Lecture 33. Beyond the Retina: Higher Order Visual Processing

Professor Nilay Yapici

Pre-lecture preparation – Posted on the course website before the lecture

Reading – Chapter 10- Pages 331-366

Optional Readings – Posted on the course website before the lecture

Lecture Objectives

- Be able to understand and construct the visual fields in the retina, lateral geniculate nucleus (LGN) and primary visual cortex (V1).
- Be able to understand the broad organization of V1.
- Be able to understand the ideas about WHERE and HOW the visual information is organized and perceived. Especially, a. Binocular vision, b. Object motion, c. Object identification.

Lecture outline

The brain needs to extract relevant information from the visual environment and subsequently organize this information along parallel pathways: the same visual scene is separated even at the level of the retina into separate processing streams. In doing so, you can see increasingly complicated receptive fields and separation of visual information as you travel down the rabbit hole of visual circuitry. We will discuss the major known features of this process.

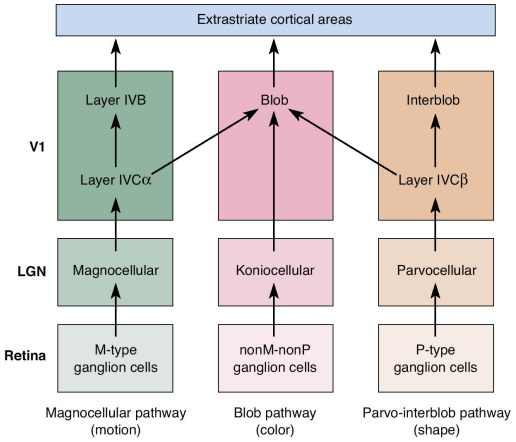
1) The visual field can be defined as the portion of the visual world that an individual can perceive at a given time. These are organized based on topography and by eye. The brain then organizes visual information in a way that separates images in your left and right visual fields via partial decussation at the optic chiasm while organizing information from your left and right visual fields. To do so, the nasal (medial) parts of your visual field of each eye cross over as the optic nerve arrives at the optic chiasm. This puts the entire left visual field to be represented in the right half of the brain, and vice versa. When the optic tract reaches the lateral geniculate nucleus of the thalamus (LGN) on each side of the brain, signals from each eye are isolated into stripes and by ganglion cell type (magnocellular and parvocellular) (Figure 10.8). These inputs are still topographically organized. The LGN then sends afferents to primary visual cortex (V1), where inputs are arranged topographically, by ocular dominance (by left or right eye), but also by several other factors (Figure 10.19).
2) Organization of V1: Magnocellular and parvocellular pathways arrive to physically separate regions in an area of layer 4 of the 6-layered V1. Receptive fields become more complicated in V1. In the retina, LGN, and some cells in the input layer 4 above, receptive fields are concentric circles. Beyond this layer, receptive fields become more complex. Cells can have receptive fields consisting of bars at specific orientations, directions of movement, and/or color combinations (Figure 10.20, Box 10.2).
3) Types of cells in V1:

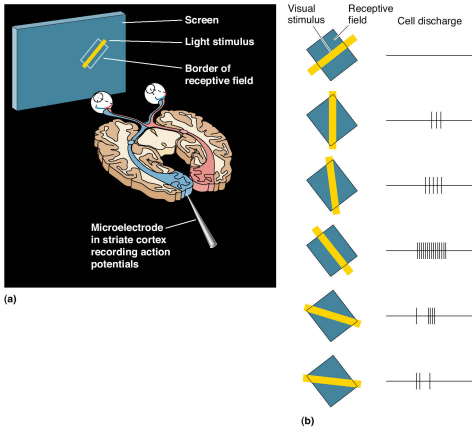
   i. Simple cells have receptive fields corresponding to a bar of light with center-surround organization at a specific place in the visual field with a specific orientation.

   ii. Complex cells are similar to simple cells, but bars of a particular orientation can be located anywhere in visual space.

4) Stereovision: our two eyes have different views of the world, even though fixate on the same point. Think about how 3D movies are made! Inputs from the two eyes are compared in binocular regions at the edges of ocular dominance columns.

5) Hypothesized organization of visual information in V1 and beyond.





Study questions:

1) What is meant by the statement that there is a map of the visual world in the striate cortex?

2) Discuss two ways in which cells from the LGN and/or V1 could converge onto simple and complex cells in order to give them their unique receptive fields.

3) What sort of experiment might you perform to investigate the relationship between visual perception and neural activity in the visual cortex?

4) A small number of neurons that seem to be responsive to specific faces have been found in the fusiform face area. Is this sufficient to convince you that perception for particular objects is encoded by a very small number of neurons in a particular brain area?

Lecture 33: Visual System II- Central processing

Nilay Yapici (ny96@cornell.edu)

Office Hours: Wednesdays 2PM-5PM

Learning objectives

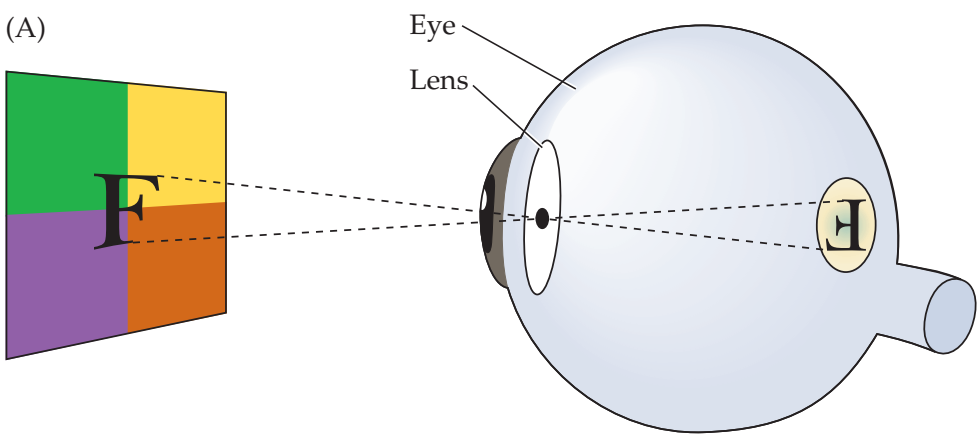
- Be able to describe the neural pathways from the eye to the primary visual cortex.

- Be able to construct the visual field with respect to the two eyes, in the.
  - Retina,
  - Lateral geniculate nucleus (LGN),
  - Primary visual cortex (V1)

- Be able to discuss the broad organization of V1, and how it may contribute to
  - Binocular vision
  - Object motion
  - Object recognition

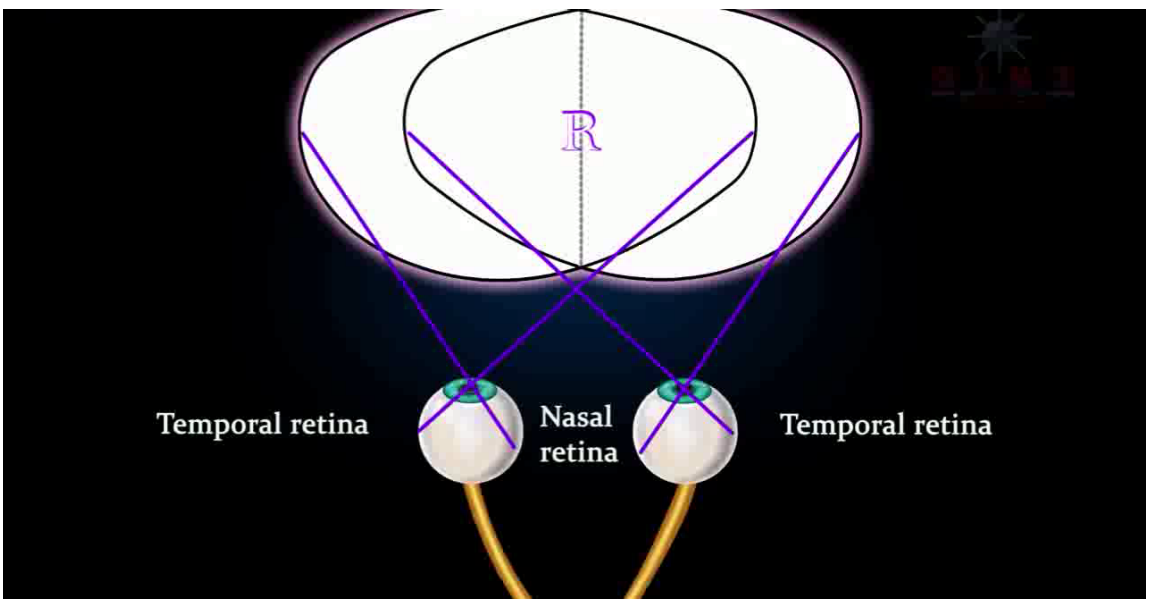
How are visual stimuli encoded in the eye and the brain?

The passage of light rays through the pupil of the eye results in images that are inverted and left–right reversed on the retinal surface.



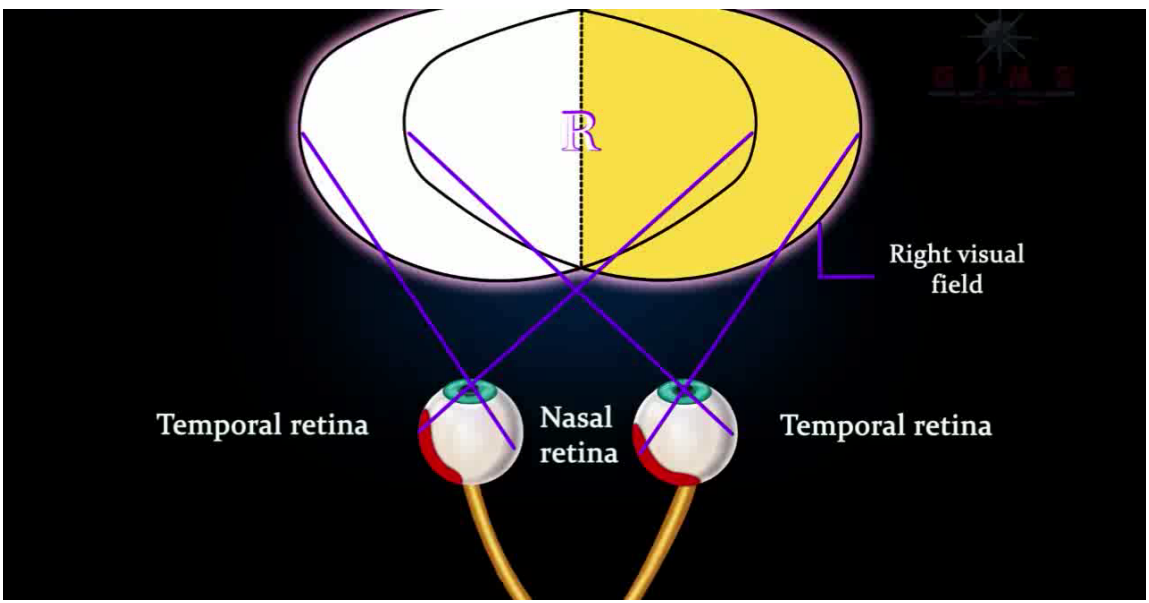
Visual fields

The visual field is organized based on topography and by eye



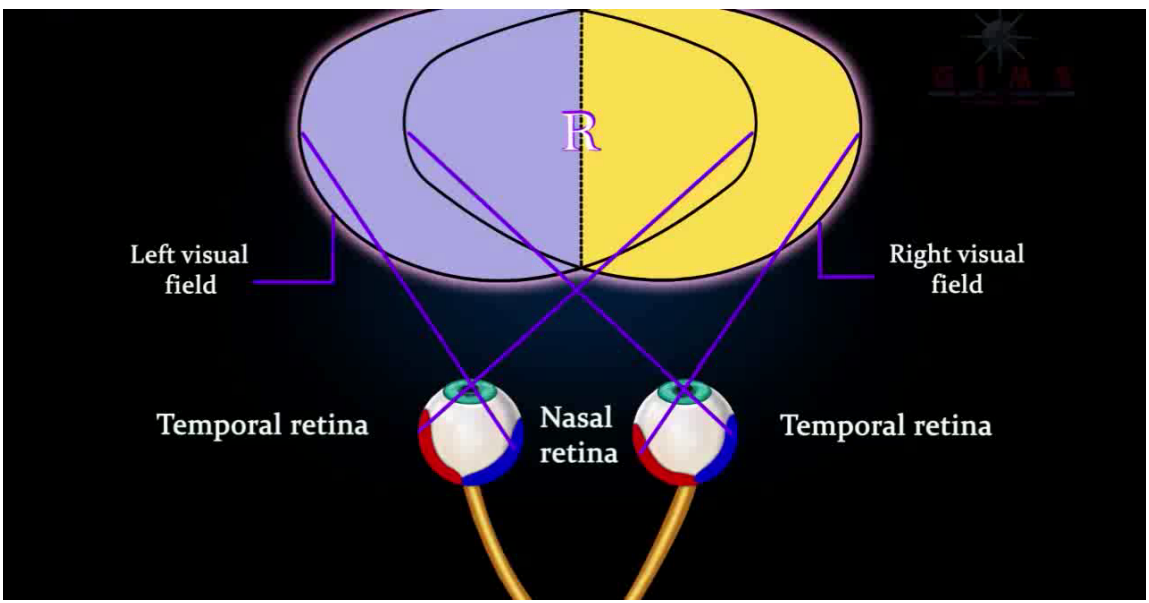
Visual fields

Right visual field is detected by the temporal left retina and the nasal right retina



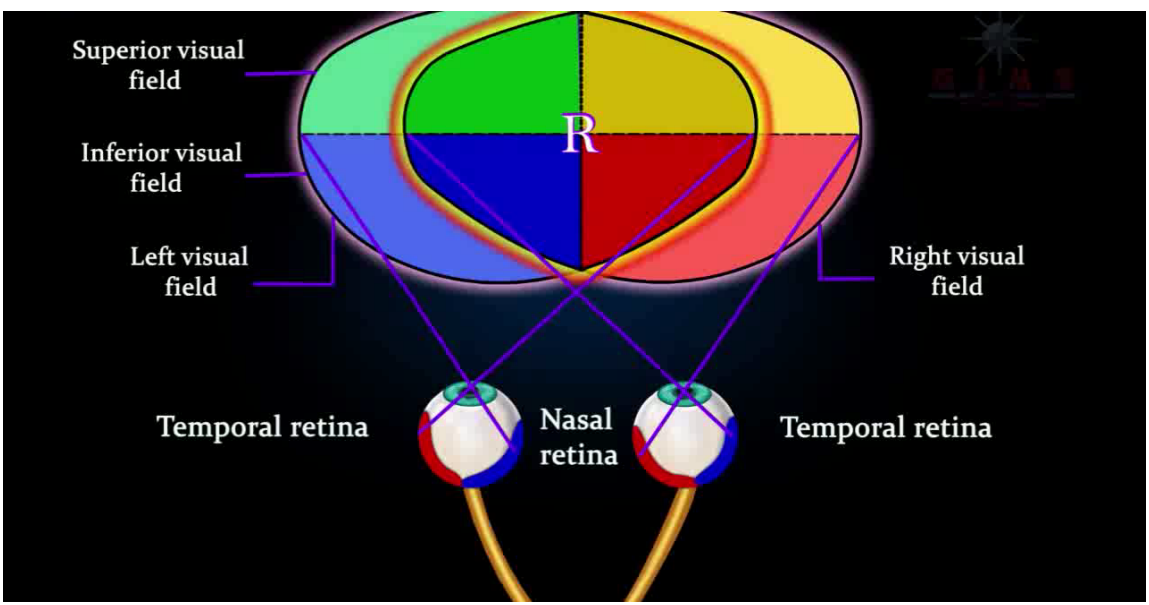
Visual fields

Left visual field is detected by the nasal left retina and the temporal right retina



Visual fields

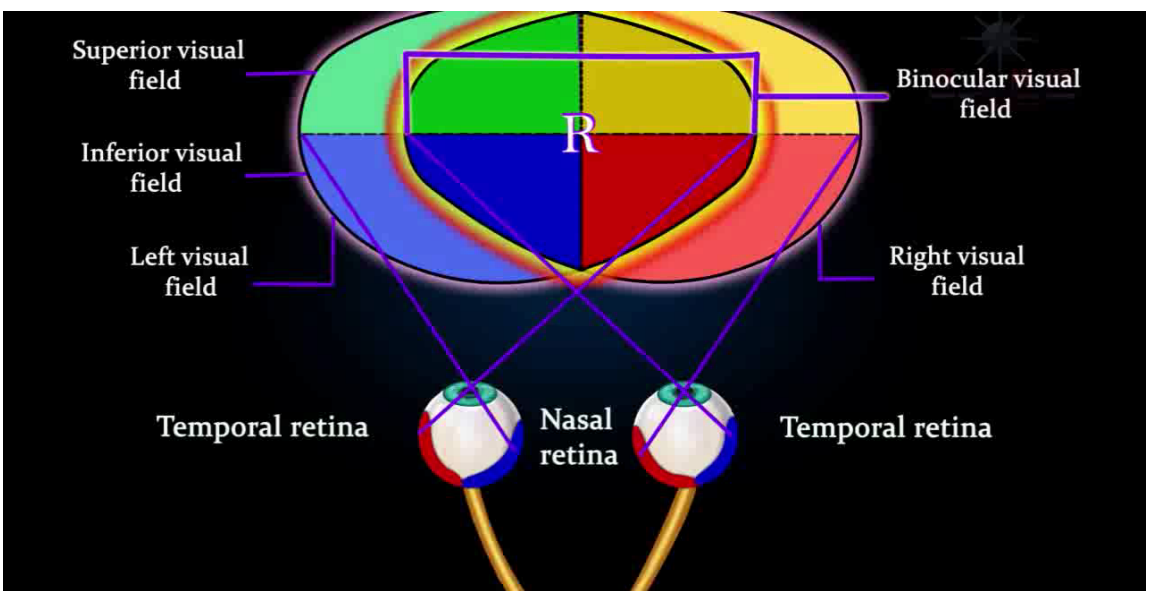
Visual field can be also divided vertical to superior and inferior fields



Visual fields

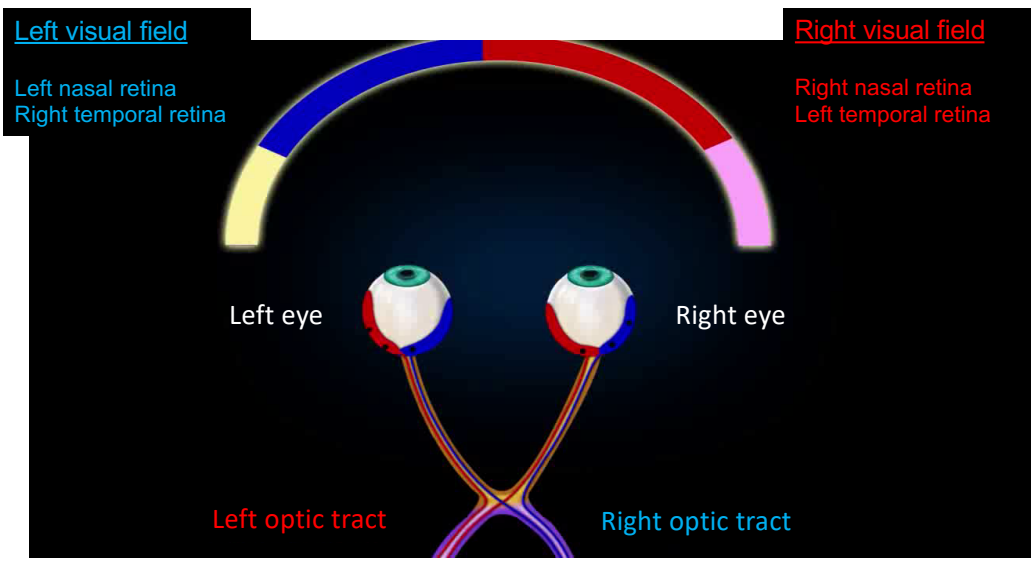
Binocular visual field= The visual field that is detected by both eyes.

Monocular visual field= The visual field that is detected only by the left eye or the right eye.



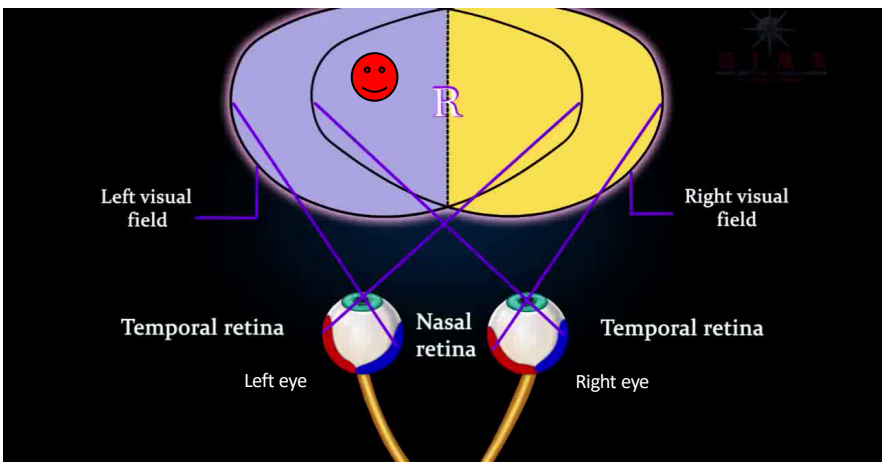
Visual fields and their representation in the retina

- The axons of ganglion cells in the **nasal retina cross in the optic chiasm**, whereas those **from the temporal retina do not**.
- As a result, information from the left visual field is carried in the right optic tract, and information from the right visual field is carried in the left optic tract to the central brain.



Clicker Question 1:

Which visual pathway(s) carries the smiley face visual information to the brain?



A. Left nasal retina>right optic tract

B. Right nasal retina>right optic tract

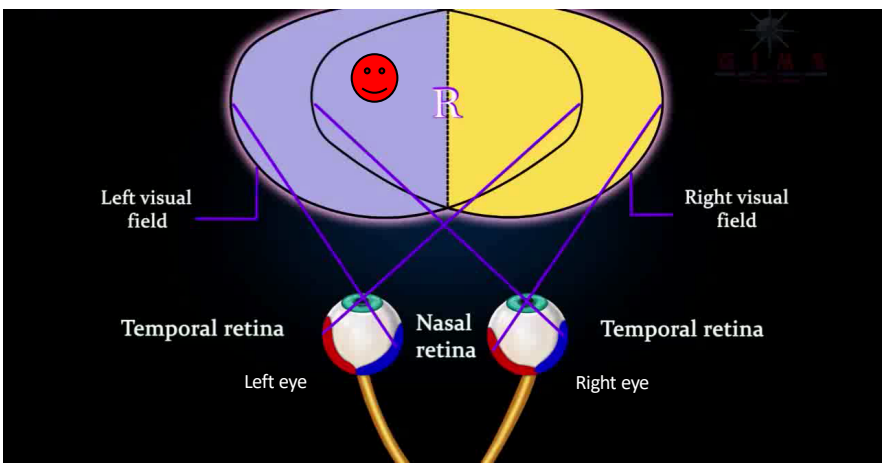
C. Right temporal retina>right optic tract

D. Left temporal retina>left optic tract

E. A and C

Clicker Question 1:

Which visual pathway(s) carries the smiley face visual information to the brain?



A. Left nasal retina>right optic tract

B. Right nasal retina>right optic tract

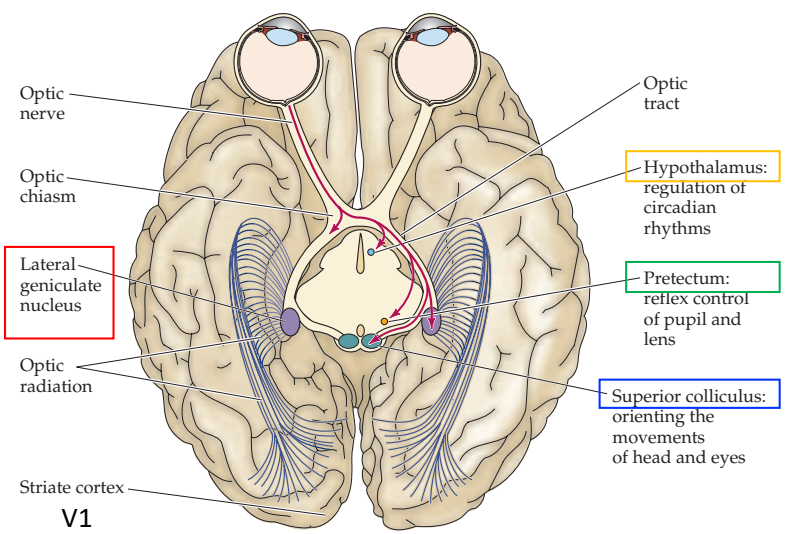
C. Right temporal retina>right optic tract

D. Left temporal retina>left optic tract

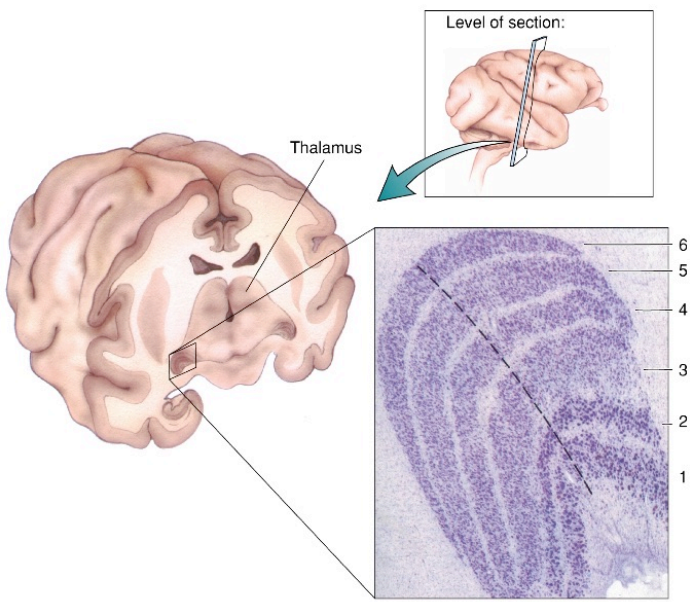
E. A and C

Central projections of retinal ganglion cells.

Ganglion cell axons terminate in the lateral geniculate nucleus (LGN) of the thalamus, the superior colliculus, the pretectum, and the hypothalamus.

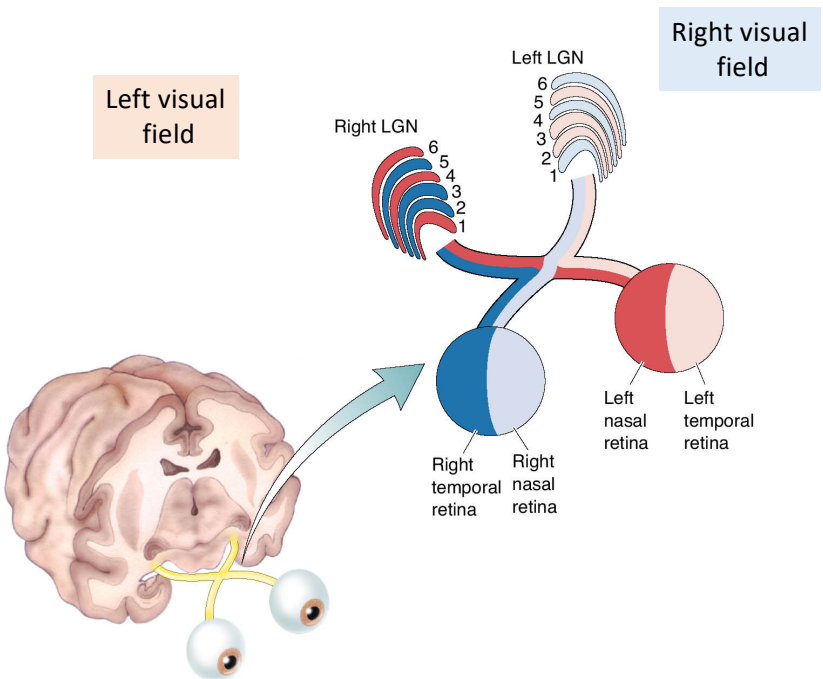


The Lateral Geniculate Nucleus (LGN): The first relay station for primary visual pathway



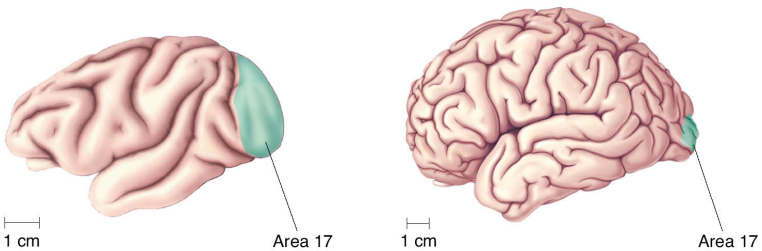
- Lateral Geniculate Nucleus is located in the dorsal thalamus and is the major target of the two optic tracts.
- Each LGN is arranged in six distinct layers of cells.
- LGN is the gateway to the visual cortex, thus to the conscious visual perception.

The Lateral Geniculate Nucleus (LGN): The first relay station for primary visual pathway

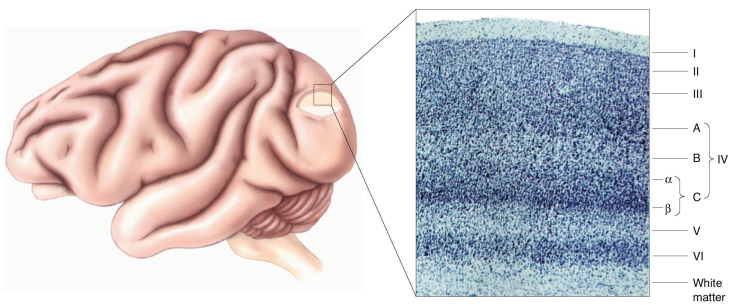


- At the LGN retinal topography and visual fields are conserved.
- Input from the two eyes are kept separate in different layers.

Primary Visual cortex (V1)

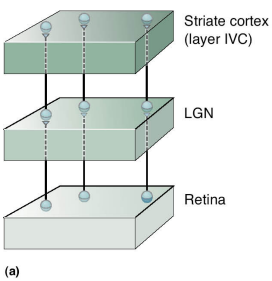


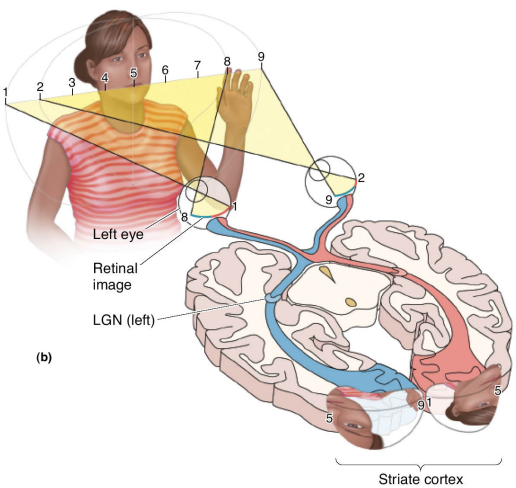
- The single major target of LGN is the primary visual cortex (V1). It is also called the striate cortex or Area 17.



- As other parts of the neocortex, cell bodies of visual cortex are organized in 6 layers.

Retinotopy: Retinal maps in the brain

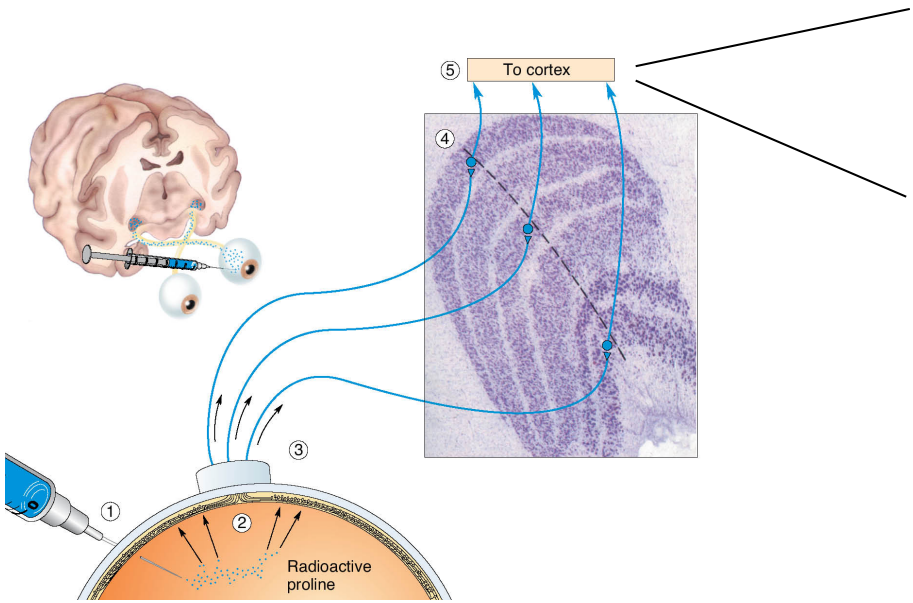


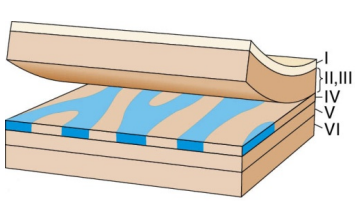


- The spatial relationships among the ganglion cells in the retina are maintained in the LGN and V1 as orderly representations or “maps” of visual space.
- Retinal maps in V1 and LGN are distorted because visual space is not sampled uniformly by the cells in the retina.

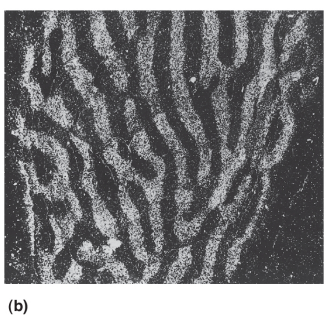
Ocular Dominance Columns in the Visual Cortex (V1)

1970 experiment from Hubel and Weisel identified ocular dominance columns



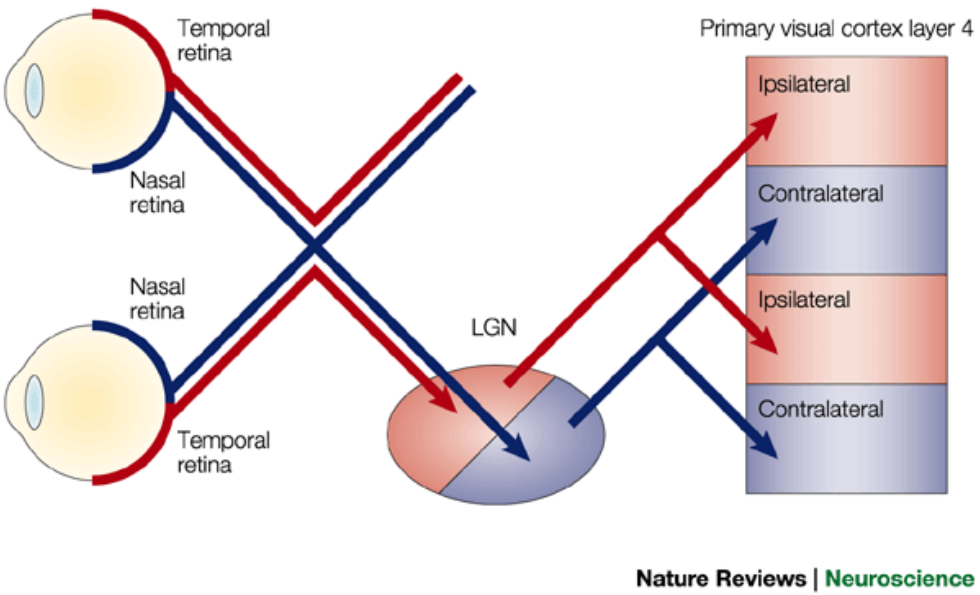


Autoradiography

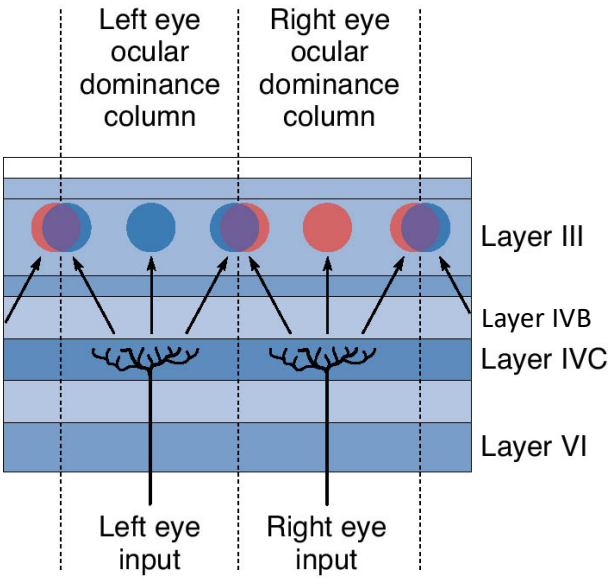


Ocular Dominance Columns in the Visual Cortex (V1)

1970 experiment from Hubel and Weisel identified ocular dominance columns



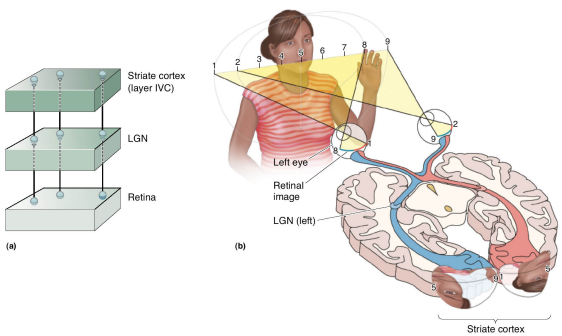
Ocular Dominance Columns in the Visual Cortex (V1)



- Most LGN neurons project to Layer IVC of Visual Cortex (V1).
- First time in the visual pathway the information from left and right eye mixes –Layer III.
- When information from each eye is integrated one eye dominates generating neurons in a column with responding to one eye dominantly: Ocular dominance

Clicker Question 2:

In the lateral geniculate nucleus of the thalamus (LGN) and in primary visual cortex, which of the following is true?



A. All information from the LEFT eye is directed towards the LEFT LGN (and V1).

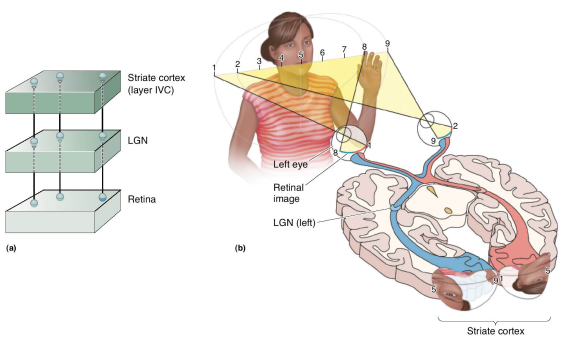
B. All information from the LEFT eye is directed towards the RIGHT LGN (and V1).

C. All information from the LEFT visual field is directed towards the LEFT LGN (and V1).

D. All information from the LEFT visual field is directed towards the RIGHT LGN (and V1).

Clicker Question 2:

In the lateral geniculate nucleus of the thalamus (LGN) and in primary visual cortex, which of the following is true?



A. All information from the LEFT eye is directed towards the LEFT LGN (and V1).

B. All information from the LEFT eye is directed towards the RIGHT LGN (and V1).

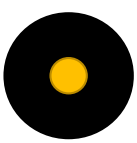
C. All information from the LEFT visual field is directed towards the LEFT LGN (and V1).

D. All information from the LEFT visual field is directed towards the RIGHT LGN (and V1).

Response profiles of visual neurons

- In the beginning of the 1960s David Hubel and Torsten Wiesel started to record from the visual cortex in response to different visual stimuli.

- Most of the neurons in retina, LGN and layer IVC of V1 have circular receptive fields and give their greatest response to a spot.

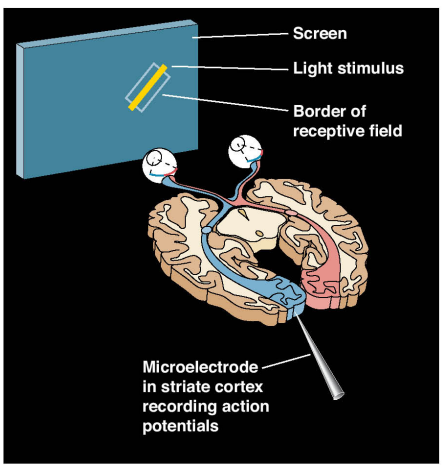


- Outside of IVC, response properties V1 neurons are different;
  - There are cells that respond to a bar of light, rather than a spot, and many times one or more of the following
  - Location (topography)
  - Orientation
  - Direction of movement

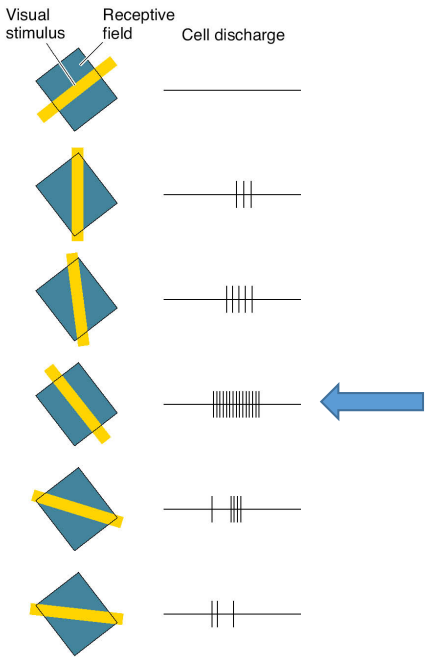
Nobel Prize in Physiology and Medicine 1981
for their discoveries concerning information processing in the visual system.

David Hubel and Torsten Wiesel

Orientation selective V1 neurons



(a)

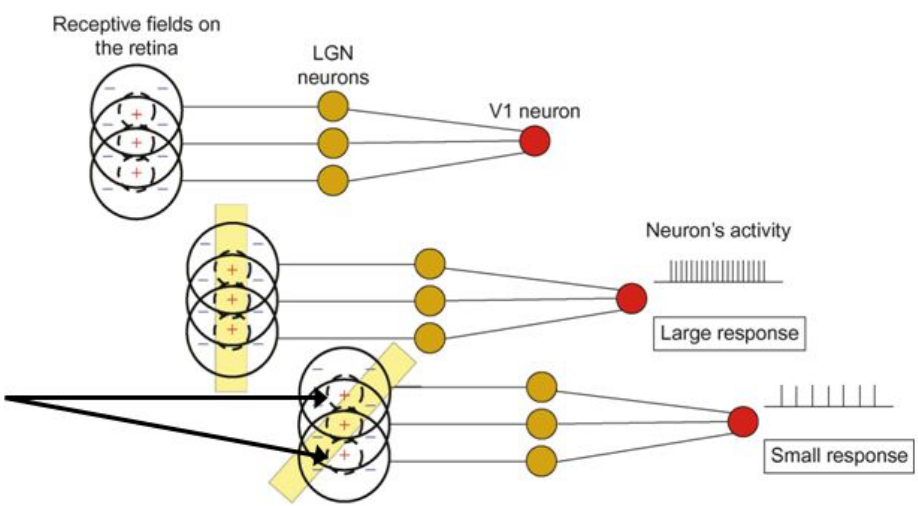


(b)

An orientation selective V1 neurons with Optimal orientation 45^{o} counterclockwise from vertical

Orientation selective V1 neurons

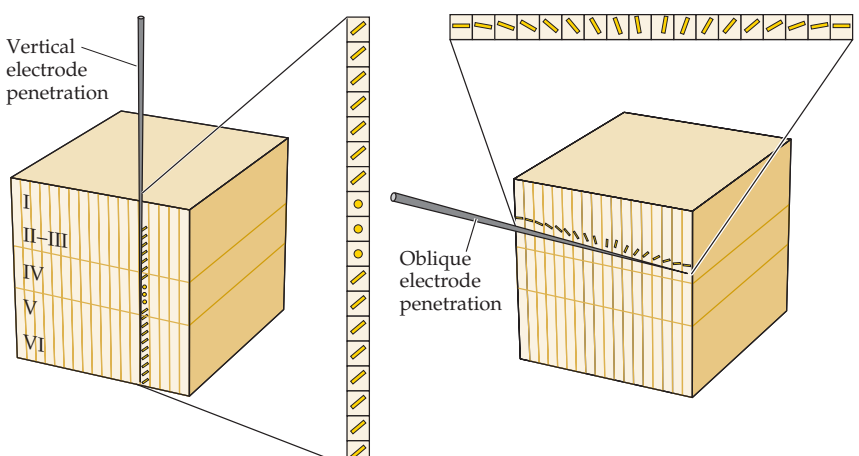
- V1 neurons receive converging input from LGN neurons.
- V1 neuron receptive field are formed by integrating the LGN neuron receptive fields.



Orientation selective V1 neurons

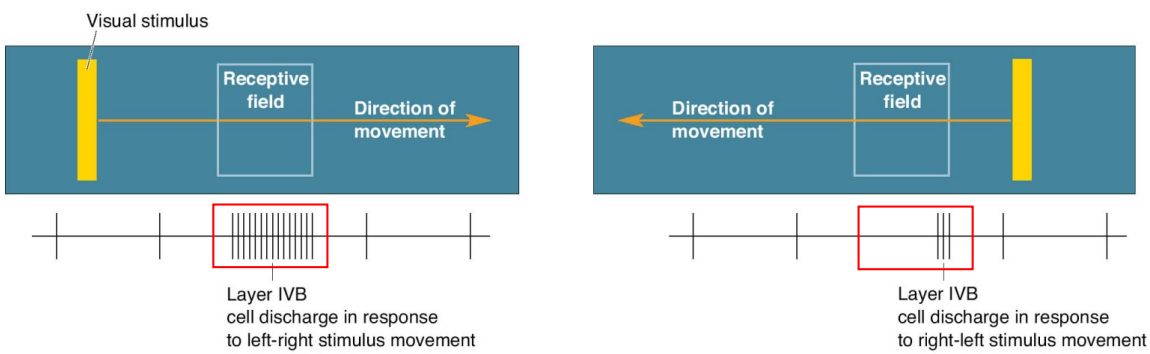
- Vertical electrode penetrations encounter neurons with the same preferred orientations= Orientation column (except layer IV).

- Tangential penetrations show a systematic change in orientation across the cortical surface.

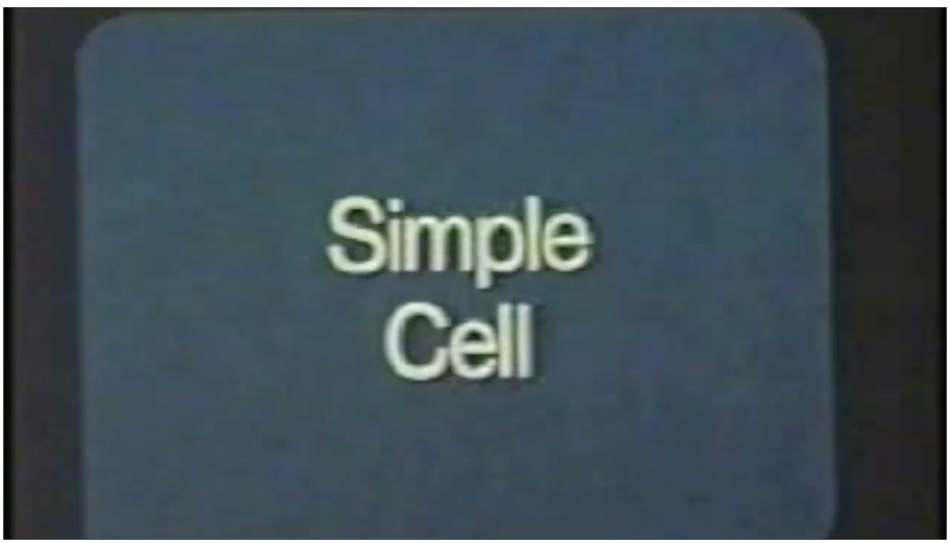


Direction selective V1 neurons

- V1 neuron firing action potentials in direction-dependent response to moving bar of light.
- The neuron responds strongly when the bar is swept to the right but weakly when it is swept to the left= *analysis of object motion*.



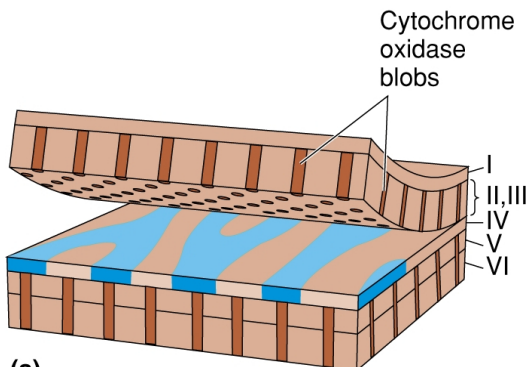
Simple and Complex V1 neurons



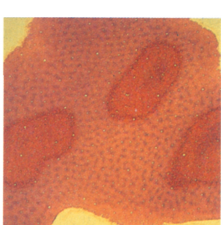
Summary of cell types in V1

- Simple cells
- Complex and hypercomplex cells
- Direction selective cells
  - A subset of simple and complex cells selective to the DIRECTION of movement.

- ‘Blob’ cells
  - No orientation/direction selectivity
  - sensitive to specific colors and color combinations



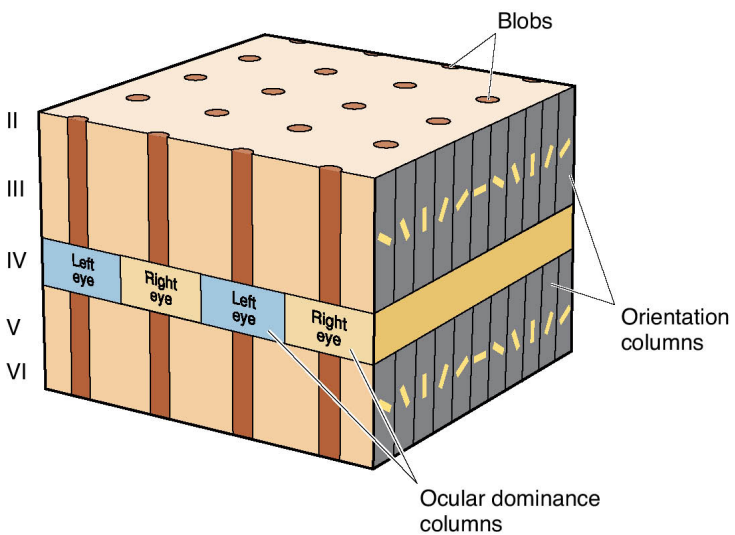
(a)



(b)

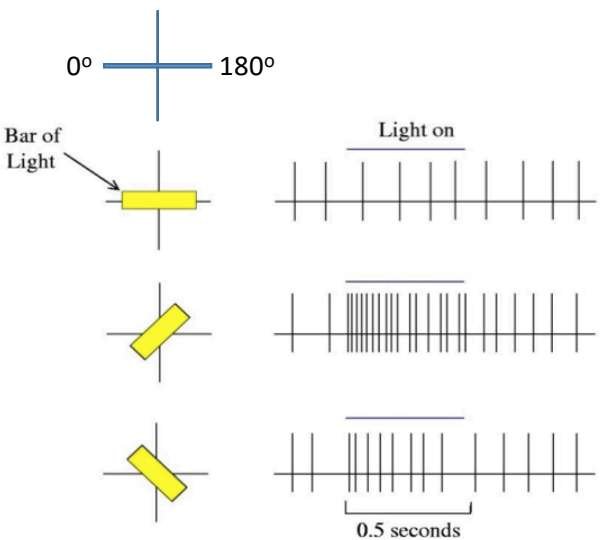
Parallel Pathways and Cortical modules

Hubel and Wiesel argued that a 2x2mm chunk of visual cortex is both necessary and sufficient to analyze the image of a point in space.



Clicker Question 3:

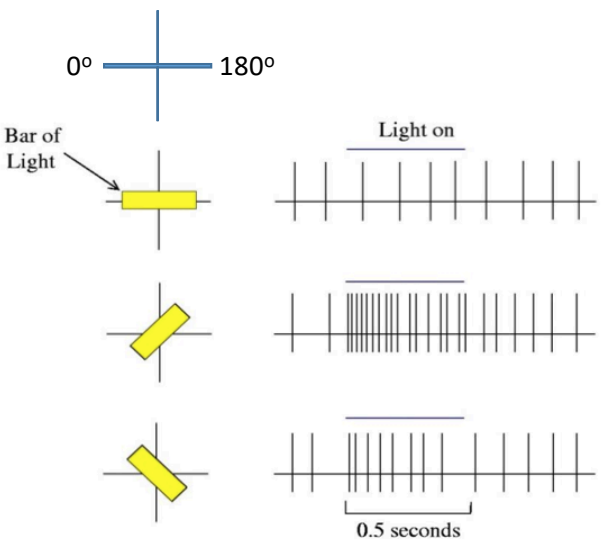
Responses of a V1 cell is shown below. What kind of V1 cell these recordings are obtained from and what is the preferred orientation of the cell?



A. Simple V1 cell, 0°
B. Complex V1 cell, 45°
C. Simple V1 cell, 135°
D. Complex V1 cell 135°
E. Simple V1 cell 45°

Clicker Question 3:

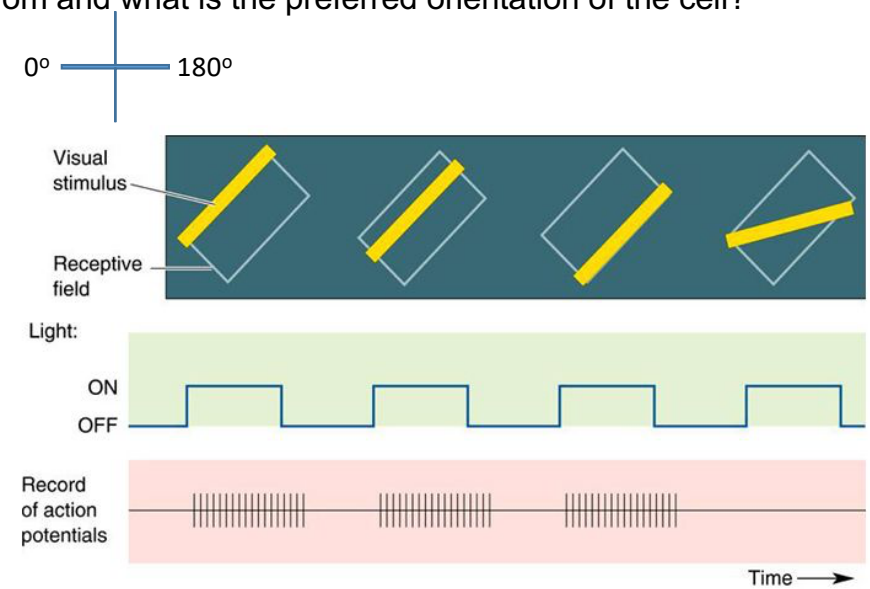
Responses of a V1 cell is shown below. What kind of V1 cell these recordings are obtained from and what is the preferred orientation of the cell?



A. Simple V1 cell, 0°
B. Complex V1 cell, 45°
C. Simple V1 cell, 135°
D. Complex V1 cell 135°
E. Simple V1 cell 45°

Clicker Question 4:

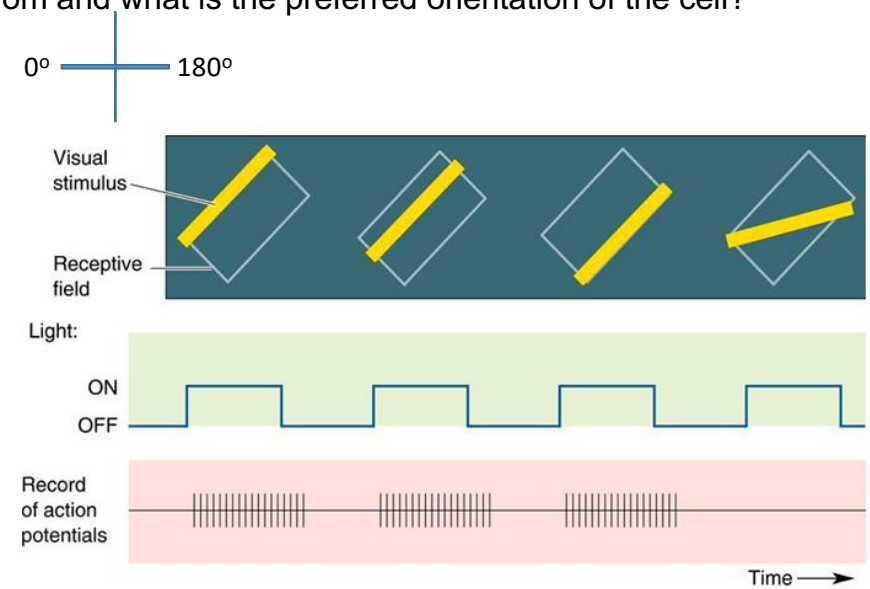
Responses of a V1 cell is shown below. What kind of V1 cell these recordings are obtained from and what is the preferred orientation of the cell?



A. Simple V1 cell, 0°
B. Complex V1 cell, 0°
C. Simple V1 cell, 135°
D. Complex V1 cell 135°
E. Simple V1 cell 45°

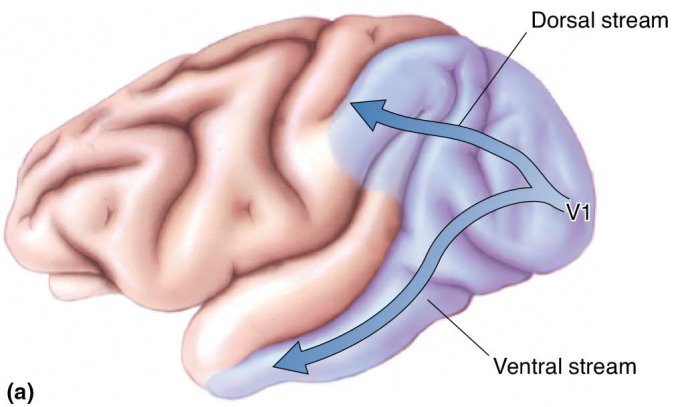
Clicker Question 4:

Responses of a V1 cell is shown below. What kind of V1 cell these recordings are obtained from and what is the preferred orientation of the cell?



A. Simple V1 cell, 0°
B. Complex V1 cell, 0°
C. Simple V1 cell, 135°
D. Complex V1 cell 135°
E. Simple V1 cell 45°

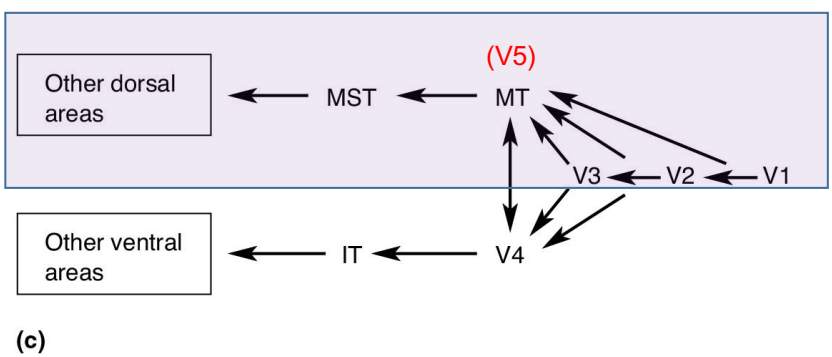
Beyond the Visual Cortex (V1)



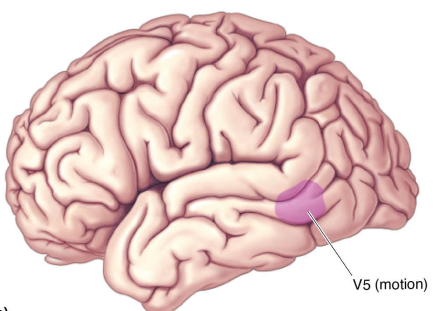
- V1 is not the only area in the cortex that respond to visual stimuli, it is the first relay station after LGN.
- Information from V1 is transferred to other parts of the cortex mainly by two pathways:
  - Dorsal stream serve to analyze visual motion and visual control of action
  - Ventral stream is thought to perceive the visual world and recognize objects

V1>>>Dorsal Stream

- Almost all neurons in V5 are motion sensitive
- Activation of V5 neurons can elucidate perception of motion in the visual field.
- Proposed biological roles of V5: Navigation, directing eye movements, motion perception.



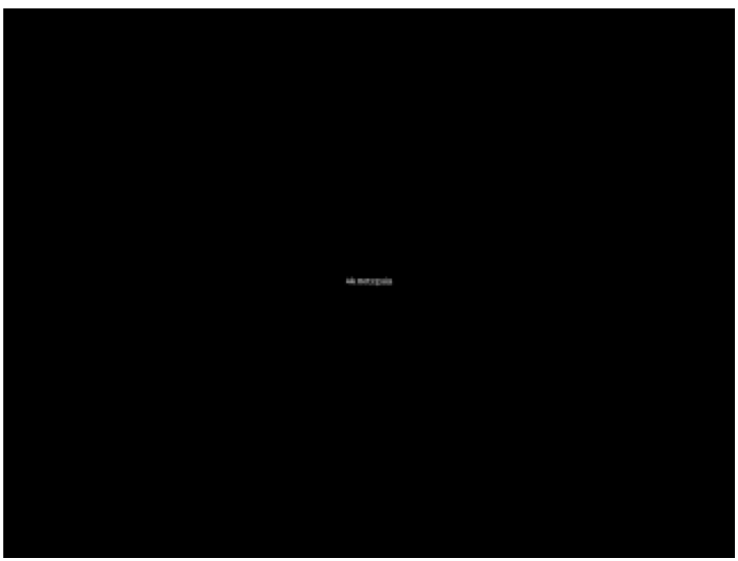
(c)

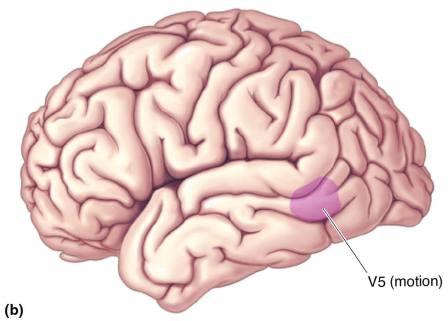


(b)

V1>>>Dorsal Stream

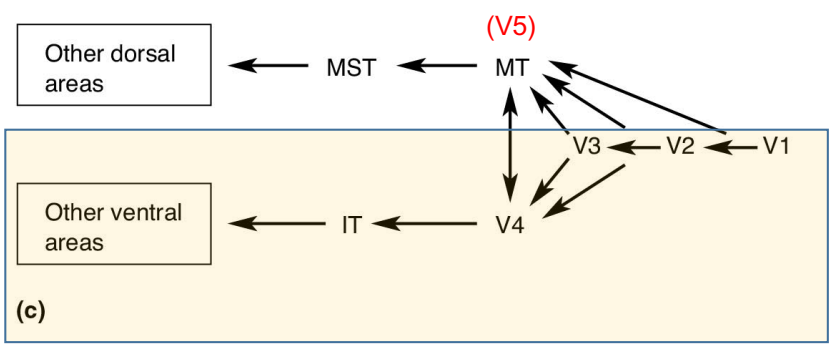
- Akinetopsia: Motion Blindness

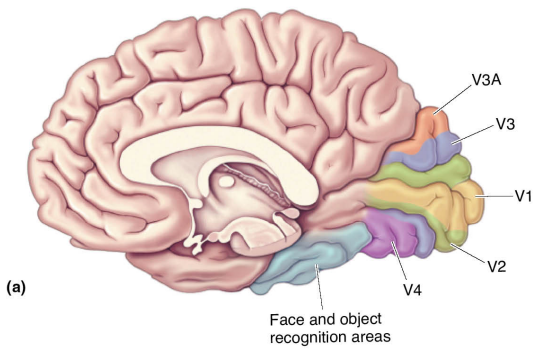




V1>>>Ventral Stream

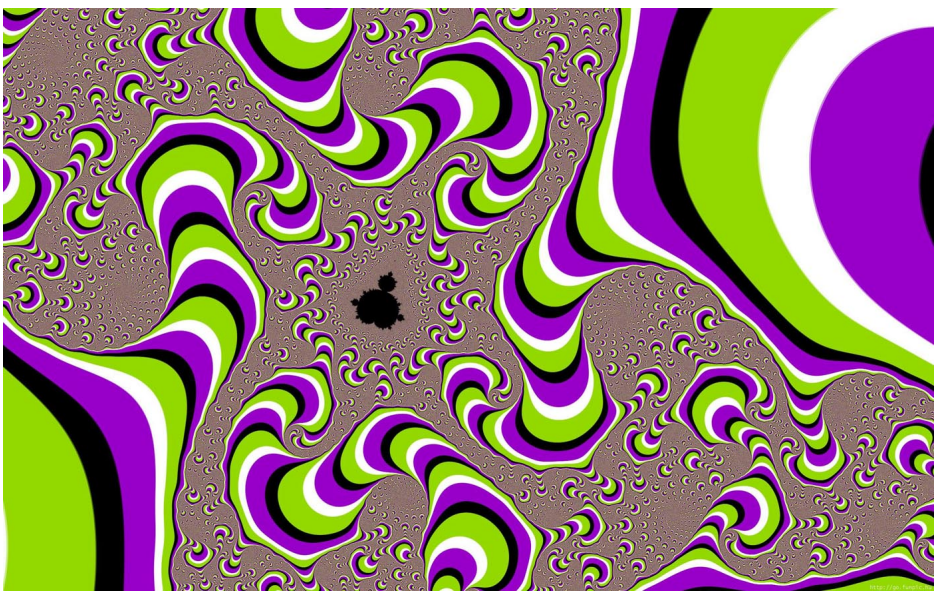
- V4 neurons are orientation and color selective.
- Main function of V4 neurons is shape and color perception.
- IT neurons in the Ventral Stream respond strongly to faces.





Where does visual perception occur?

Still an open question!



Lecture summary

- The visual field is organized based on topography and by eye. The information from the left visual field is carried in the right optic tract, and information from the right visual field is carried in the left optic tract to the central brain. Learn this mechanism well!
- Retinotopy: The spatial relationships among the ganglion cells in the retina are maintained in the LGN and V1.
- Neurons in the layer IVC of V1 respond to spots. Other neurons in different layers of V1 respond to bars.
- Simple V1 cells respond to a bar in a certain orientation and location. Complex cells respond to bars in a range of locations.
- Dorsal Stream neurons (V5) respond to motion and play a role in motion perception.
- Ventral Stream neurons (V4) respond to shapes and colors, they play a role in object recognition.