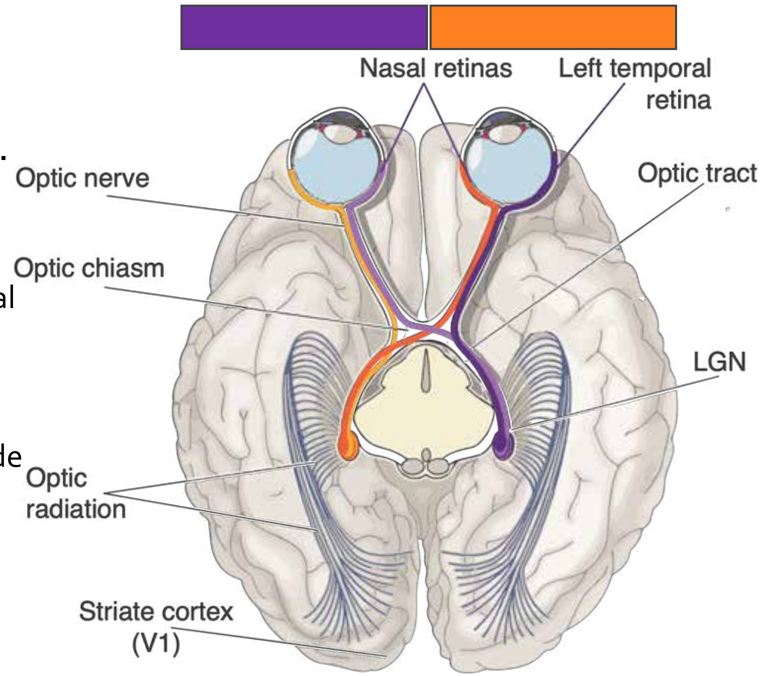
- Pathway of optic nerve to brain called retinofugal (fugal meaning “to flee”). Has 5 parts before reaching visual cortex
  1. Optic Nerve - axons from the R and L retina exit the eye through the optic disc .
     - Section between retina and optic chiasm (X)
  2. The chiasm is site of a decussation (crossing) so that each half of the visual field ends up on the opposite (contralateral) side





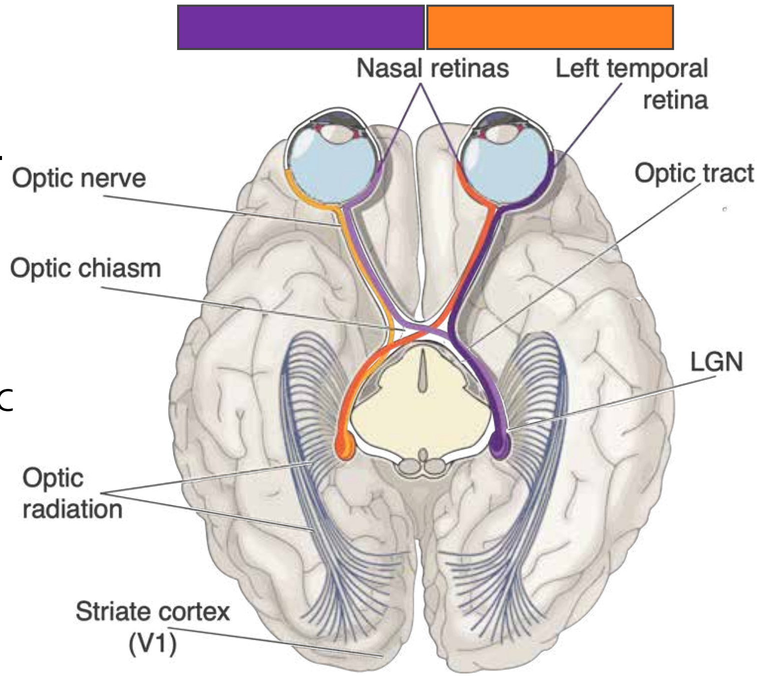
Retinofugal projection puts the left and right visual fields in the right and left cerebral cortex, respectively

1. Optic Nerve - axons from the R and L retina exit the eye through the optic disc .
2. The chiasm is site of a decussation (crossing)
   - L visual field from both eyes project to R cortical hemisphere (and R field to L hemisphere)
   - Nasal part of retinal crosses to contralateral (opposite)
   - Temporal part remains on ipsilateral (same) side



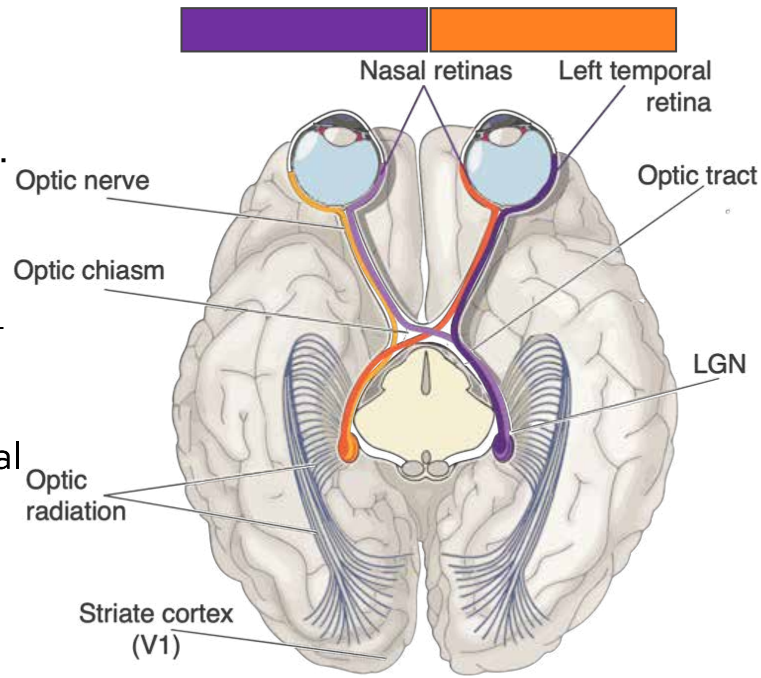
Retinofugal projection puts the left and right visual fields in the right and left cerebral cortex, respectively

1. Optic Nerve - axons from the R and L retina exit the eye through the optic disc .
2. The chiasm is site of a decussation (crossing)
3. After the chiasm, the R and L optic tracts contain axons from both eyes
   - ipsilateral temporal and contralateral nasal RGC axons



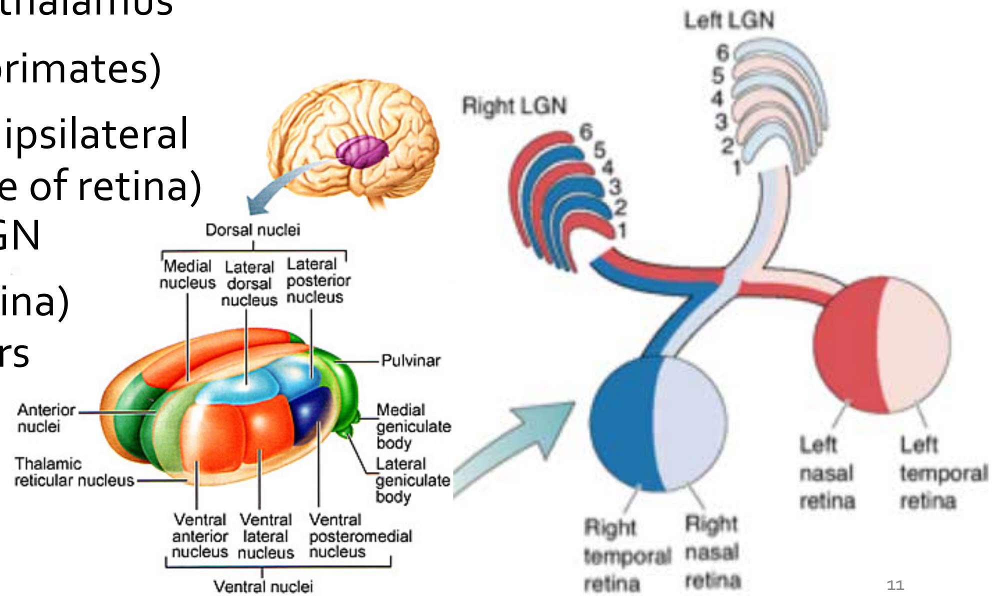
Retinofugal projection puts the left and right visual fields in the right and left cerebral cortex, respectively

1. Optic Nerve - axons from the R and L retina exit the eye through the optic disc .
2. The chiasm is site of a decussation (crossing)
3. After the chiasm, the R and L optic tracts contain axons from both eyes
4. R and L lateral geniculate nucleus of the thalamus (LGN) contain the L and R visual fields, respectively
5. Axons of the LGN neurons exit the thalamus to primary visual cortex (V1). Through the optic radiations

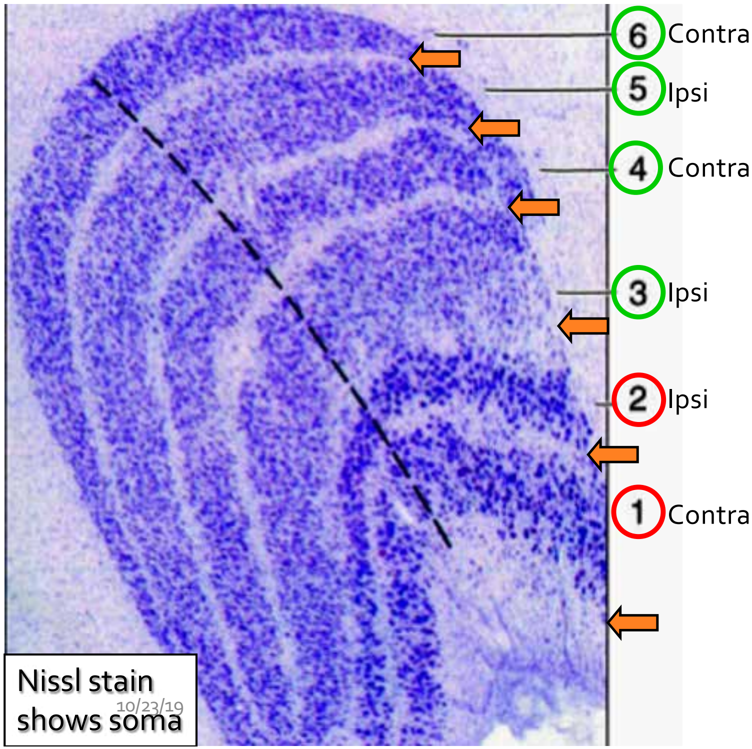


The lateral geniculate nucleus (LGN) in the thalamus

- In dorso-lateral part of thalamus
- Each has six layers (in primates)
- Retinal axons that stay ipsilateral (i.e., from temporal side of retina) project to 3 layers of LGN
- Contralateral (nasal retina) projects to other 3 layers



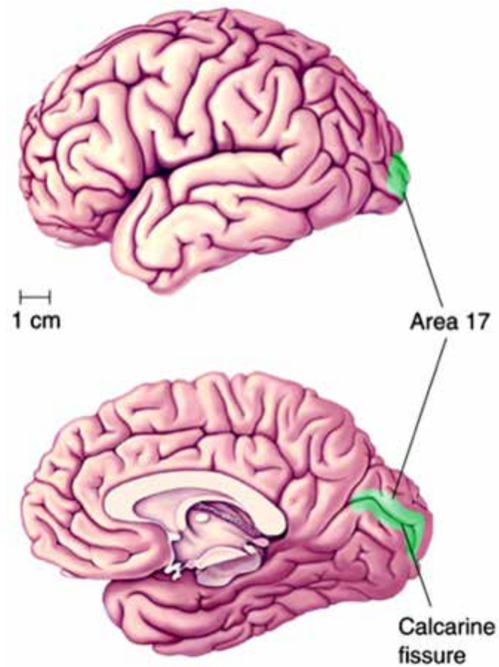
Three functional streams in the LGN



- Ventral most layers 1 and 2 contain larger neurons (magnocellular) for Motion
- The four more dorsal layers small cells (parvocellular) for Shape
- Just ventral to each layer, numerous tiny neurons (koniocellular) for Color
- M-type, P-type, and "nonM-nonP" *retinal ganglion cells* thought to innervate 3 LGN cell types respectively
- Example of "parallel processing"

Output of thalamus is primary visual cortex (aka: Striate cortex, or V1, or Area 17)

- Located in occipital cortex



Output of thalamus is primary visual cortex (aka: Striate cortex, or V1, or Area 17)

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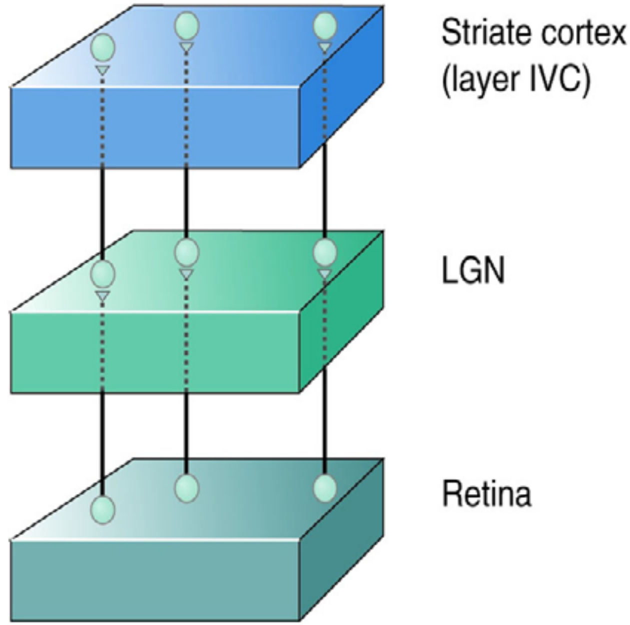
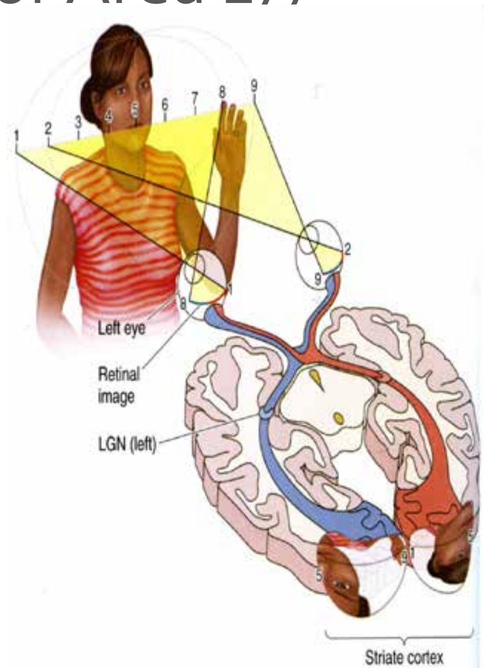
- "Retinopy": 2 dimensional surface of retina mapped (topographically arranged) onto two dimensional surface of the subsequent structures (thalamus and cortex)

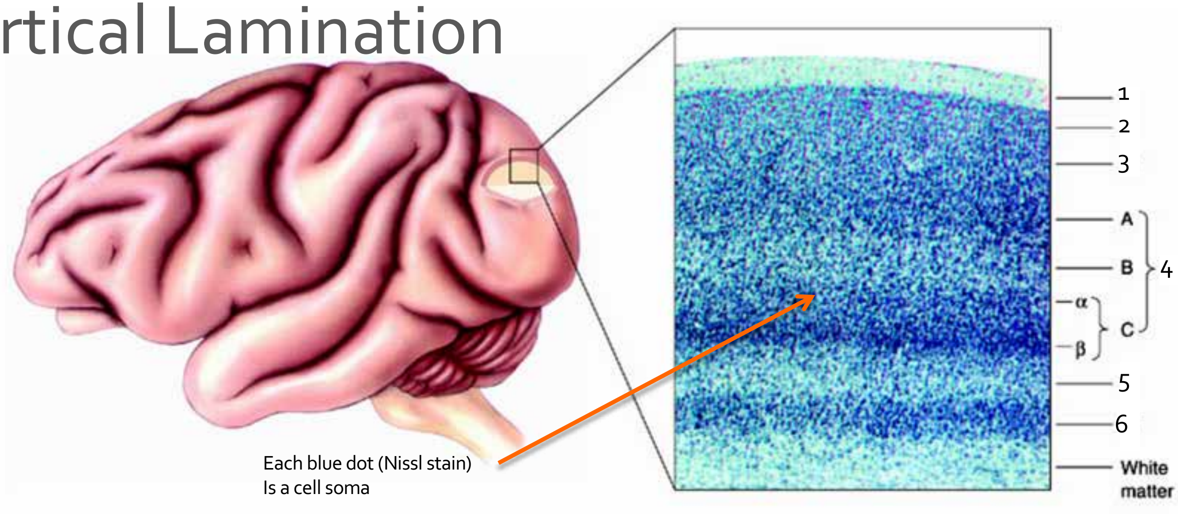


Output of thalamus is primary visual cortex (aka: Striate cortex, or V1, or Area 17)

- Located in occipital cortex
- "Retinopy": 2 dimensional surface of retina mapped (topographically arranged) onto two dimensional surface of the subsequent structures (thalamus and cortex)
- L and R visual field seamlessly knit together despite being in very different parts of the brain
- Central few degrees of visual field are over-represented (magnified) for better acuity in the center of the visual field



Cortical Lamination



- About 6 distinct layers (with a few possible sublayers) in the gray matter, total 2 mm in thickness
- Division of function as in LGN but with an entirely different organization
- Much of the thalamic (LGN) input to Layer 4

Cortical neurons are extraordinarily diverse

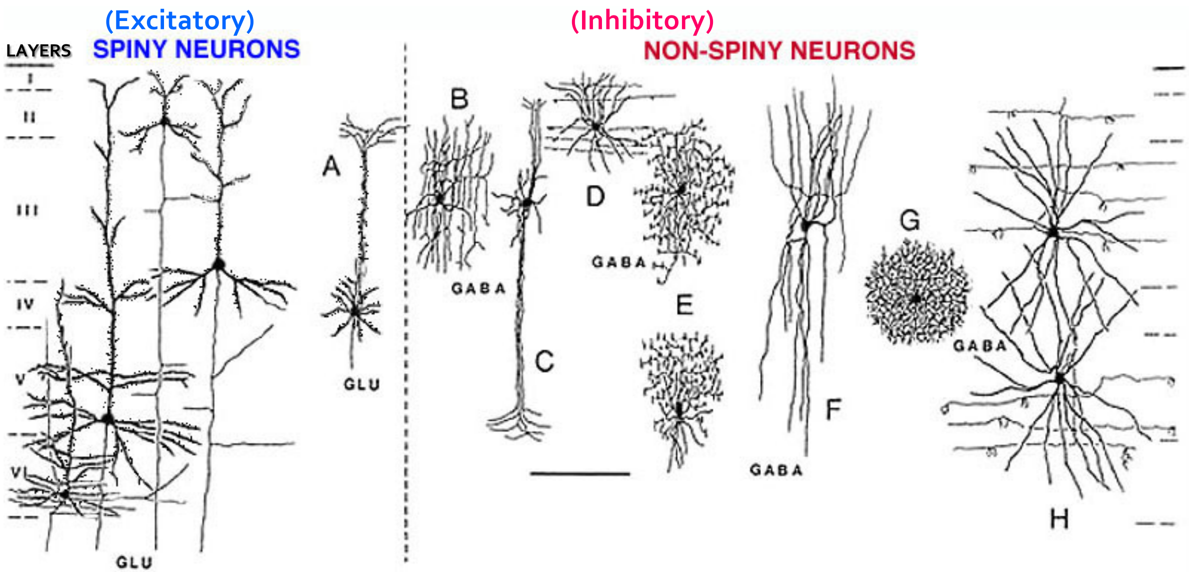
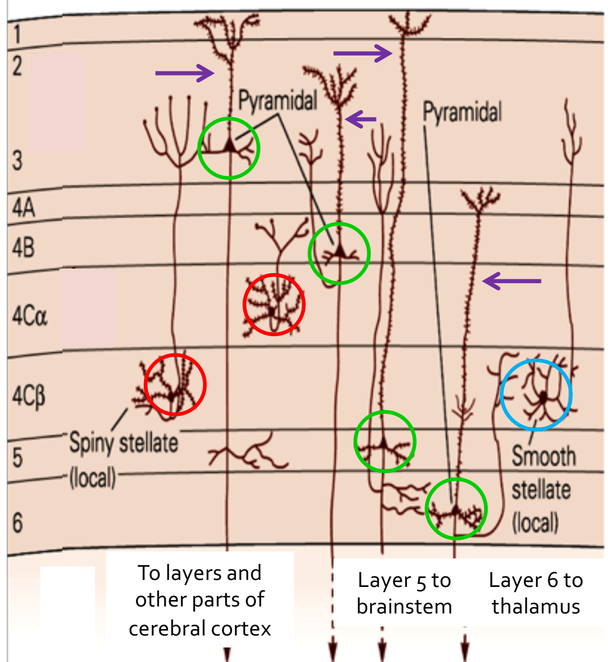


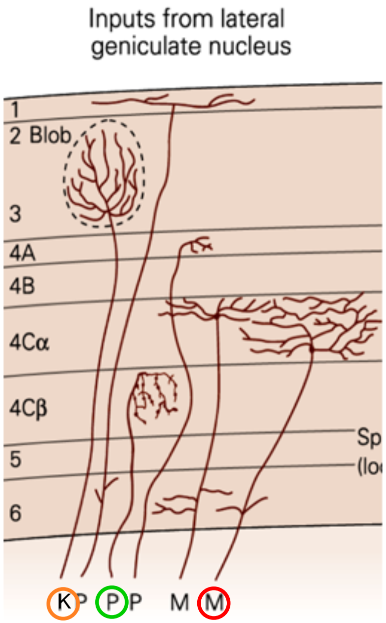
Figure 12. Basic cell types in the monkey cerebral cortex. Left: spiny neurons that include pyramidal cells and stellate cells (A). Spiny neurons utilize the neurotransmitter glutamate (Glu). Right: smooth cells that use the neurotransmitter GABA. B, cell with local axon arcades; C, double bouquet cell; D, H, basket cells; E, chandelier cells; F, bitufted, usually peptide-containing cell; G, neurogliaform cell.

Cortical neurons are different in different layers

- Layer 4: stellate shaped excitatory neurons (spiny)
- Outside 4 mainly pyramidal shaped excitatory neurons each with one ascending "apical" dendrite (spiny)
- Many kinds of inhibitory interneurons interspersed in all layers (smooth)
- Very few neuronal somata in layer 1 which is filled with axons and dendrites



Thalamic input to primary visual cortex

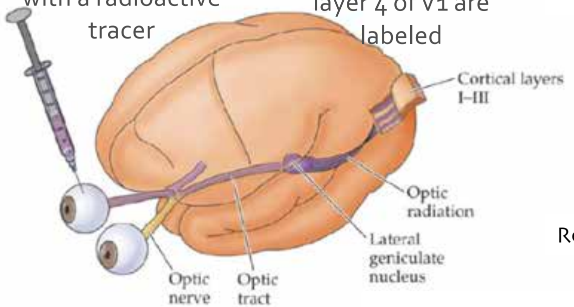


- Unlike LGN where every layer gets input from the retina (and sends output to the cortex), in the cortex, input only comes to specific layers
- Largest input to spiny stellates in layer 4
  - Magnocellular
  - Parvocellular
- Input to layers 2 and 3 from the Koniocellular axons
- In layer 4 the input driven by the L and R eyes are segregated from each other

Radioactive labeling of ocular dominance columns

Inject one eye with a radioactive tracer

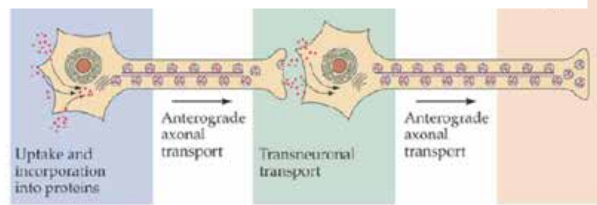
Axon terminals in layer 4 of V1 are labeled



RGCs

thalamocortical neurons

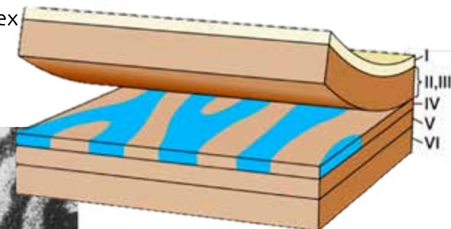
thalamocortical terminals



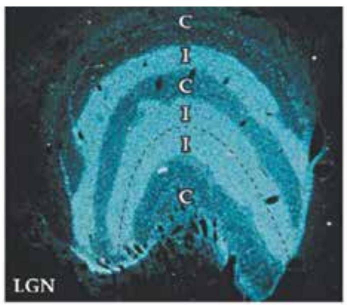
Retina

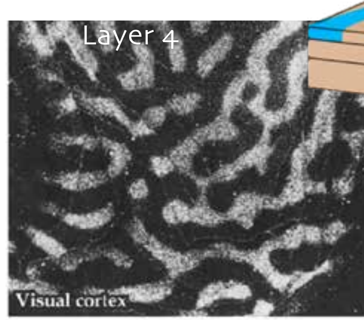
Thalamus (LGN)

Cortex



Radioactive label can be detected in the RGC terminals in LGN associated with one eye
&
in the terminals of thalamocortical cells in the visual cortex

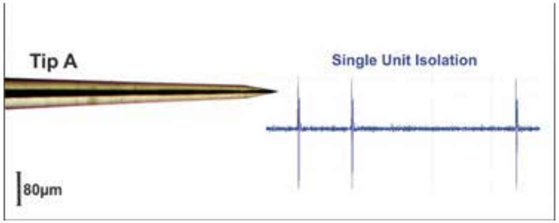




Each column is 0.5 mm wide and only in layer 4 is the left and right eye input is segregated. (WHY?)

The Physiology of Primary Visual Cortex

- 1960's Hubel and Wiesel extended Kuffler's retinal ganglion cell receptive field mapping first to LGN and then to V1
- They developed an "extracellular" electrode that picked up the action potential activity of neurons in the vicinity of the electrode while animals (mostly cats) looked at things



On-Center Surround neuron in LGN

Click sounds represent action potentials

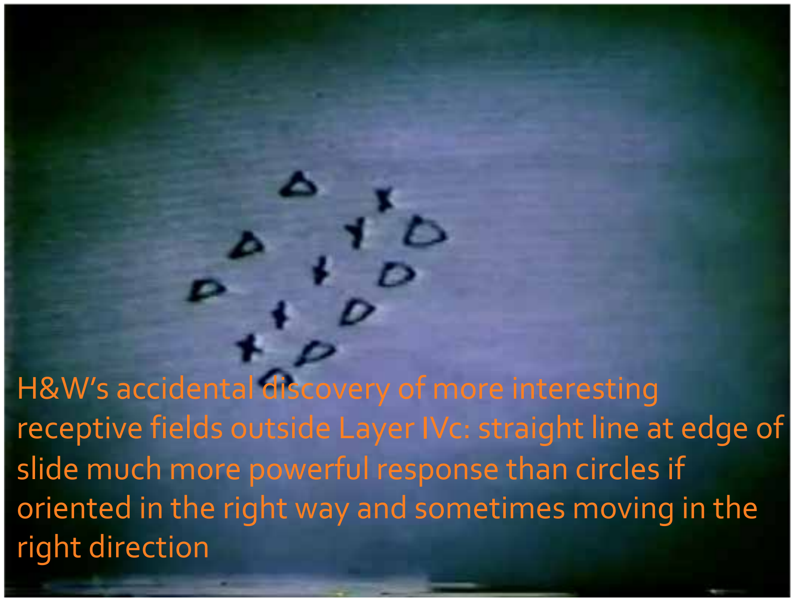
The receptive fields In LGN are: circular (center-surround) & monocular (one eye or the other)

Screen that animal is looking at

The Physiology of Primary Visual Cortex

- In Layer IV (as in LGN) neurons have receptive fields like RGCs
  - Monocular
  - Center surround
- Outside layer IV things start to get very interesting....

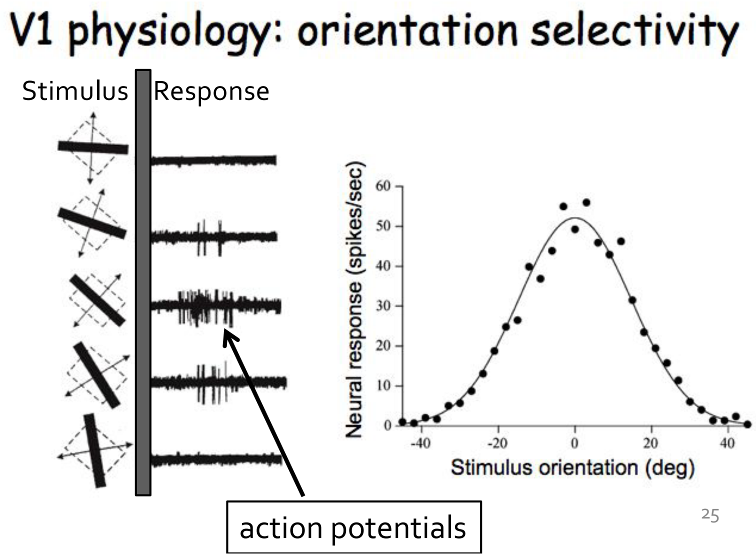
H&W's accidental discovery of more interesting receptive fields outside Layer IVc



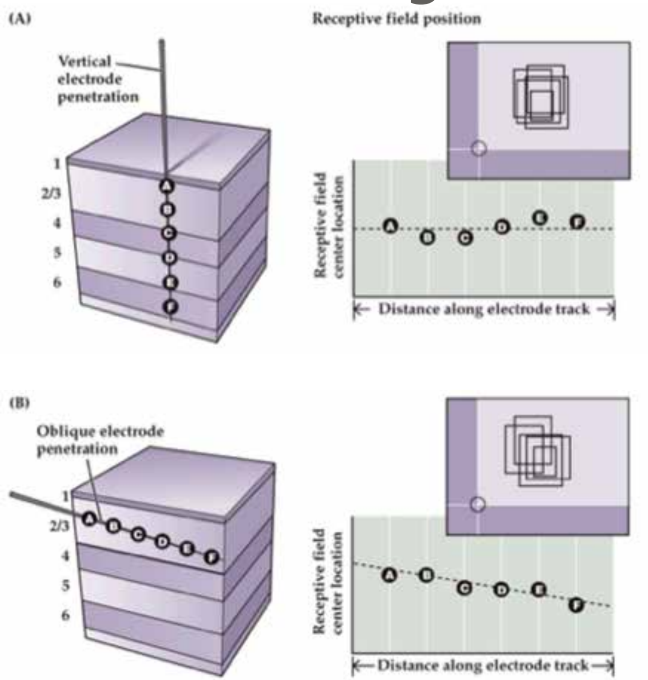
H&W's accidental discovery of more interesting receptive fields outside Layer IVc: straight line at edge of slide much more powerful response than circles if oriented in the right way and sometimes moving in the right direction

Receptive field properties outside Layer IVc of V1

- Retinotopic map
- Orientation selectivity of the receptive field
  - Simple cells – respond best to line at specific angle
  - Elongated ON or OFF area flanked with antagonistic surround
- Binocular: V1 cortical neurons can respond to both eyes



Columnar organization in cortex

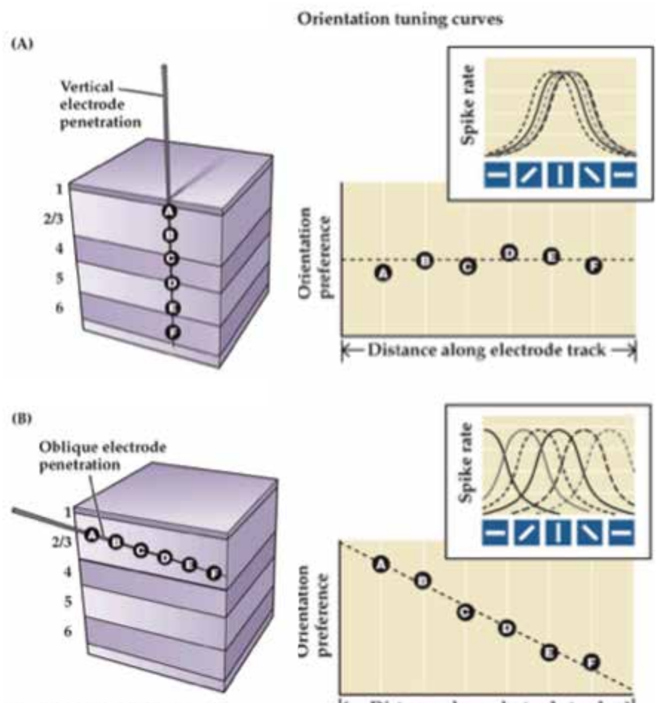


NEUROSCIENCE 5e, Figure 12.11

- Neurons in a "column" have similar tuning
  - Location in visual field
  - Orientation
  - Ocularity (except layer 4)

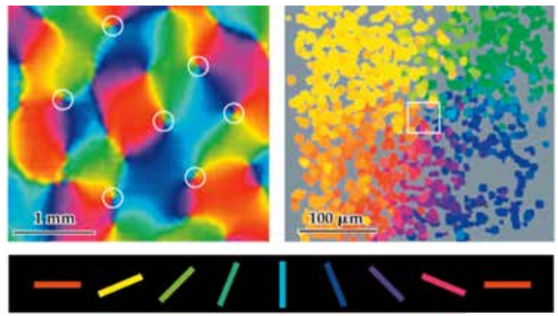
- Progressing tangentially show progression of receptive tuning

Columnar organization in cortex

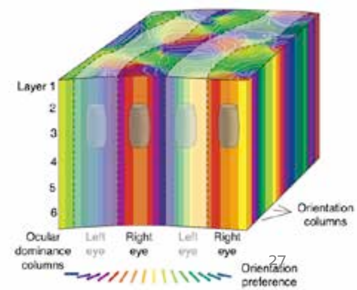


NEUROSCIENCE 5e, Figure 12.11

- Smooth progression of preferred orientation except at pinwheel center



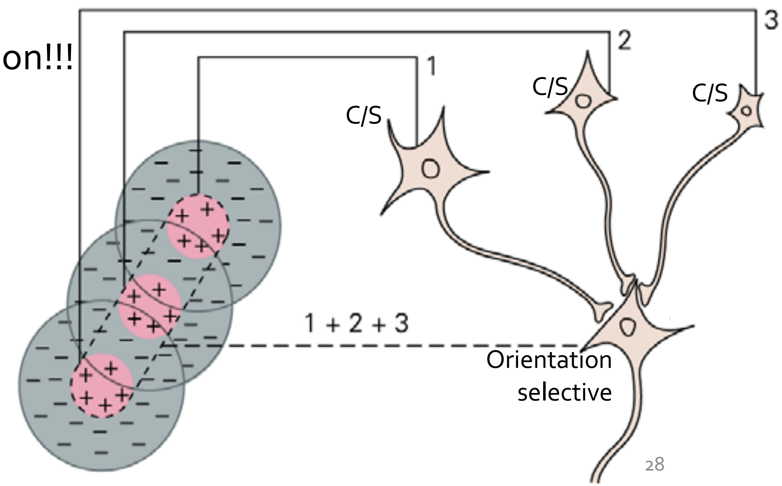
←surface of V1



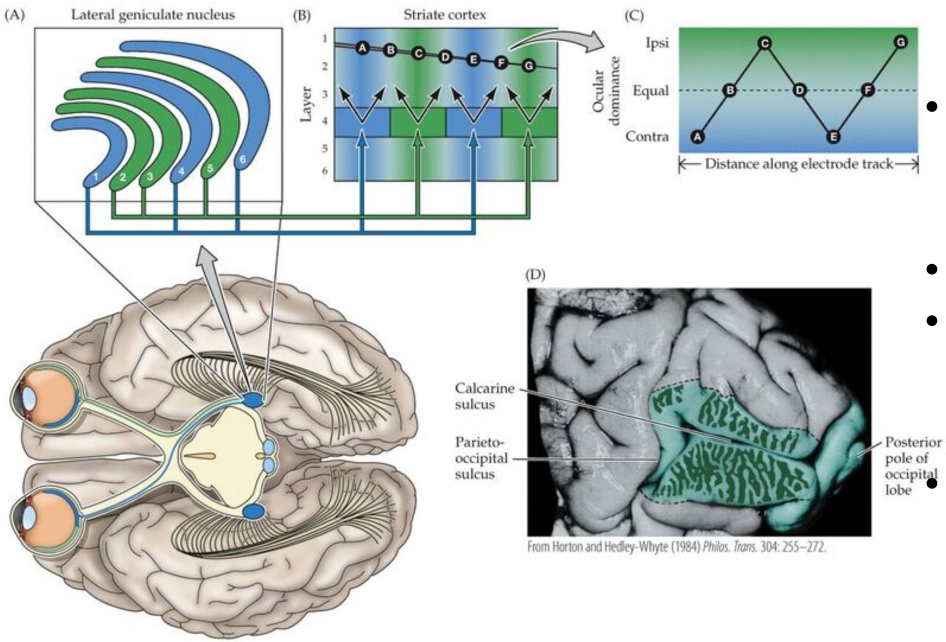
What kind of circuit could generate orientation specificity?

Parts of the pathway closer to the retina are all on or off center with antagonistic surround
Maybe convergence of several center surround cells that form a line is the basis of the orientation specificity -
An AMAZING insight into brain organization!!!

This hypothesis suggests that receptive field properties get more complex the deeper into a sensory system and do so by combining simpler receptive fields to generate more complicated ones



Mixing of information from the two eyes

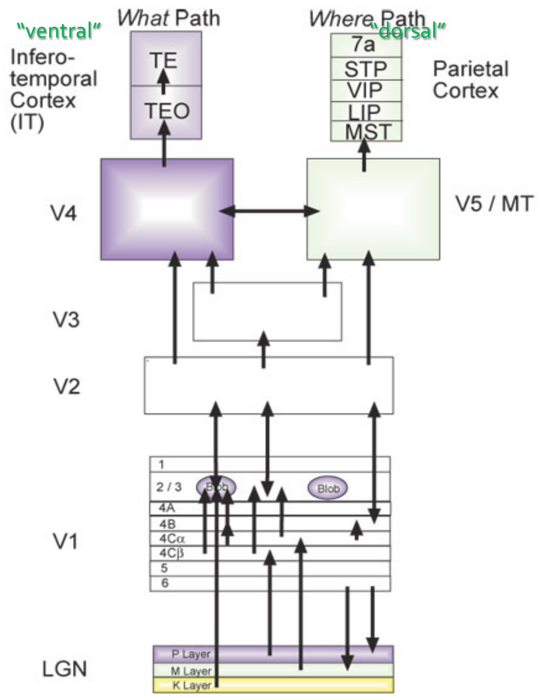


NEUROSCIENCE 6e, Figure 12.11

- First binocular neurons found in striate cortex (layer IV neurons are mostly monocular).
- Ocular dominance columns
- Beyond layer 4, cells can be binocular to varying degrees (ie, respond to stimuli in both eyes)
- Just like the layer 4 cells converging to create simple cell receptive fields, convergence also leads to binocular neurons

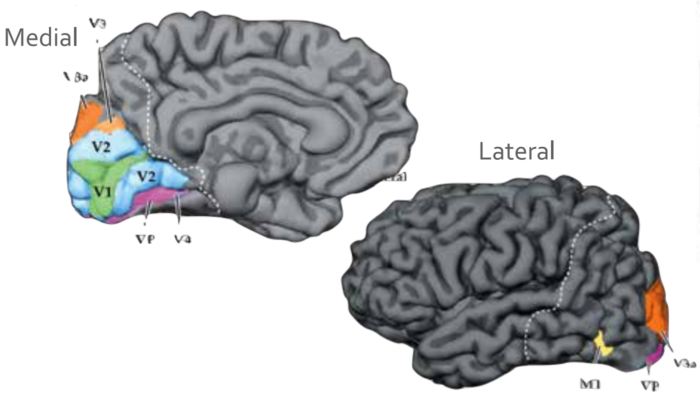
What happens to receptive field properties outside of V1?

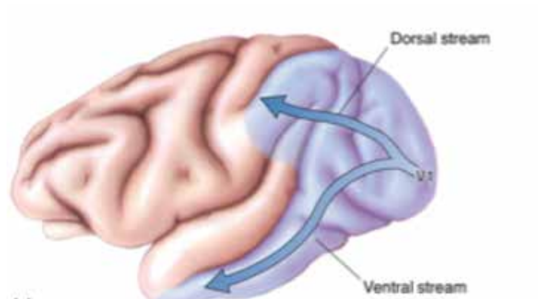
- Two major pathways out of V1 : What and Where
- As move into progressively higher sensory processing centers of the brain receptive fields might continue to get progressively more complicated



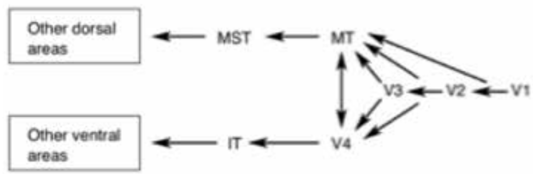
Beyond the primary visual cortex

- Dorsal stream
  - “Where”
  - Analysis of visual motion and the visual control of action
- Ventral stream
  - “What”
  - Perception of the visual world and the recognition of objects





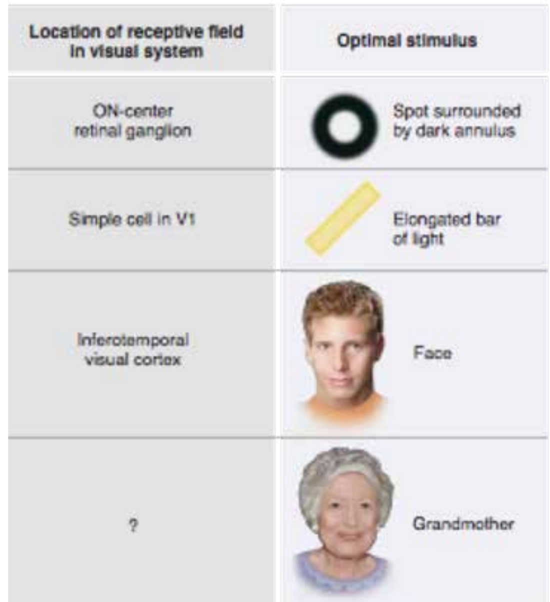
(a)



(c)

The ventral stream

- V1, V2, V3, V4, IT, other ventral areas
- Area V4—shape and color perception
  - Achromatopsia: clinical syndrome caused by damage to area V4—partial or complete loss of color vision
- Area IT
  - Major output of V4
  - Receptive fields respond to a wide variety of colors and abstract shapes.
  - May be important for both visual perception and visual memory (such as faces)
- Visual perception
  - Identifying and assigning meaning to objects



nature 2005 435:1102-7.

Vol 435|23 June 2005|doi:10.1038/nature03687

LETTERS

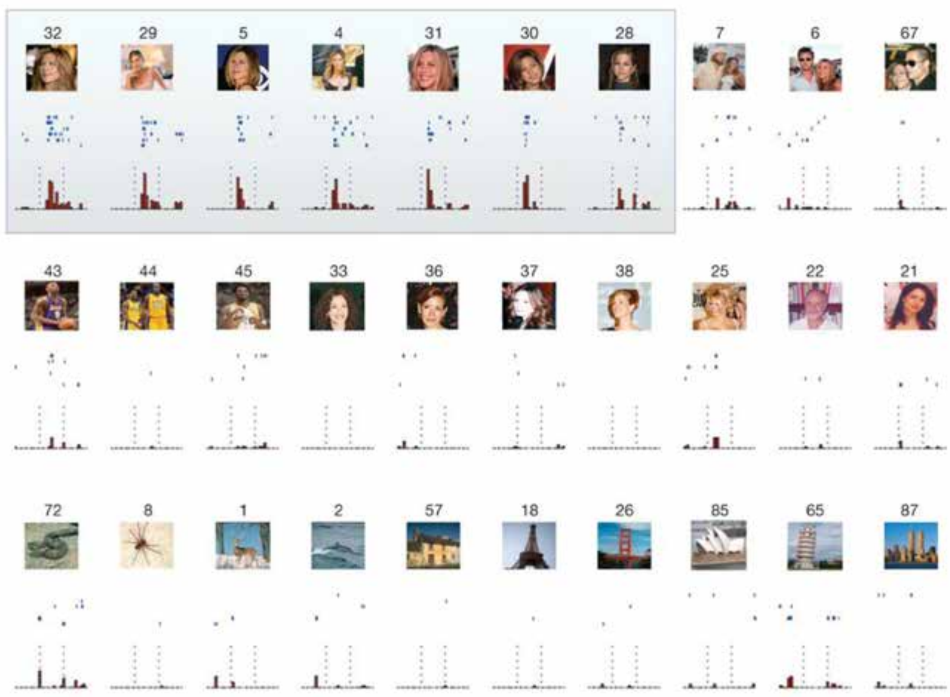
Invariant visual representation by single neurons in the human brain

R. Quian Quiroga[1,2]†, L. Reddy[1], G. Kreiman[3], C. Koch[1] & I. Fried[2,4]

It takes a fraction of a second to recognize a person or an object even when seen under strikingly different conditions. How such a robust, high-level representation is achieved by neurons in the human brain is still unclear[1–6]. In monkeys, neurons in the upper stages of the ventral visual pathway respond to complex images such as faces and objects and show some degree of invariance to metric properties such as the stimulus size, position and viewing angle[2,4,7–12]. We have previously shown that neurons in the human medial temporal lobe (MTL) fire selectively to images of faces, animals, objects or scenes[13,14]. Here we report on a remarkable subset of MTL neurons that are selectively activated by strikingly different pictures of given individuals, landmarks or objects and in some cases even by letter strings with their names. These results suggest an invariant, sparse and explicit code, which might be important in the transformation of complex visual percepts into long-term and more abstract memories.

patient. The mean number of images in the screening session was 93.9 (range 71–114). The data were quickly analysed offline to determine the stimuli that elicited responses in at least one unit (see definition of response below). Subsequently, in later sessions (testing sessions) between three and eight variants of all the stimuli that had previously elicited a response were shown. If not enough stimuli elicited significant responses in the screening session, we chose those stimuli with the strongest responses. On average, 88.6 (range 70–110) different images showing distinct views of 14 individuals or objects (range 7–23) were used in the testing sessions. Single views of random stimuli (for example, famous and non-famous faces, houses, animals, etc) were also included. The total number of stimuli was determined by the time available with the patient (about 30 min on average). Because in our clinical set-up the recording conditions can sometimes change within a few hours, we always tried to perform the testing sessions shortly after the screening

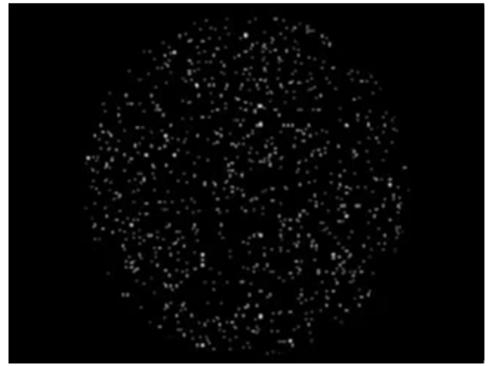
“Jennifer Aniston” neuron?



Quian Quiroga, Reddy, Kreiman, Koch and Fried, Nature, 2005

The dorsal stream

- V1, V2, V3, MT, MST, other dorsal areas
- Area MT (temporal lobe)
  - Most cells are direction-selective, respond more to the motion of objects than their shape.
- Beyond area MT—three roles proposed for cells in area MST (parietal lobe)
  - Navigation
  - Directing eye movements
  - Motion perception



Learning Objectives – Lecture 14

- Understand visual fields. *Explain how they are projected on to the retina, and how they propagate through the LGN and then to cortex*.
- Describe the columnar organization and retinotopic (topographic) organization of visual cortex.
- Compare the receptive fields of neurons in layer IV of visual cortex to both cells in the LGN/RGCs and the other layers in V1.
- Illustrate and explain how information from both eyes combine to create binocular vision.
- Use the dorsal and ventral visual processing streams to illustrate parallel processing in the visual system.

Lecture 14 - Vision 3: Central pathways

Pre-class notes for October 23, 2019
Reading: *Neuroscience ed. 6* by Purves et al., pages **261-279**

Visual field - portion of the external world that can be seen at a given time.

Retinotopy - the orderly arrangement cells in visual areas of the brain where neighboring cells in the retina feed information to neighboring places in later structures and thus respond to adjacent areas of visual space.

Ipsilateral - pertaining to the same side of the body

Contralateral - pertaining to the opposite side of the body

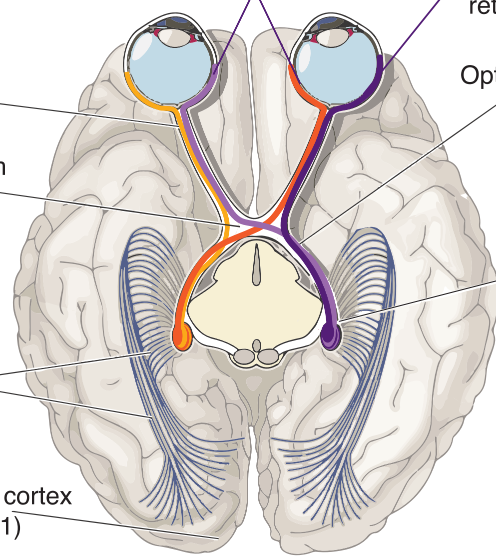
Temporal retina - Half of the retina closest to the temple, receives visual information from the *contralateral* visual field and fibers project to the *ipsilateral* LGN

Nasal retina - Half of the retina closest to the nose, receives visual information from the *ipsilateral* visual field and fibers project to the *contralateral* LGN

Optic nerve - bundle of retinal ganglion axons that sends visual information from the eye to the brain before the optic chiasm. Each nerve contains axons from 1 eye, both visual fields.

Optic chiasm - structure in the midline where the axons from the nasal retina cross to the contralateral side.

Optic tract - bundle of retinal ganglion axons after the optic chiasm. Each nerve contains axons from both eyes, just 1 visual field, contralateral to the tract.



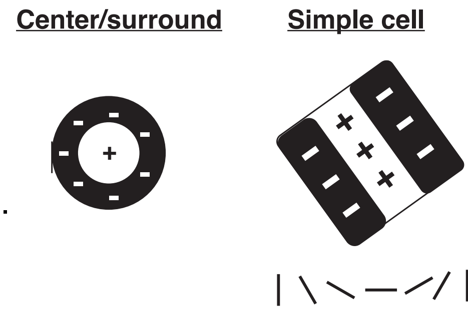
Lateral geniculate nucleus (LGN) - nucleus in the *<u>thalamus</u>* that receives visual input from retinal ganglion cell axon and sends output to the primary visual cortex. The LGN as a whole receives visual information from both eyes, but individual layers (6 layers in primates) including individual neurons, receive synaptic connections from just one eye.

In primates, the most ventral layers (#1 and 2) are known as the magnocellular layers. Layer 1 receives input from the contralateral M-type RGCs and layer 2 receives input from the ipsilateral M-type RGCs. Layers 3 through 6 are the parvocellular layers. Layers 4 and 6 receive input from the contralateral P-type RGCs and layers 3 and 5 receive input from the ipsilateral P-type RGCs. Between the lays are numerous, tiny neurons known as **koniocelluar** cells that are critical for processing color.

Optic radiation - axons from the LGN that carry visual information to the cortex.

Primary visual cortex (V1)/Striate cortex - the cortical area that receives direct input from the LGN. The cortex is a layered structure and cells in layer 4 receive direct connections from the LGN. Layer 4 neurons typically make synapses onto layer 2/3 neurons, which make connections to layer 5/6 neurons and other locations in the brain. The term *striate* refers to the fact that area V1 has an unusually dense stripe of myelinated axons run-in parallel to the surface that appears white in installed sections.

Extrastriate cortex - areas of cortex beyond V1 that receive and respond to visual information. Receptive fields tend to change in extrastriate areas, generally retinotopy persists, but receptive field covers a larger area of the visual field and may also respond to other visual information (e.g. movement or shape).



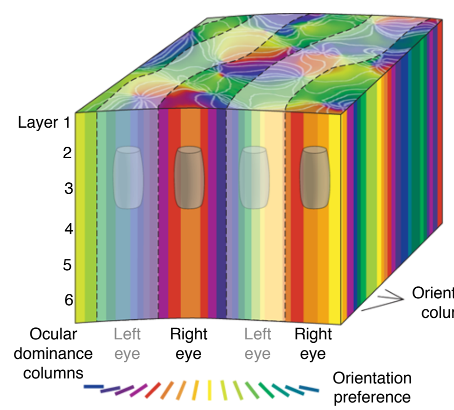
Simple cell - descriptive term for a neuron in V1 with a _receptive field_ shaped not like the simple center/surround found in the retina (and LGN) but rather an elongated field with a specific orientation (see diagram)

Tuning - neuronal tuning is the idea that neurons can respond dynamically (usually firing rate) to different stimuli. If a neuron is tuned to a particular aspect of a stimulus, that neuron will have a greater response to the preferred stimulus and weaker or no response to non-preferred stimuli.

Orientation tuning - simple cells in the visual system are tuned for orientation, or edge (line) direction.

Monocular - in this instance, monocular refers to neurons that are only responsive to one eye (either R or L). Neurons in the retina, LGN, and layer 4 of V1 are all monocular.

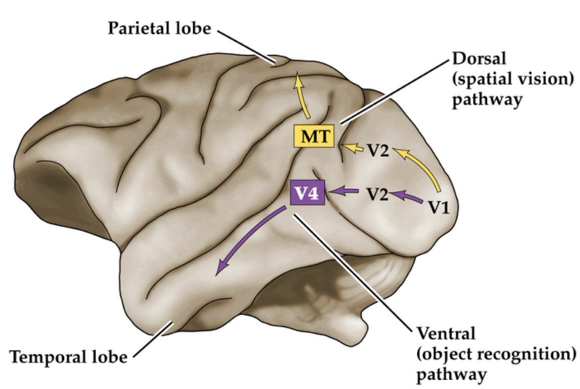
Binocular - in this instance, monocular refers to neurons that are only responsive stimulation of either eye. A neuron might be mored turned to either R or L, and respond weakly to stimulation of the non-tuned eye, or a neuron might respond to both eyes equally. _Ocular dominance_ is the term used to describe the preference a neuron has for one eye or another. Binocular neurons are found after layer 4 in the visual system.



Columnar organization - Neurons within a column of V1 (from layer 2/3 down to layer 6) have the same tuning (e.g. same orientation selectivity), and there is an orderly shift in orientation across a small area of V1. Additionally, there are alternating columns of L or R ocular dominance. Although typically drawn as a grid, the columns are not particularly parallel or straight.

Parallel processing - the idea that different stimulus attributes are process by the brain in parallel using distinct (parallel) pathways.

Beyond the primary visual cortex (V1), the receptive field properties become increasingly more complex. There are two major processing pathways out of primary visual cortex: the *ventral* and *dorsal* streams.



NEUROSCIENCE 5e, Figure 12.18

Dorsal stream - visual processing pathway from primary visual cortex to the parietal cortex. It is responsible for analyzing motion and depth. The "where" stream.

Ventral stream - visual processing pathway from primary visual cortex to the temporal cortex. It is responsible for analyzing form and color. The "what" stream.

Learning Objectives: (By the end of Lecture 14 you should be able answer the following)

1. Understand visual fields. *Explain how they are projected on to the retina, and how they propagate through the LGN and then to cortex*.
2. Describe the columnar organization and retinotopic (topographic) organization of visual cortex.
3. Compare the receptive fields of neurons in layer IV of visual cortex to both cells in the LGN/RGCs and the other layers in V1.
4. Illustrate and explain how information from both eyes combine to create binocular vision.
5. Use the dorsal and ventral visual processing streams to illustrate parallel processing in the visual system.