Central visual pathways: retinal targets

- The **retina** projects to multiple areas in the brain. Each area is specialized for different functions
- Dorsal **lateral geniculate nucleus** (dLGN)– located in the thalamus- receives visual info from retina and sends it to the visual cortex. Most important visual projection with respect to visual perception
- **Pretectum**– located at midbrain-thalamus boundary. Responsible for pupillary light reflex
- **Superior colliculus**– in midbrain, coordinates head and eye movements
- **Suprachiasmatic nucleus**– hypothalamus, involved in day/night cycles

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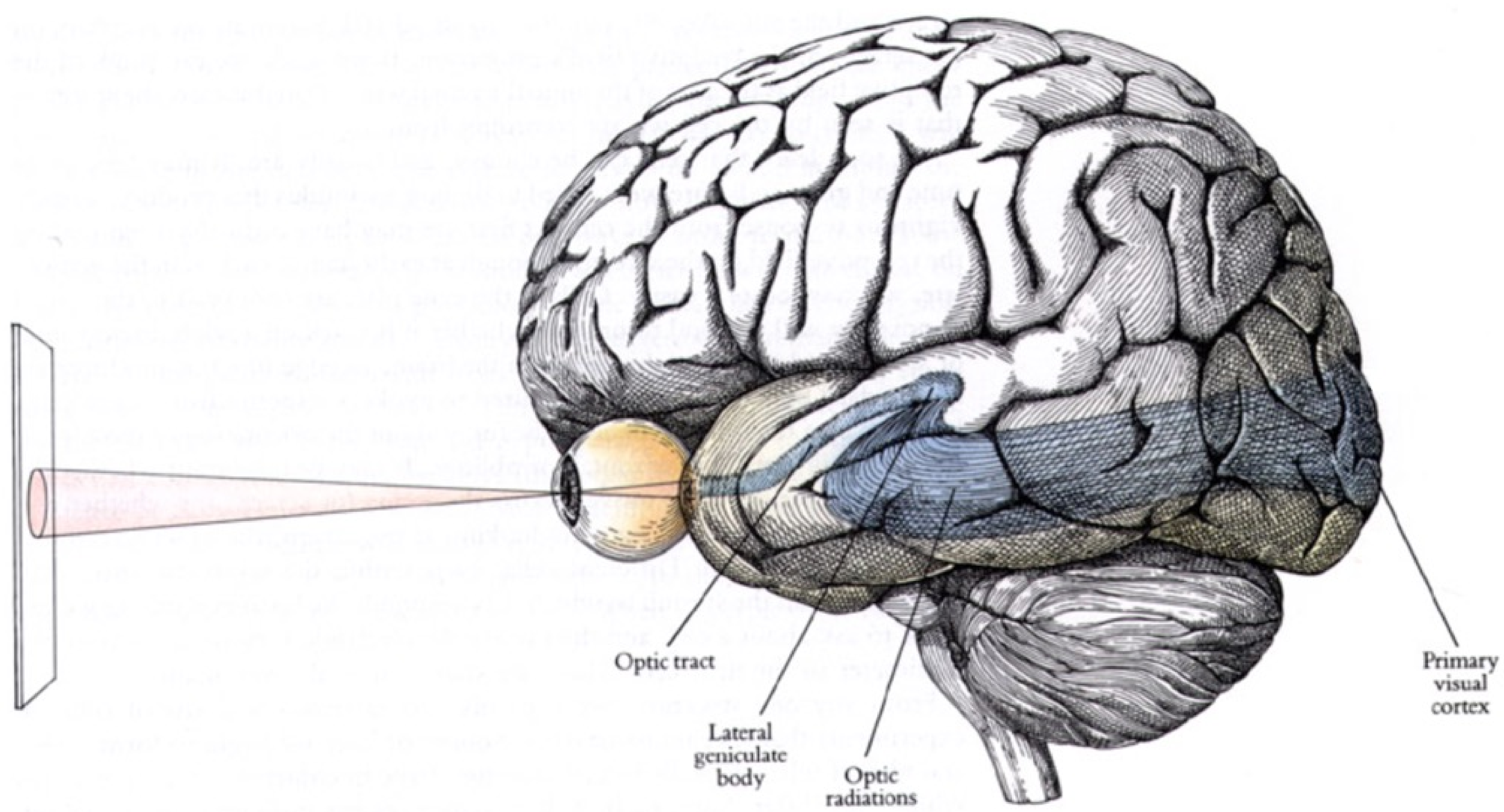
Speaker notes

No notes on this slide.

The human visual system



Hubel, 1988

Speaker notes

The output neurons of the eye-- the retinal ganglion cells-- form synaptic connections in two visual centers the lateral geniculate nucleus and the superior colliculus.

And the geniculate neurons have in turn formed synaptic connections with the visual cortex, thus forming the basic visual pathway from the eye to the cerebral cortex.

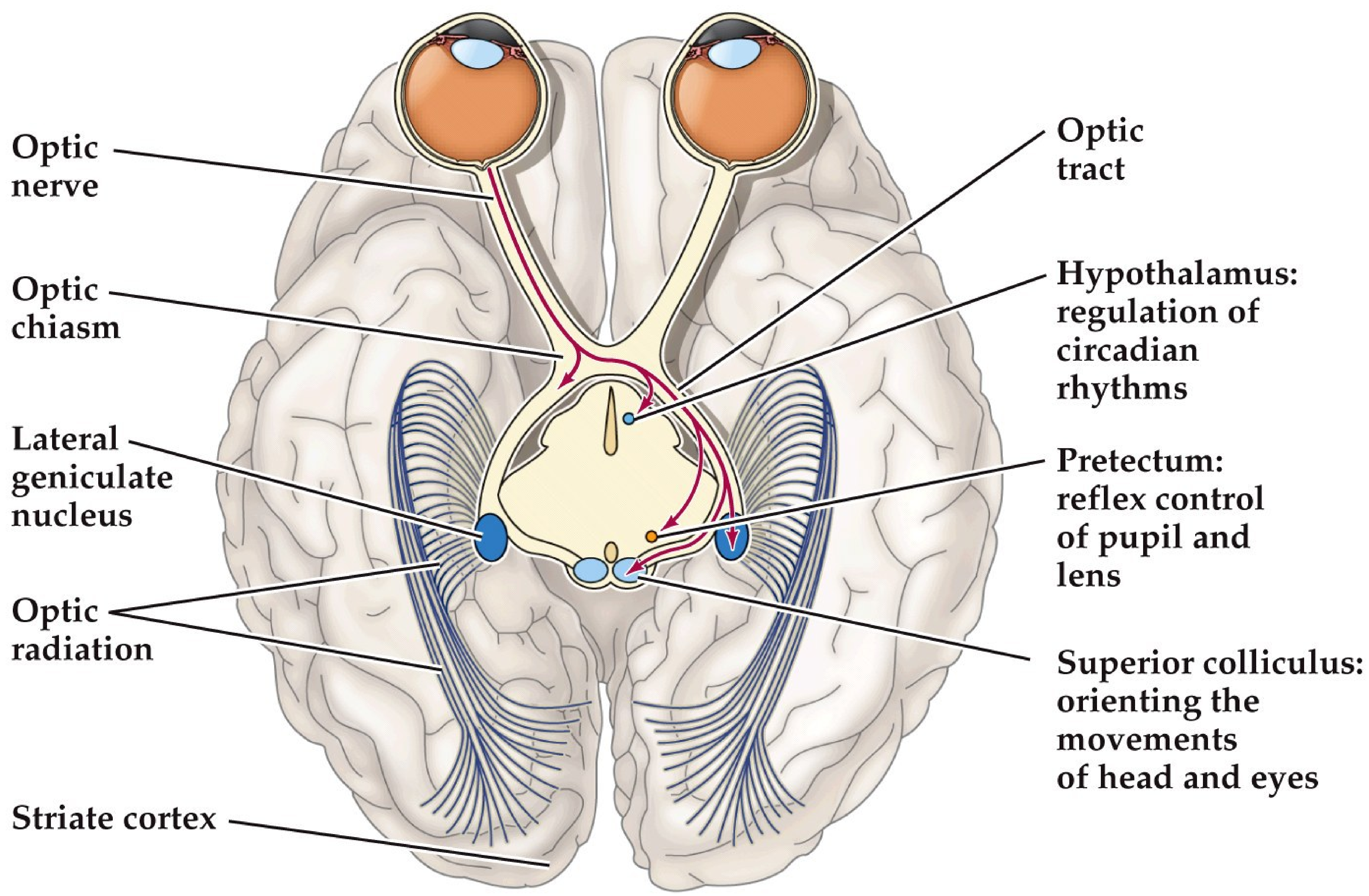
Visual system terminology

- **Optic disc, optic nerve**- All the retinal ganglion cell (RGC) axons exit the eye at the optic disk (results in a blind spot) and form a big myelinated nerve called optic nerve (cranial nerve II).
- **Optic chiasm**- where the optic nerve enters the brain, at the base of the hypothalamus.
- **Optic radiation**- portion of the internal capsule (connection between thalamus and cortex) containing the axons from dLGN that project to the visual cortex
- **Primary visual cortex**– V1/area 17/striate cortex

Speaker notes

finger test

Human visual system



Neuroscience 5e Fig. 12.1

Speaker notes

No notes on this slide.

The pupillary light reflex

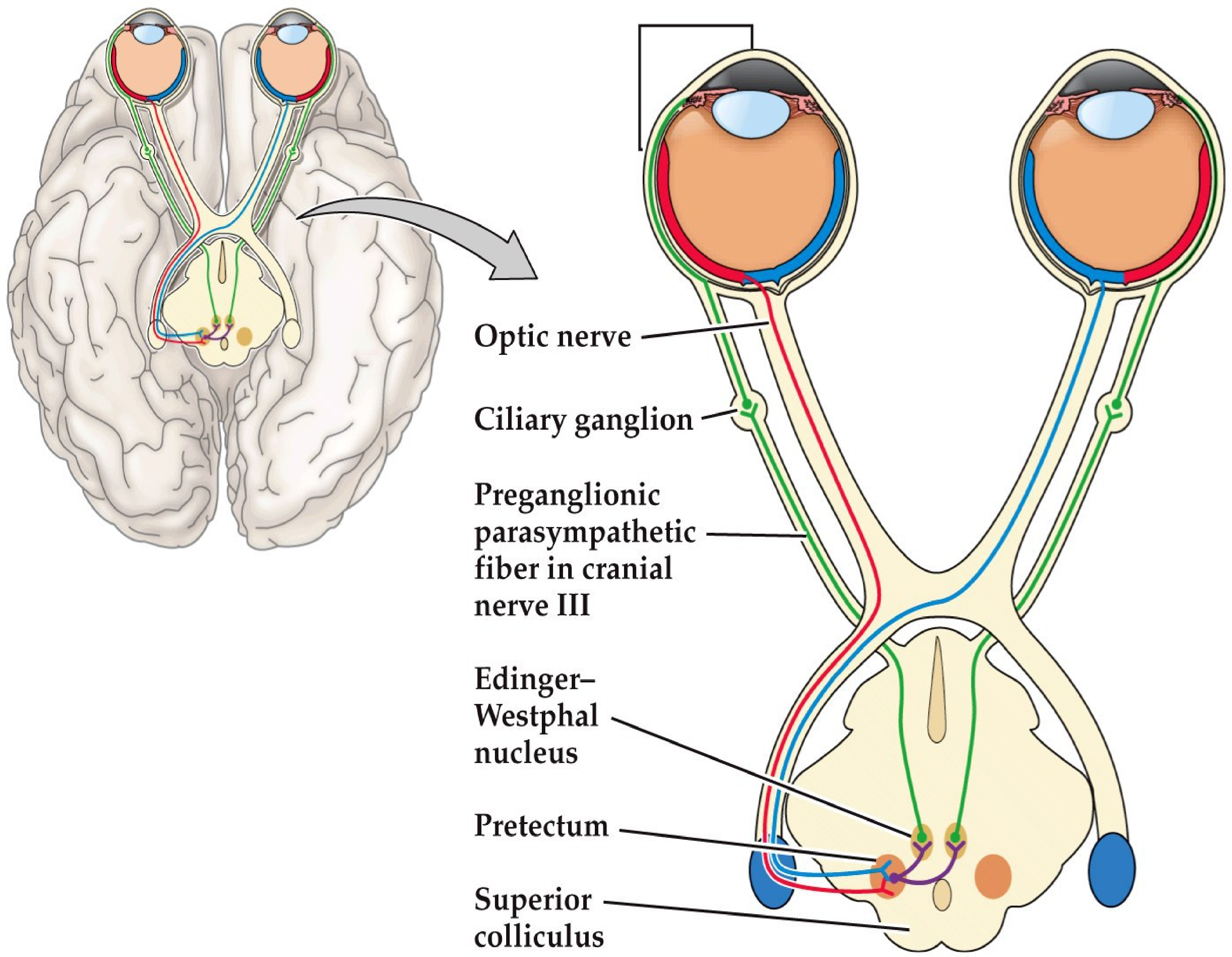
- Light hits retina, sends out axons to both sides of brain that go to the pretectum
- Pretectal neurons project to contra- AND ipsi-lateral Edinger-Westphal nuclei (in midbrain)
- Edinger-Westphal nucleus projects to the ciliary ganglion (PNS)
- Ciliary ganglion projects to the constrictor muscle in the iris. Shining light in one eye leads to constriction of both eye's muscles

atropa belladona
:'deadly nightshade'
: atropine
: mydriasis
: dilation of the pupil

Speaker notes

- atropine blocks contraction of the **circular **pupillary constrictor muscles muscle (classified as an anticholinergic drug) by being a competitive inverse agonist for muscarinic ACh receptors
- allows the radial pupillary dilator muscle to contract and dilate the pupil
- mydriasis (dilation of the pupil)

Circuitry responsible for the pupillary light reflex



Neuroscience 5e Fig. 12.2

- Question: Where is the site of injury if shining a light into the left eye causes both eyes to constrict but shining light into the right eye does not cause either eye to constrict?
  - **right optic nerve**

Speaker notes

answer: right optic nerve

http://library.med.utah.edu/kw/animations/hyperbrain/parasymp_reflex/

The spatial relationships among the RGCs are maintained in their targets

- Referred to as visual maps or topographic maps (e.g. retinal topography or 'retinotopy')
- Images are inverted and left-right reversed as they are projected onto the retina through the lens
- The left half of the visual world is represented in the right half of the brain and vice versa (compare to somatosensory system)
- Because humans are binocular, some inputs from each eye project ipsilaterally and some contra-laterally

Speaker notes

Neighboring retinal ganglion cells in the eye detect changes in contrast from similar portions of the visual field, thus forming a 2D map of visual space in the retina. This spatial representation of objects in the retina is then projected onto -->multiple down stream visual areas, so that maps of retinal topography, or retinotopy, are maintained at multiple levels in the visual system.

Other visual functional organization that is present at birth includes maps of ocular dominance, where the responses of neuronal groups is dominated by that of one eye or the other and orientation selectivity where the responses of neighboring neurons is dominated by high contrast edges of particular orientation.

Binocular vision

- There is an overlap in visual fields, such that objects in the central visual field are seen by both eyes
- Objects in the left visual field are seen by the nasal retina of the left eye and the temporal retina of the right eye
- Objects on extreme periphery are seen only by the nasal retina on that side
- Nasal retinal derived axons cross the midline at the optic chiasm (contra lateral) and temporal retinal axons do not cross at the chiasm (ipsilateral)
- Images in the left visual field project onto the nasal retina of the left eye and the temporal retina of the right eye. These go to the same side of the brain. Therefore the left visual field is mapped onto the right side of the brain
- The visual map is maintained all the way to V1. The two halves of the visual fields only merge after getting connections from the other half through the corpus callosum

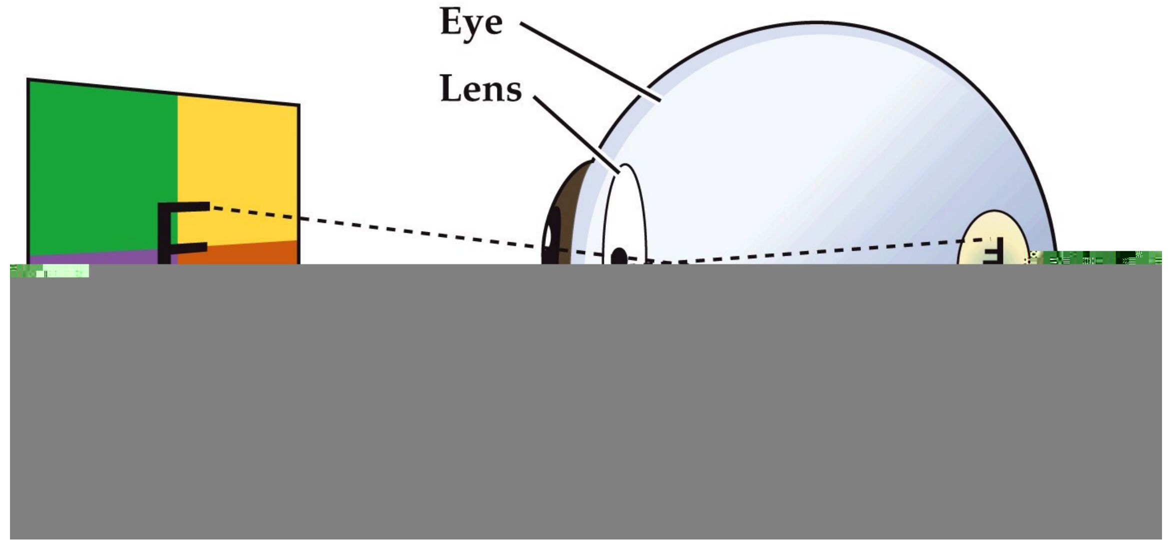
Speaker notes

humans have binocular vision, such that there is overlap…

this is crucial for stereopsis, or depth perception (finger disparity)

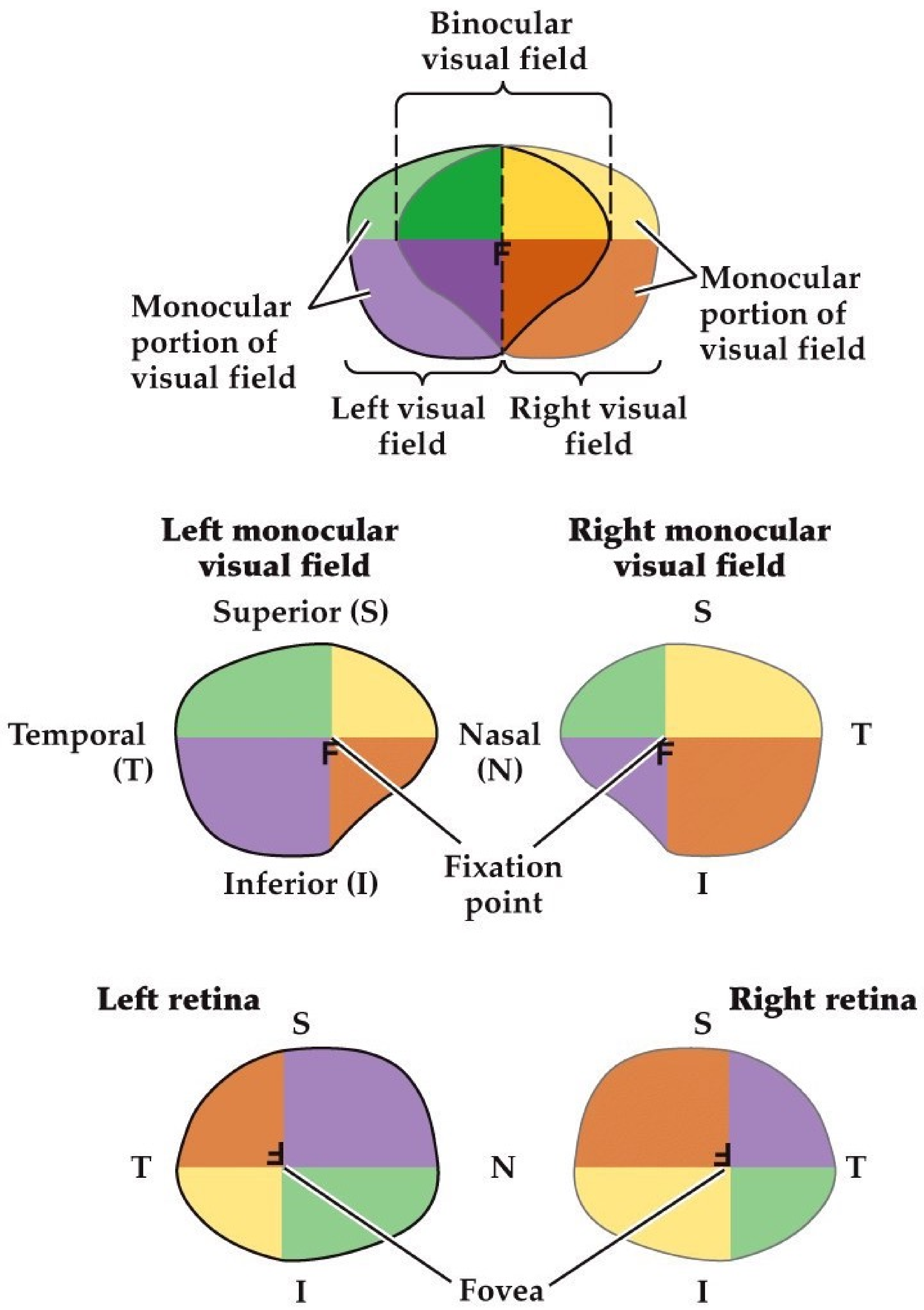
Projection of the visual field onto the retina

visual field



Neuroscience 5e Fig. 12.3

retinal visual hemi-fields



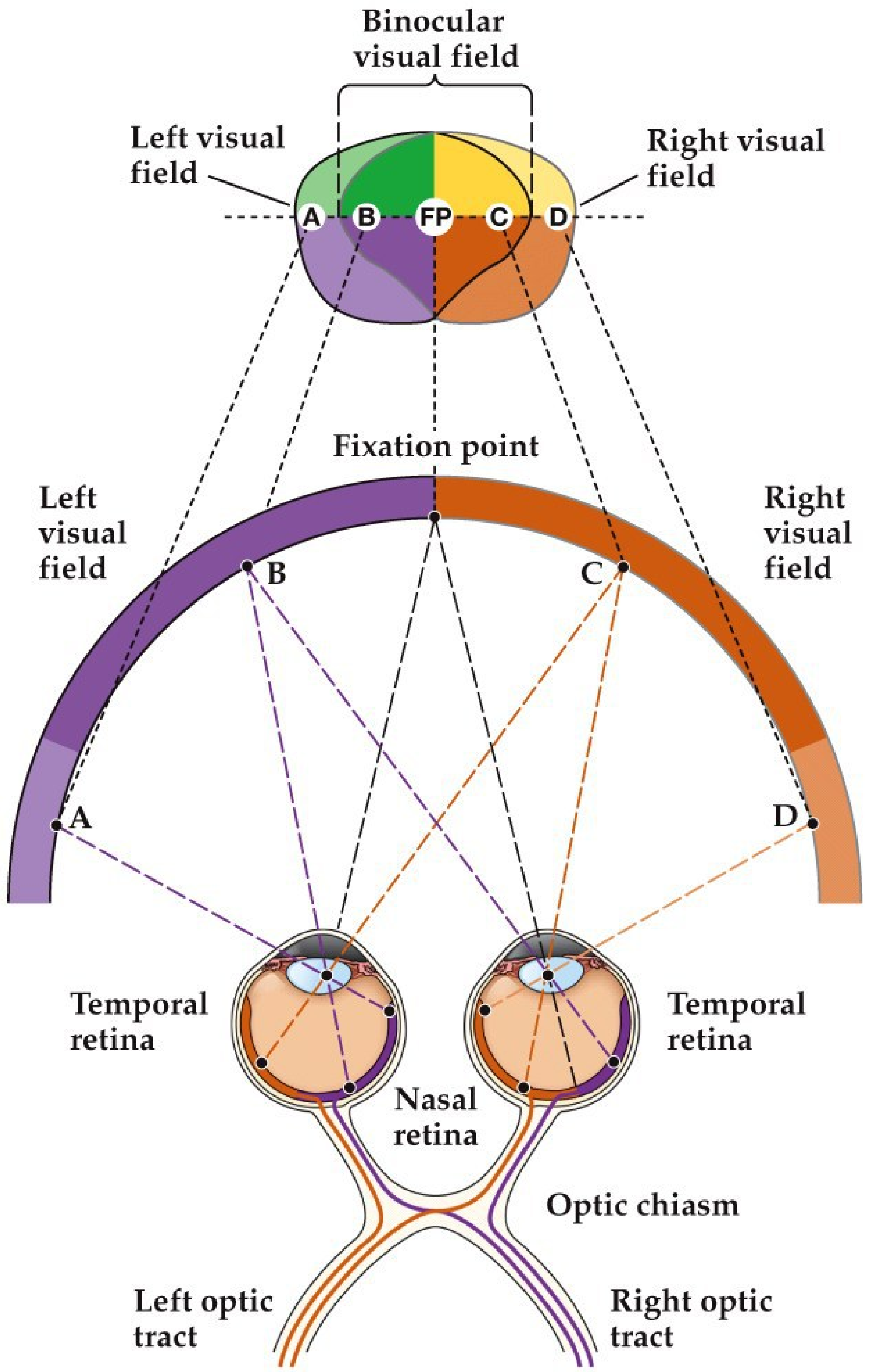
Neuroscience 5e Fig. 12.3

Speaker notes

So now lets go over the projection of the visual field on to the retina in a more detail

Binocular visual field

binocular vision (overlapped color in middle)



Neuroscience 5e Fig. 12.4

Speaker notes

Projection of the Binocular Field of View Relates to Crossing of Fibers in Optic Chiasm

Visual pathways summary video

Neuroscience 5e Animation 12.1

Speaker notes

start at binocular vision point

Lateral geniculate nucleus (LGN)

- 90% of the retinal axons go to the dLGN in the thalamus
- dLGN projects to visual cortex (striate cortex)
- Contains 6 layers, that are specific with respect to eye (ipsi vs contra) and with respect to type of ganglion cell— magnocellular (detects gross shape and movement) and parvocellular (form and color)
- Layers align in order to align visual fields
- Each dLGN receives input from 1 or 2 RGCs therefore like RGCs there also have center-surround responses that are either on or off

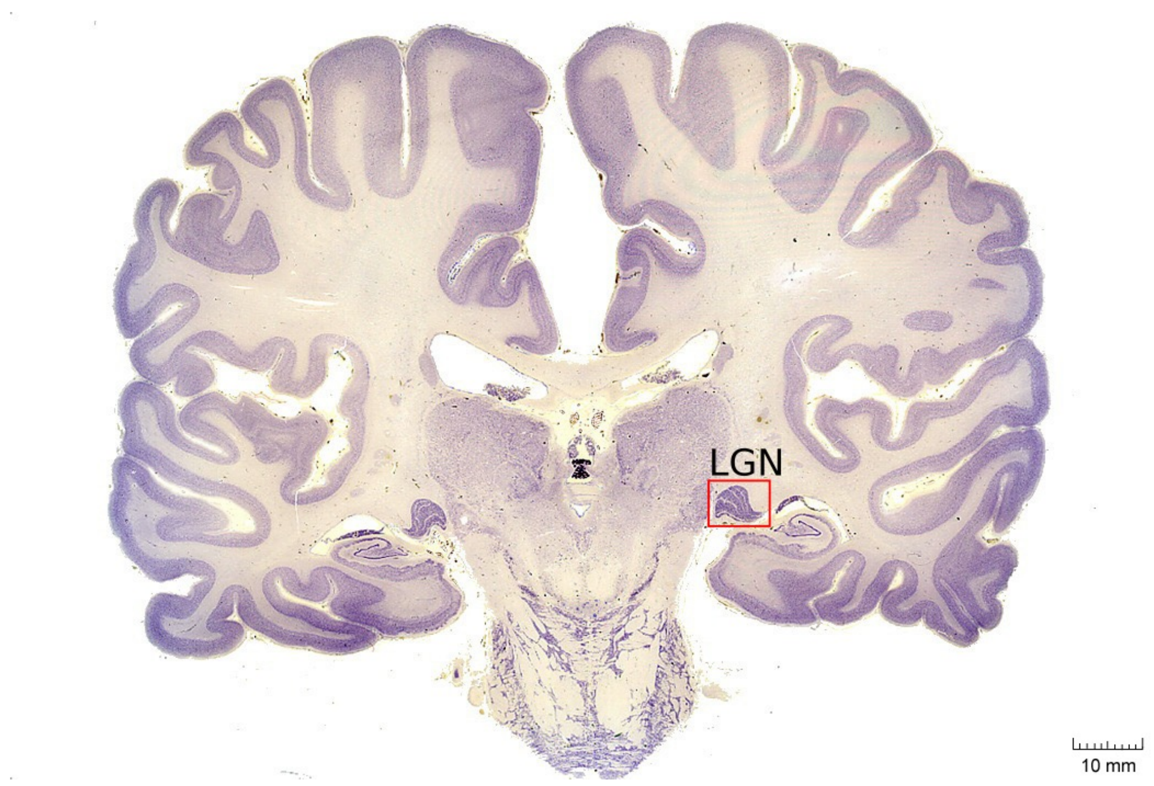
Speaker notes

show human visual system slide from earlier, thalamus slide?

Laminar organization of the LGN

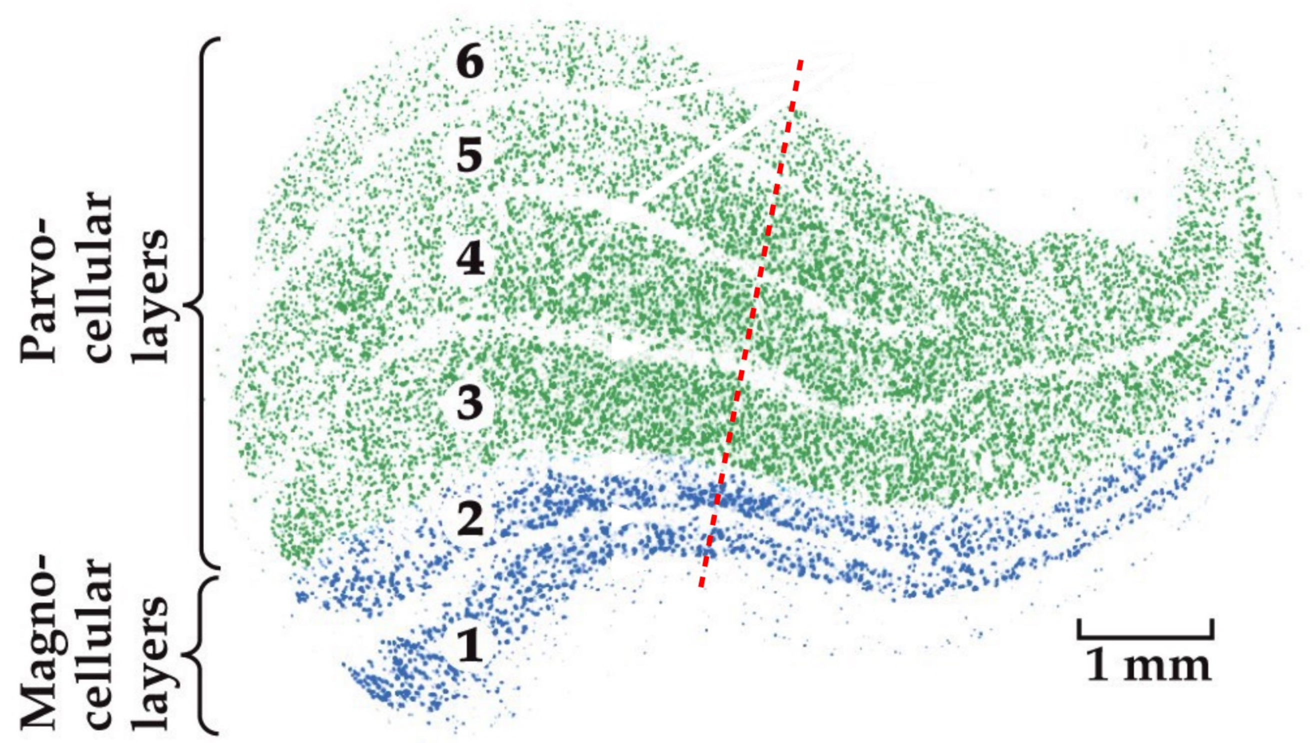
- Each LGN layer is eye-specific
- The projections from the retinal ganglion cells maintain the field of view as it was seen - this is called a retinotopic map. The LGN contains 6 layers of cell bodies; each layer receives input from only one eye. The two most ventral layers receive M (magno) ganglion cell inputs, while the other 4 receive P (parvo) inputs

Human LGN



Brain Biodiversity Bank MSU, NSF

Neurons along the dotted line see the same point in visual space.
Neurons in different layers receive info from different types of RGCs.



LGN, adapted from Neuroscience 5e Fig. 12.15

Speaker notes

parvocellular retinal ganglion cells : small dendritic trees, small receptive fields, used for high acuity form vision, color vision

magnocellular retinal ganglion cells : large dendritic trees, larger receptive fields, used for motion vision

Visual cortex

- The first point in the central visual pathway where the receptive fields of cells are significantly different from those of the retina
- Located in occipital lobe near the parieto-occipital sulcus
- There is topographic organization of each visual hemifield
- Upper visual field is represented below the calcarine sulcus, the lower field above the calcarine sulcus
- Superior and inferior visual fields take different routes to the visual cortex. Meyer’s loop, where superior axons diverge and go into temporal lobe before going to occipital lobe

Speaker notes

No notes on this slide.

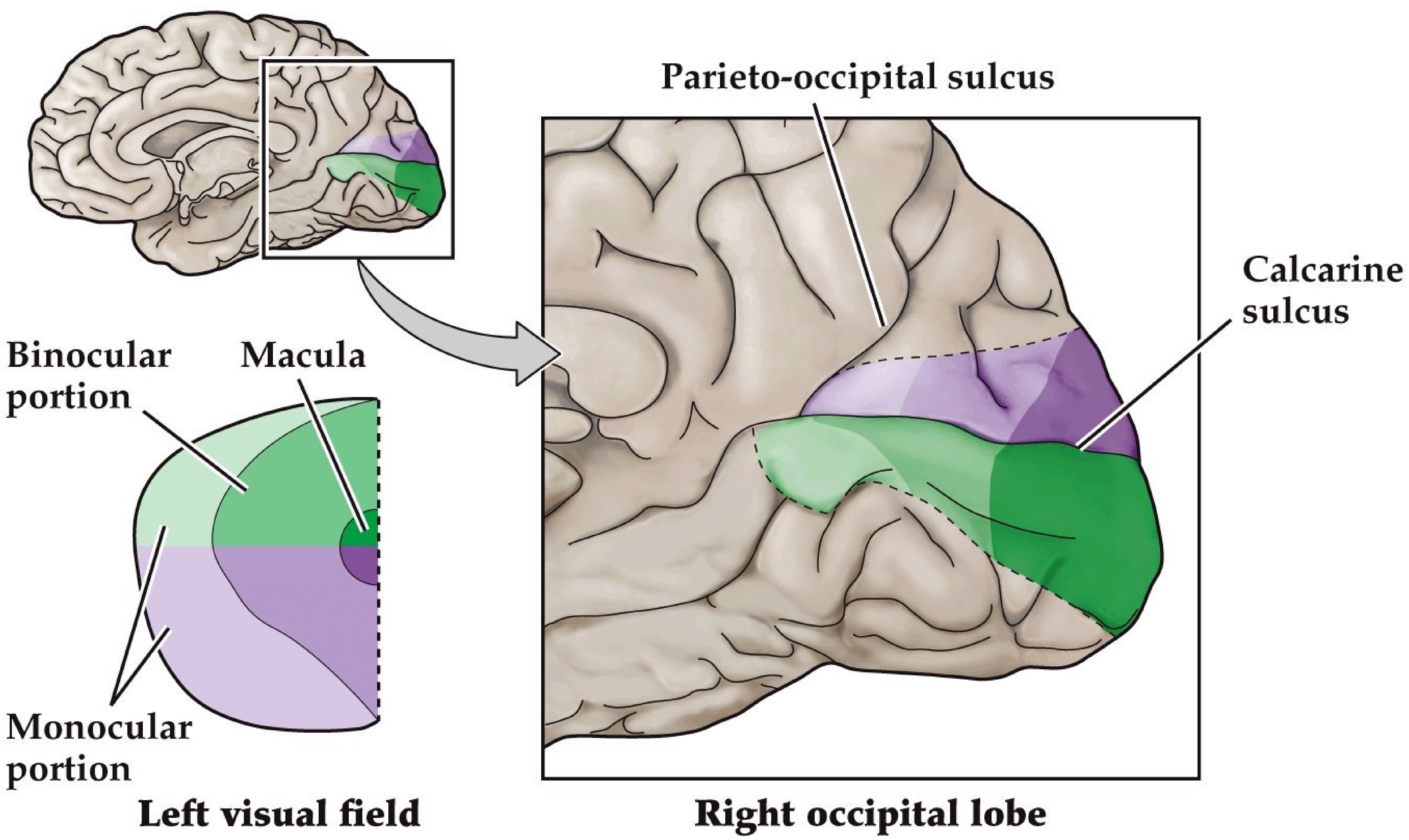
Projection to cortex

- The visual field is projected in a retinotopic fashion
- The right visual field is projected onto the left cortex, while the left visual field is represented on the right
- The region of the fovea (highest density of cones and central to our visual attention) is represented by a huge amount of the cortex

Speaker notes

Incr representation sound familiar? think of hand and lip representation in human somatosensory cortex we discussed a couple classes ago…

Visuotopic organization in the right occipital lobe



Neuroscience 5e Fig. 12.5

Speaker notes

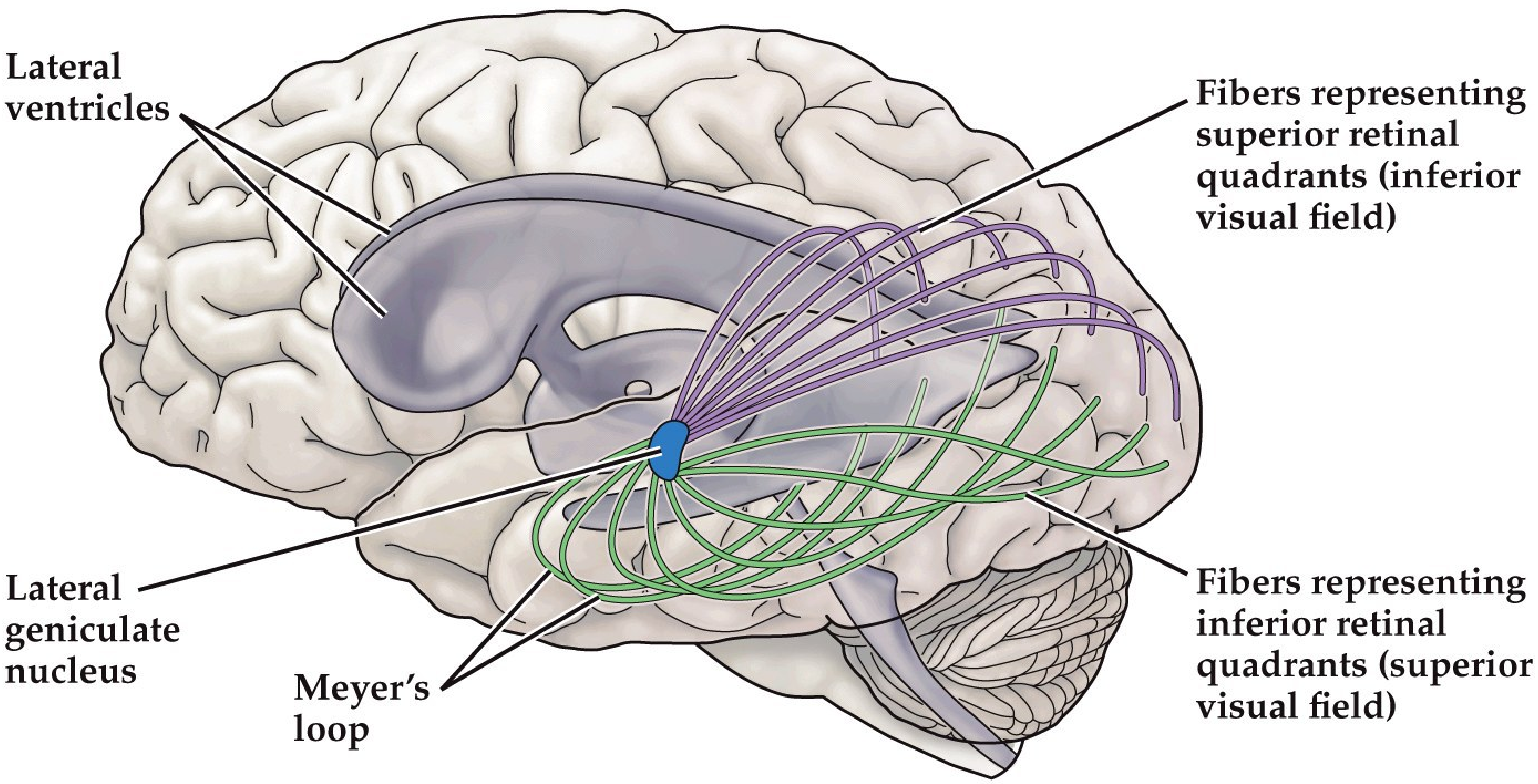
No notes on this slide.

Speaker notes

No notes on this slide.

Thalamocortical projections to the visual cortex ('optic radiation')

lower visual field (dorsal retina): purple, upper visual field (ventral retina): green



Neuroscience 5e Fig. 12.7

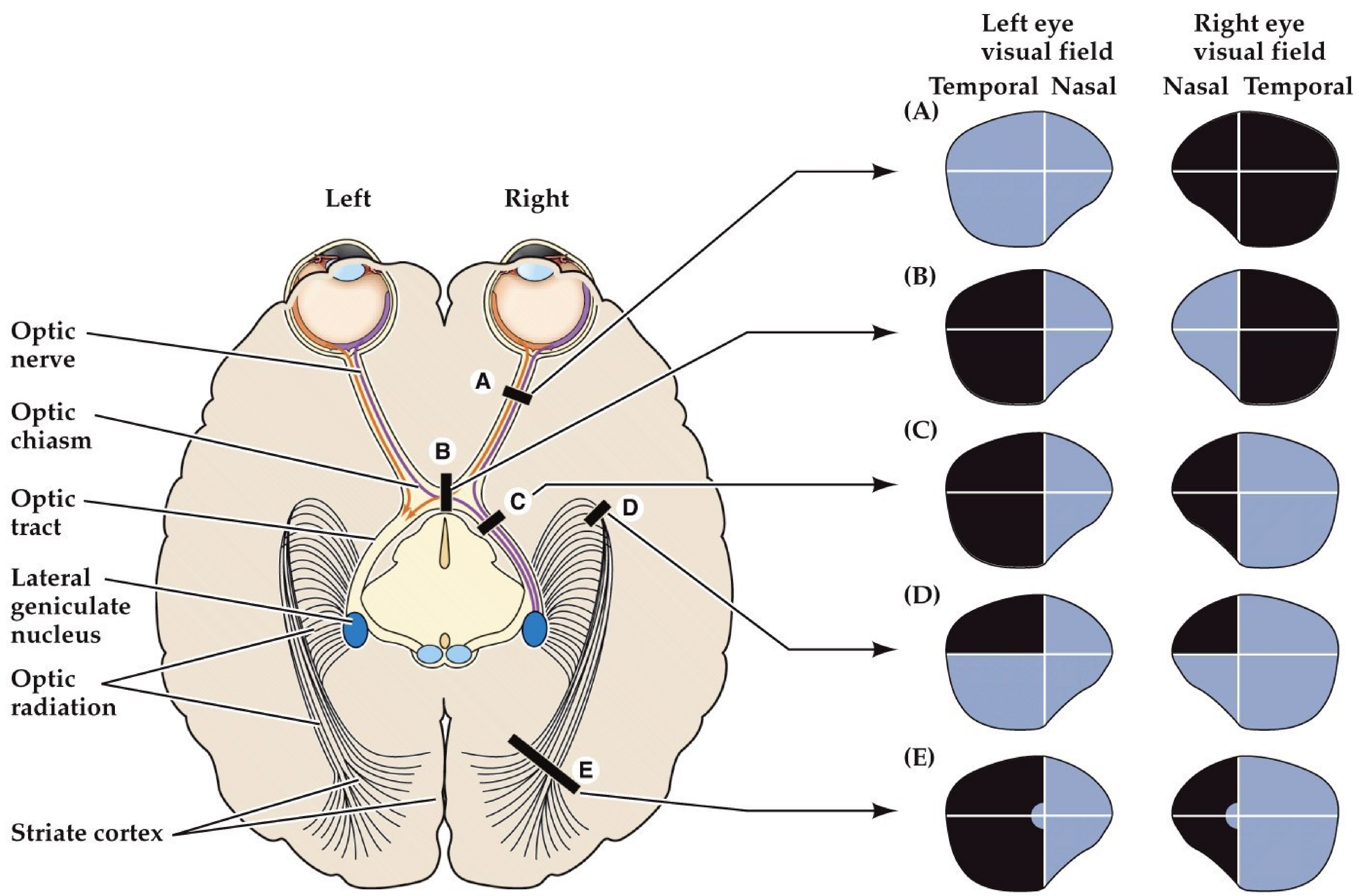
Visual field defects

- The spatial relationships in the retina are maintained in the brain
- Careful analysis of the visual field defects of a patient can often indicate where brain damage is located
- Anopsias— relatively large deficits
- Scotomas— smaller deficits

Speaker notes

No notes on this slide.

Visual field deficits resulting from damage along the primary visual pathway



Black means blind
Blue means see

(A) blindness in R eye

(B) bitemporal hemianopsia

(C) L homonymous hemianopsia

(D) upper quadrant hemianopsia

(E) homonymous hemi-anopsia with macular sparing

Neuroscience 5e Fig. 12.6

Speaker notes

Reasons for macular sparing not known. Has been proposed that there is overlap in the pattern of crossed and uncrossed ganglion cells that provide central vision

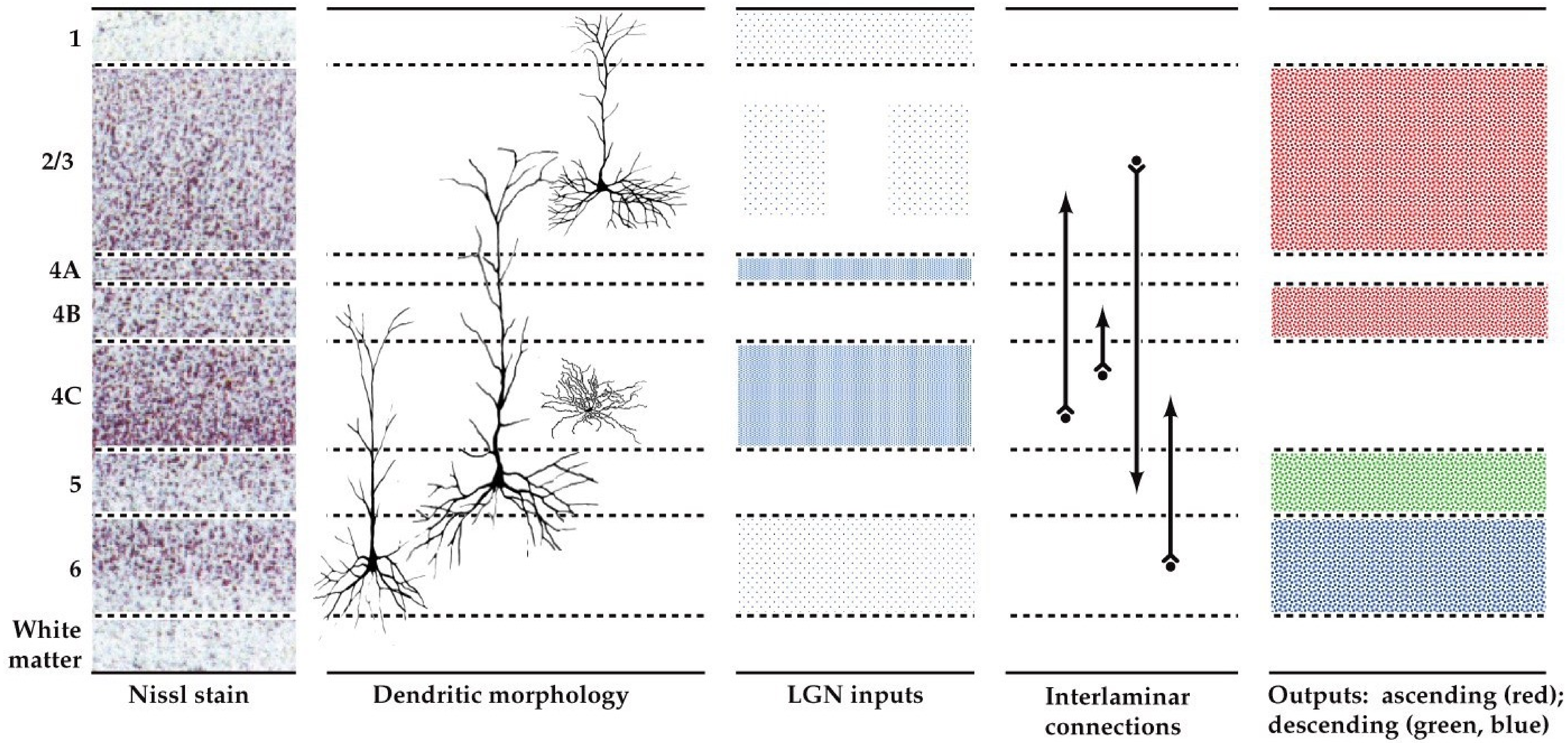
The columnar organization of visual cortex

- The visual cortex is layered. Each layer has stereotypical inputs and outputs. LGN projects to layer 4. Output layer is layer 5.
- Each column of neurons in the vertical plane typically respond to the same part of the visual field and the same orientation.
- Neurons in the horizontal plane respond to neighboring areas of the visual field and change orientation preferences that repeats each milimeter or so.
- Neurons in layer 4 respond to just one eye or the other (monocular cells) but other layers have neurons that can respond from either eye. This sets up ocular dominance columns in the cortex.

Speaker notes

Now let’s go over the structural and functional organization of visual neocortex

Anatomical organization of visual cortex



Neuroscience 5e Fig. 12.10

Speaker notes

4Ca: magnocellular
4Cb: parvocellular

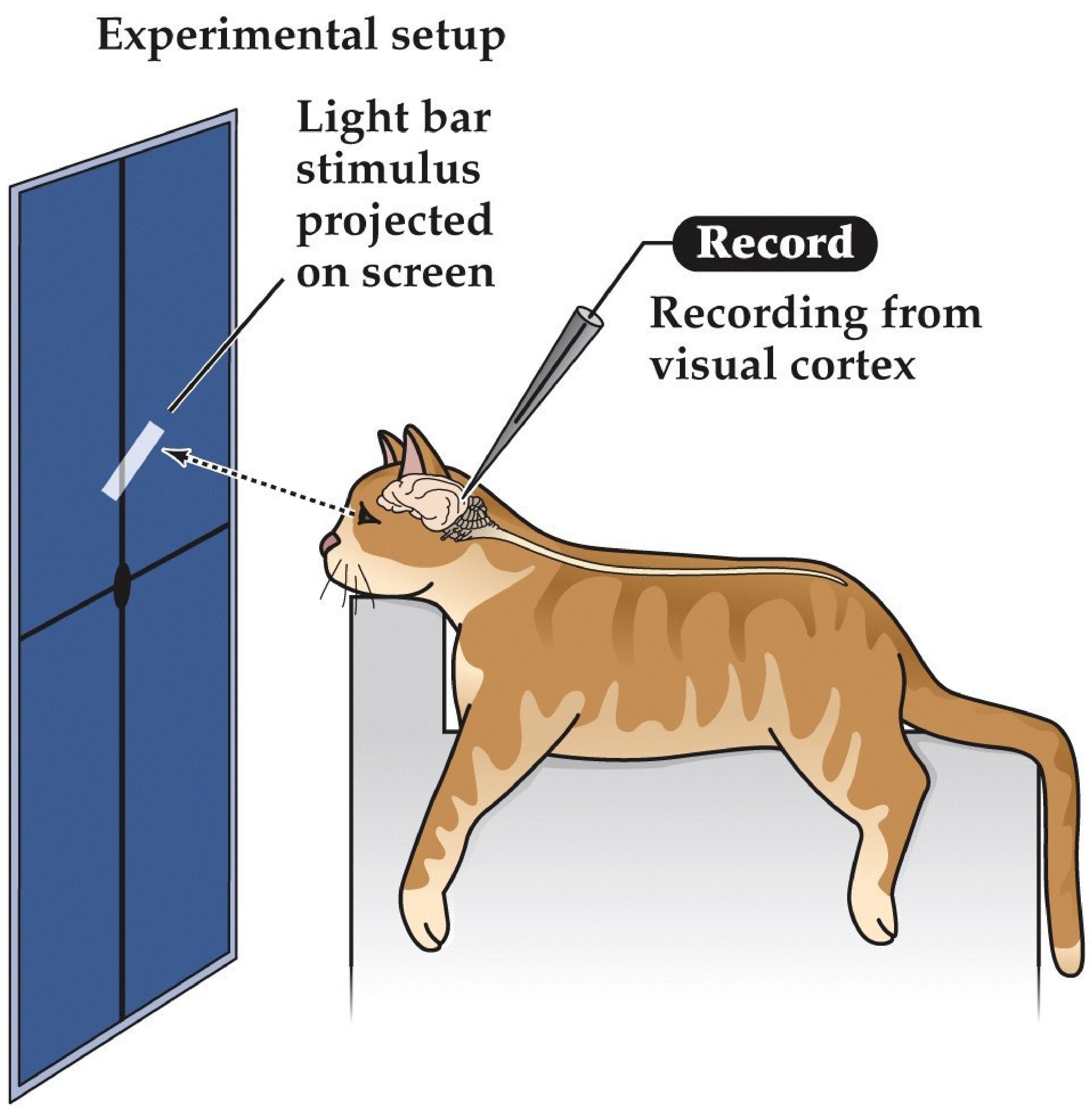
Neurons in the primary visual cortex respond selectively to oriented edges

- David Hubel and Torsten Wiesel— measured responses of neurons in visual cortex. Found not center-surround like RGCs and LGN neurons but found that they respond to bars or lines but only of a particular orientation
- Two types of cells:
  - Simple, respond to stimulus only if matches orientation. Spots of light don't do much, bars or lines make them fire. They also have surround inhibition. Receptive fields can be generated by having 3-4 LGN neurons innervate one simple cell
  - Complex cells- bigger receptive fields, not strongly orientation selective, no clear on or off zones, detect movement

Speaker notes

No notes on this slide.

Neurons in the primary visual cortex respond selectively to oriented edges



Neuroscience 5e Fig. 12.8

Speaker notes

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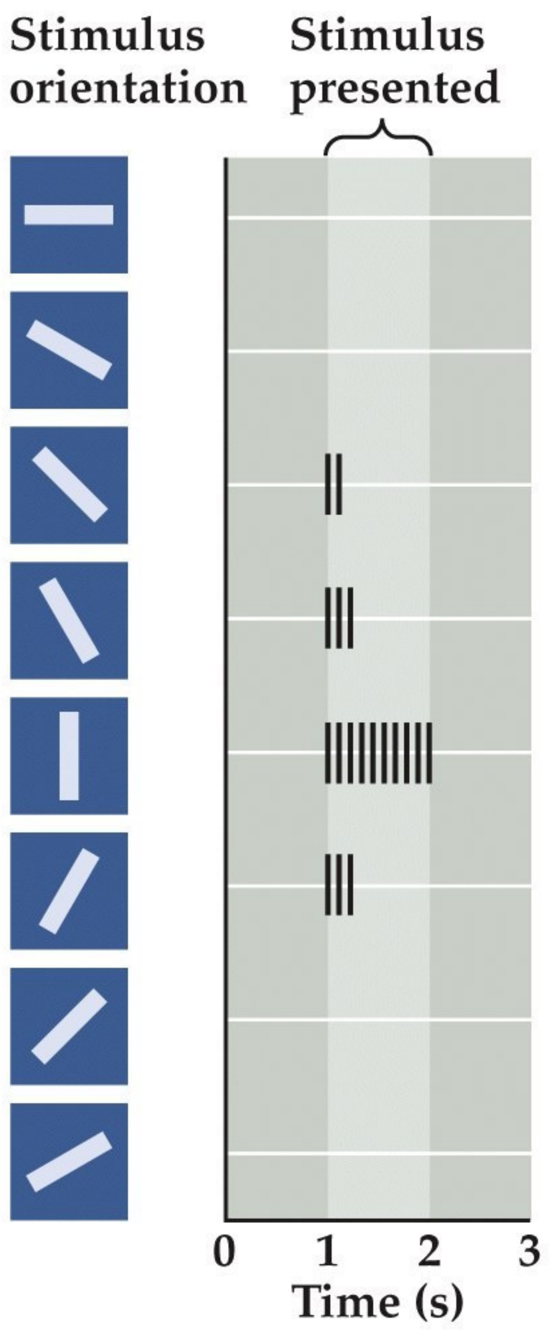
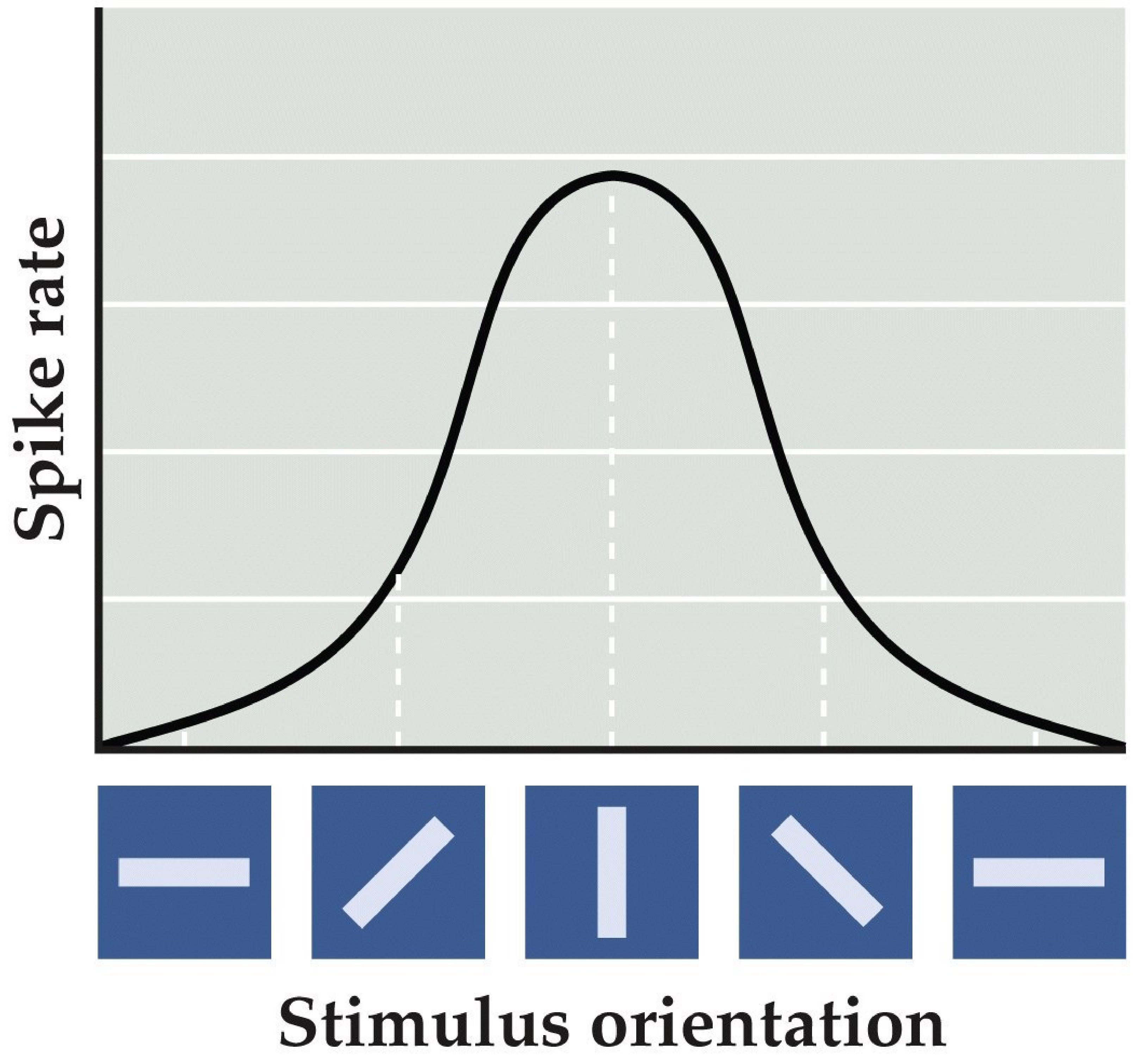
Neurons in the primary visual cortex respond selectively to oriented edges

Spiking response from a V1 neuron to oriented visual stimuli



Neuroscience 5e Fig. 12.8

Oriention tuning curve for a single V1 neuron



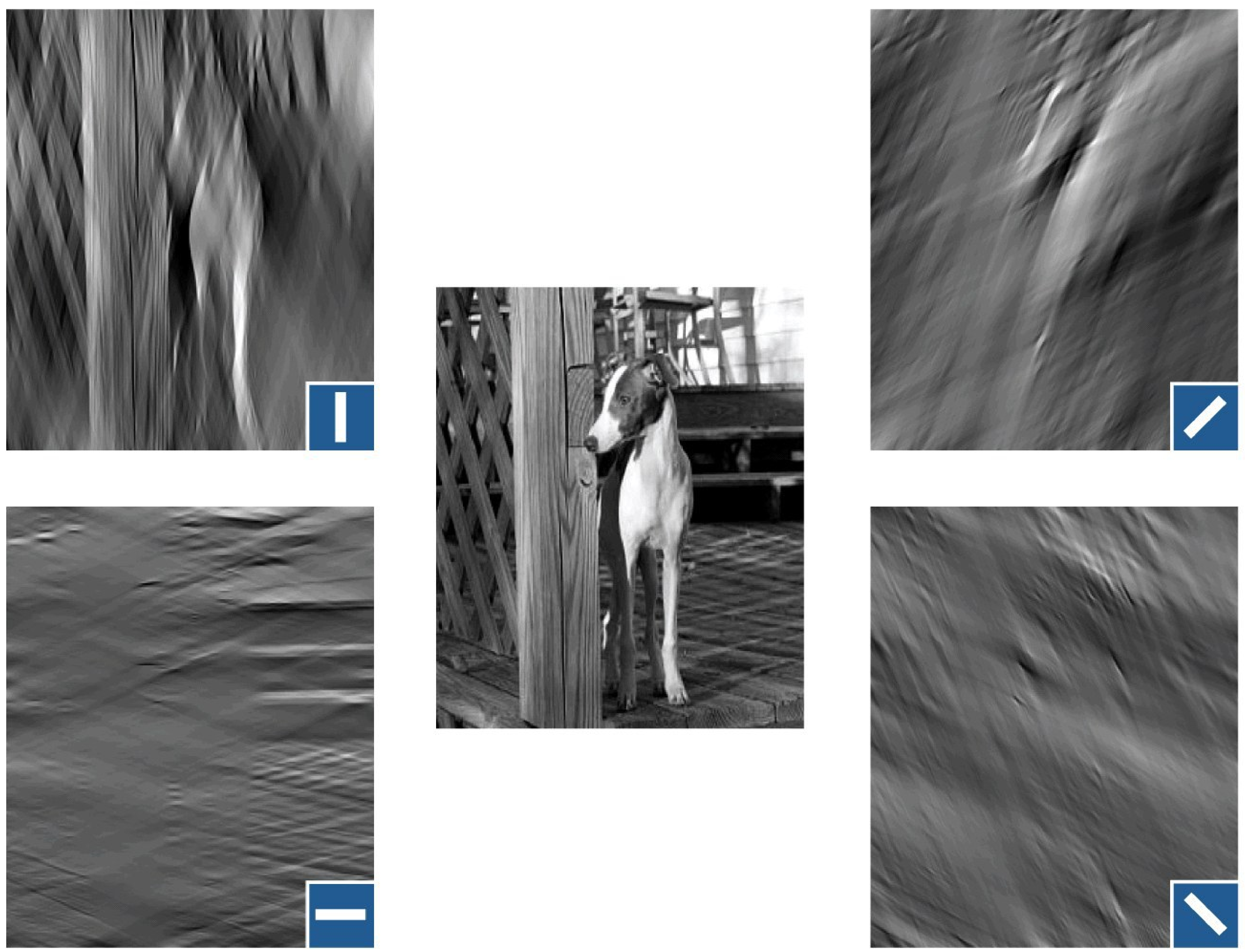
Neuroscience 5e Fig. 12.8

Speaker notes

- neurons in primary visual cortex typically respond strongly to a bar presented at a particular orientation and less strongly at other orientations.
- orientation tuning curve for a single example neuron in visual cortex, highest spike rate at its preferred orientation

Neurons in the primary visual cortex respond selectively to oriented edges

Simulated edge components from a natural visual scene detected across a population of V1 neurons



Neuroscience 5e Fig. 12.9

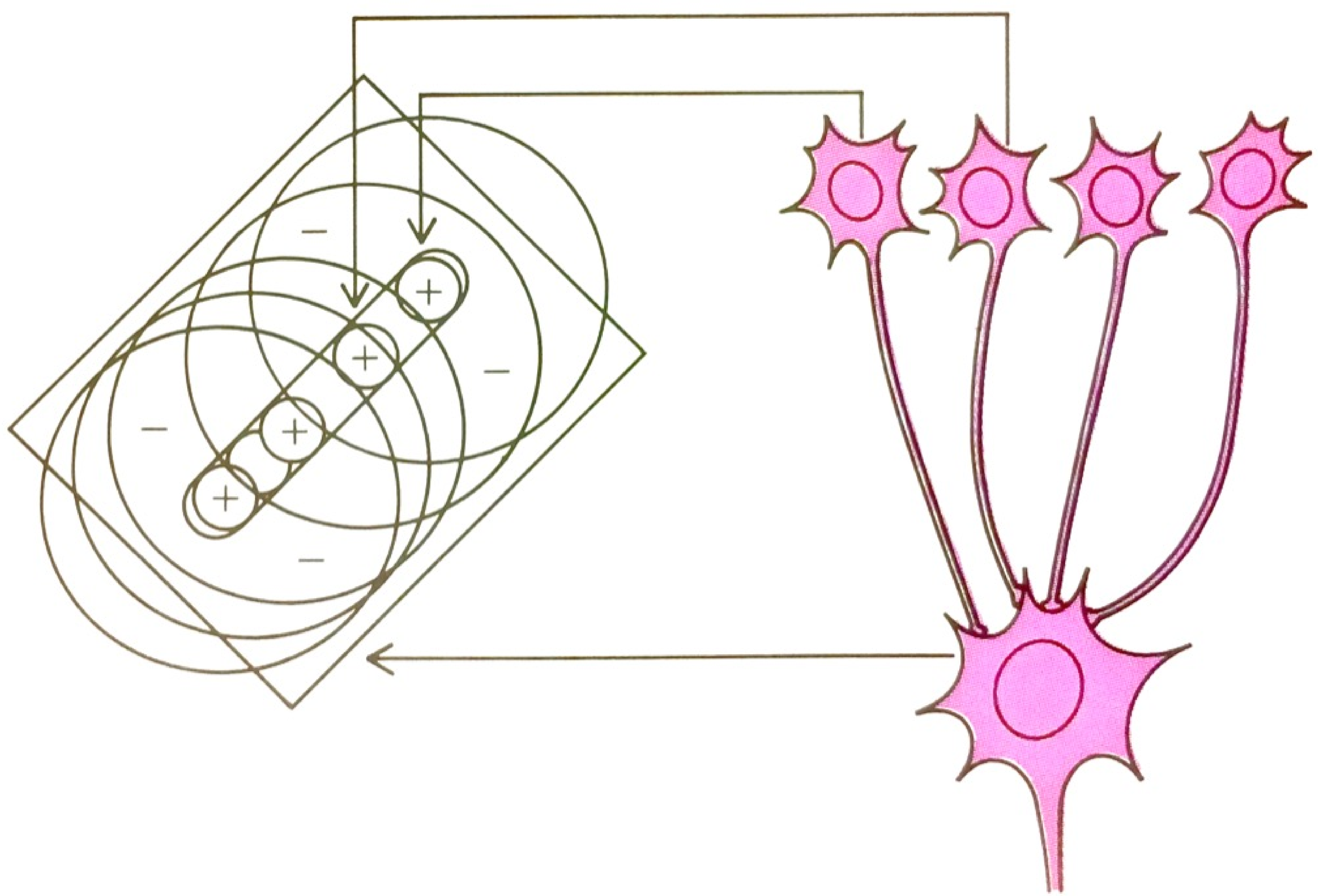
Speaker notes

Natural scenes consist of a spectrum of high contrast, oriented edges.

Selective filtering using Fourier transform (from training in linear algebra and signal processing)

Hubel and Wiesel model circuit underlying a V1 neuron receptive field (RF)

Inputs from several RGC center-surround RFs may be integrated to create a oriented edge RF for V1 neurons



D. Hubel. *Eye, Brain, and Vision* p. 74

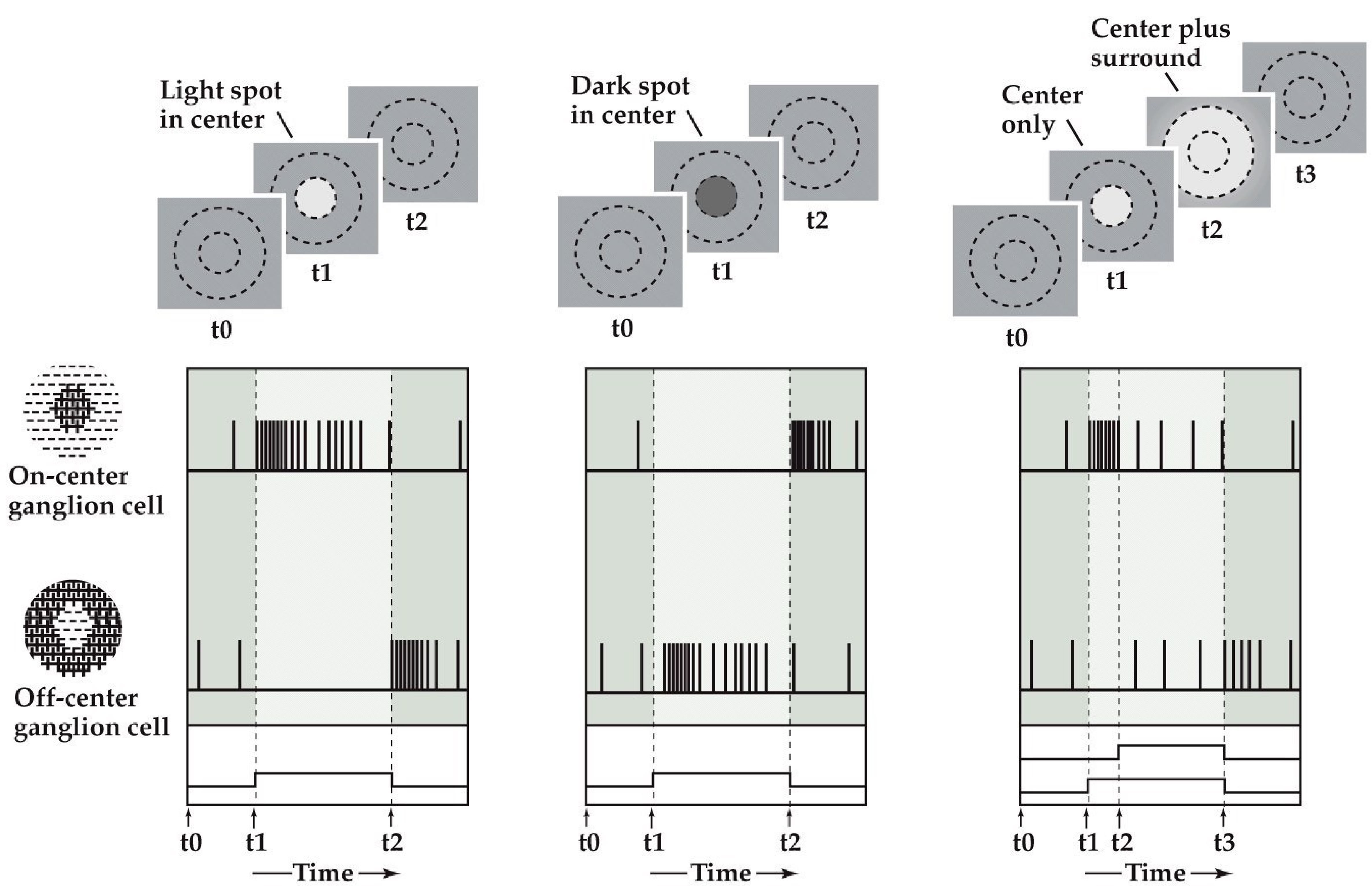
Speaker notes

- monkey 70-80% of cells have orientation specificity
- cat all cells appear to be orientation selective

complex cells are also all orientation selective and retinotopic, but need moving lines. Do not react to stationary stimuli. Most common functional cell type in striate cortex, maybe 75% of population. Glass slide in field of view was first stimulus.

0.25 degs RF size (fovea) to 1 degree RF (peripheral retina)

On- and off-center retinal ganglion cell responses to stimulation of different regions of their receptive fields



Neuroscience 5e Fig. 11.17

Speaker notes

No notes on this slide.

Visual cortex neuron receptive fields

Filtering of info from multiple LGN cells is used to make receptive fields for neurons in visual cortex

LGN ON neuron receptive fields

V1 neuron receptive fields, D. Hubel, M. Pavel

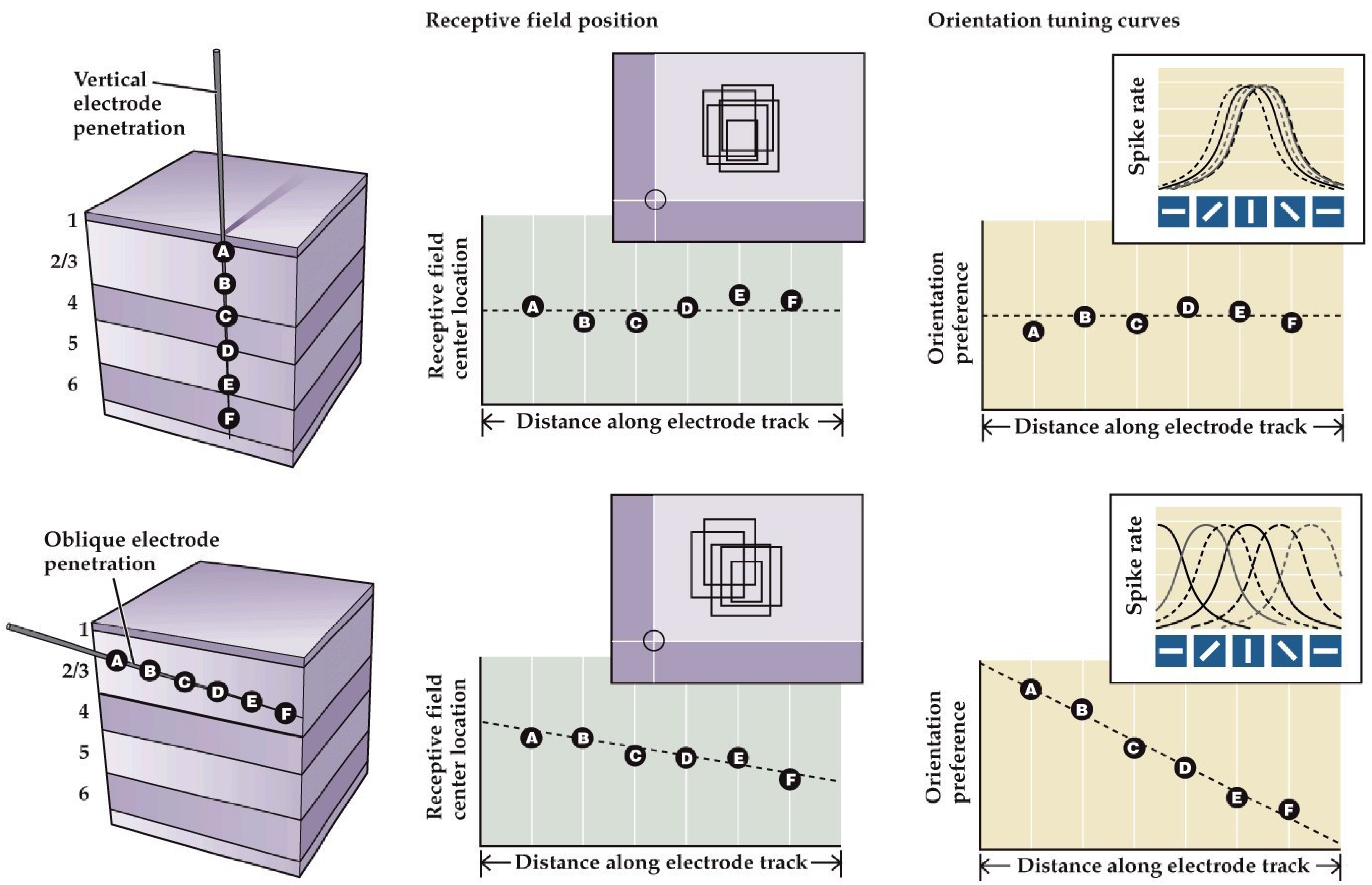
Speaker notes

other hubel vid I saw and marked times…

- david hubel 1:24-2:18:
- 125 million rods and cones in each eye
- misha pavel
    - try to build a robot to see and interpret images and it's hard 3:15-3:30
    - sobel filter cat 4:00-4:20
    - perception of motion for visual detection cat 4:44

: 4:45 nice example of movement and perception of cat face

The basis of functional maps in primary visual cortex



Neuroscience 5e Fig. 12.11

Speaker notes

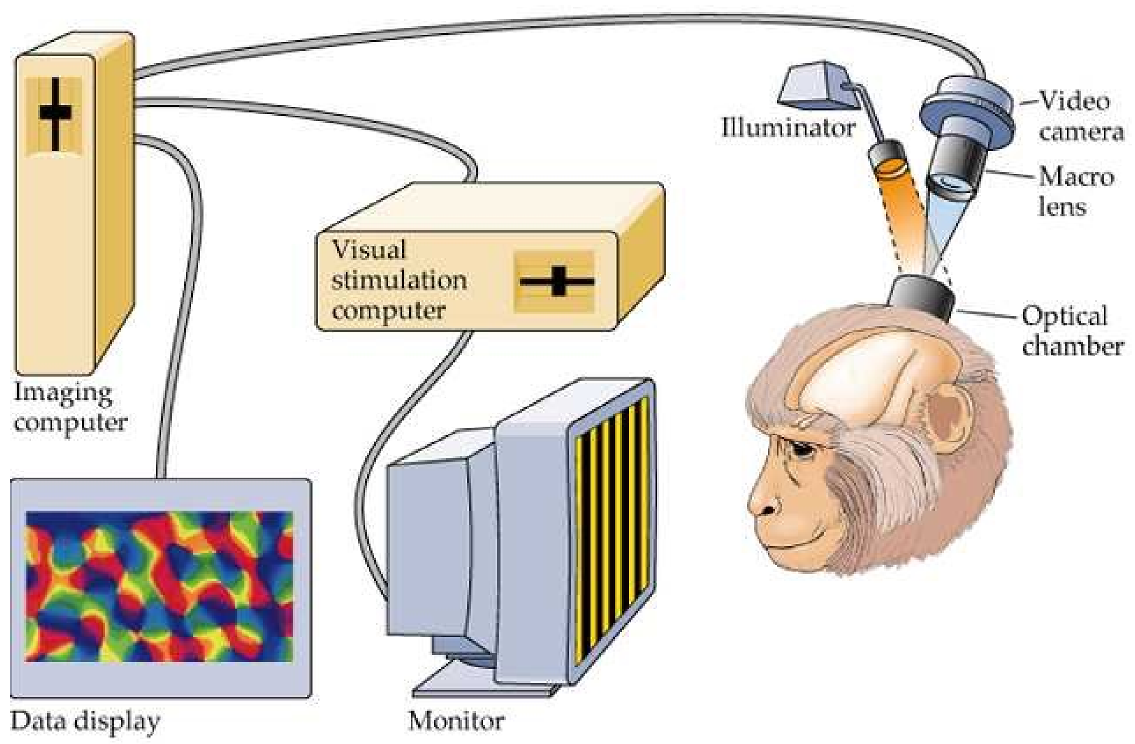
No notes on this slide.

Speaker notes

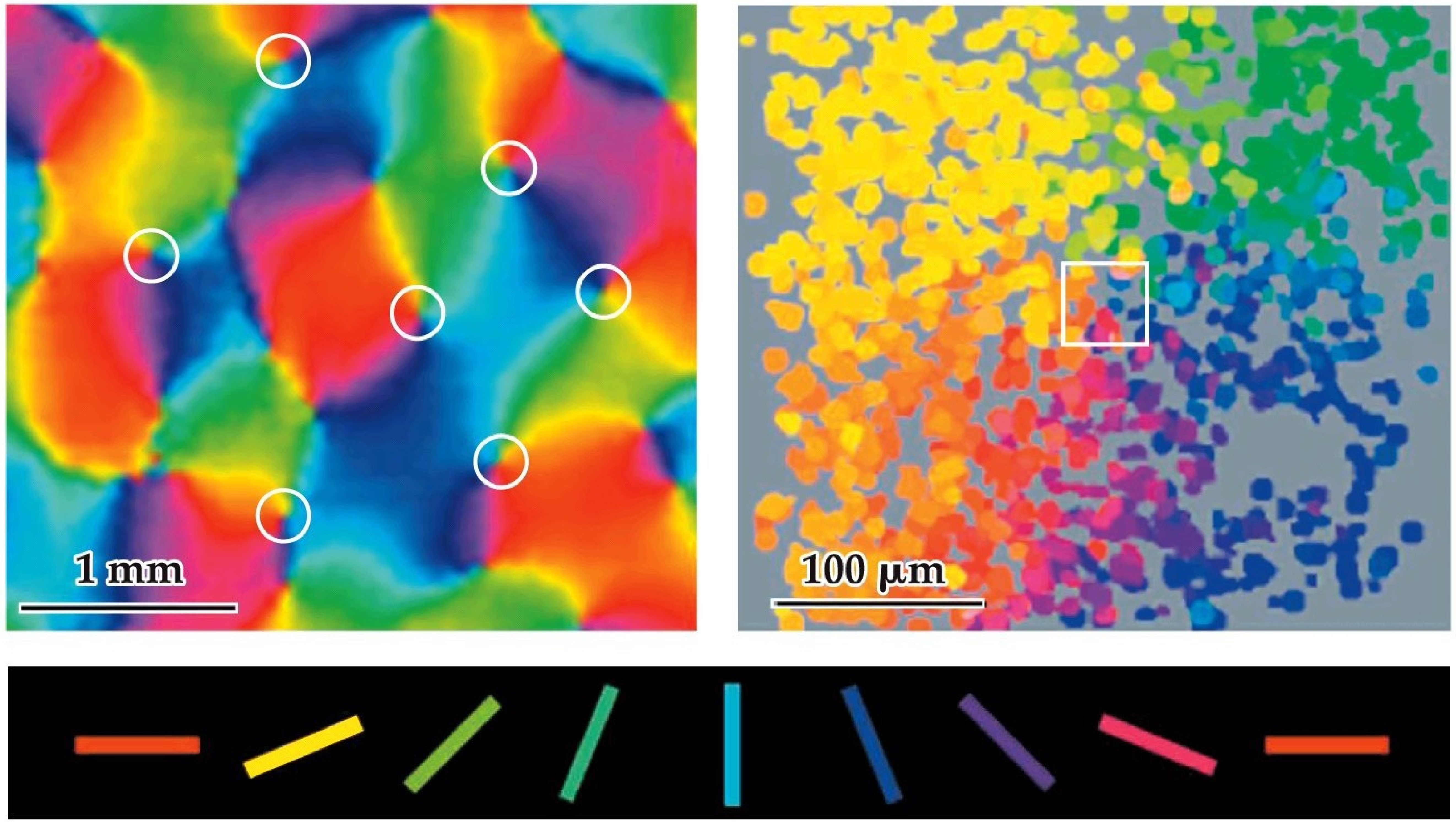
data display, surface of brain

Mapping receptive fields in the living brain

- Illuminator adds red light to help measure oxy-deoxy hemoglobin levels (a sign of increased neural activity)
- Show monkey monitor that contains a given orientation of a line. Program computer to color-code areas that respond to a certain orientation
- Repeat for all such orientations, get a pinwheel affect



Repeating units of orientation columns in visual cortex



Neuroscience 5e Fig. 12.12, D. Fitzpatrick (left), Ohki et al. *Nature* 2006 (right)

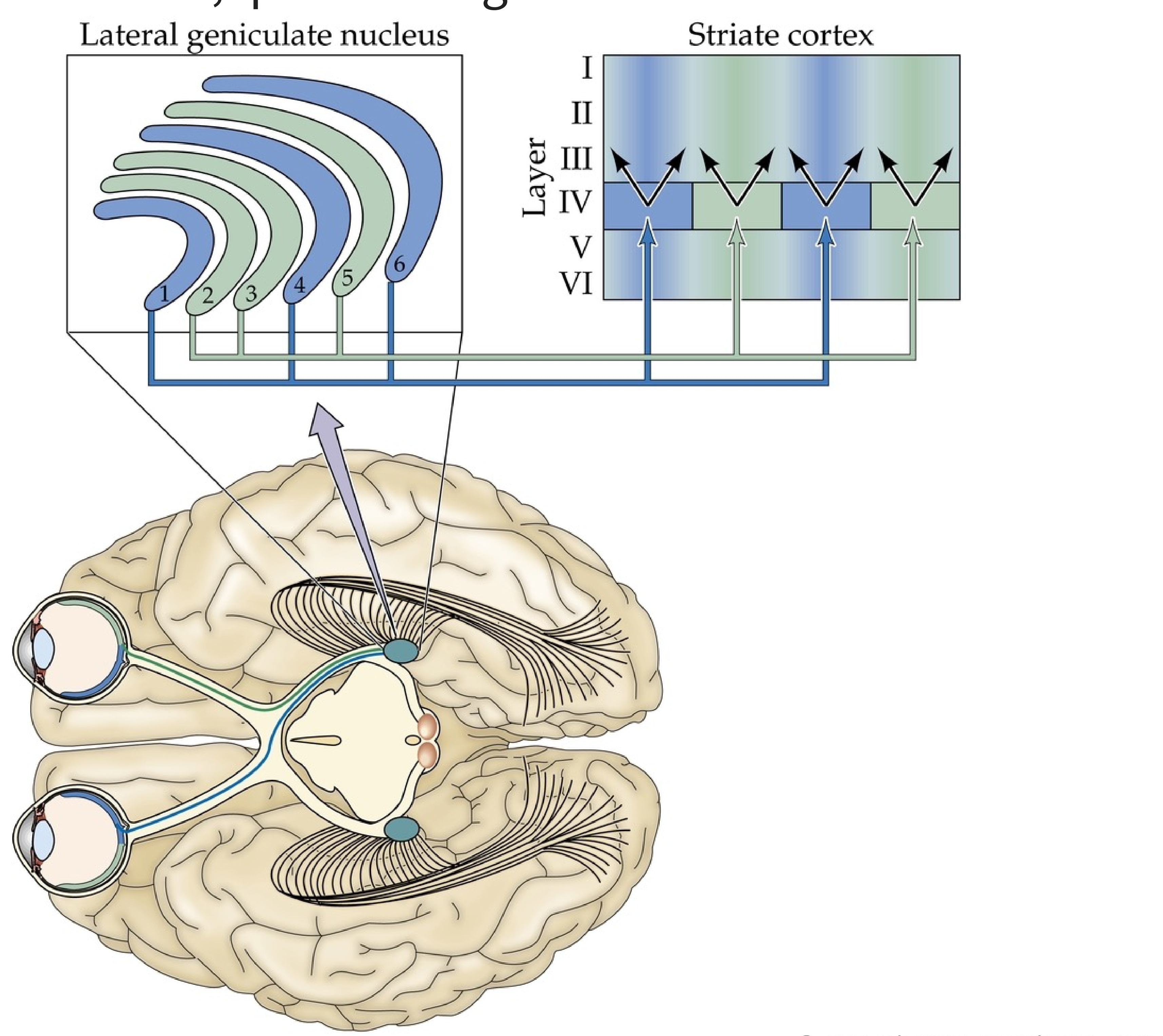
≡

Speaker notes

No notes on this slide.

Mixing of pathways from the two eyes first occurs in the visual cortex

contralateral: blue, ipsilateral: green



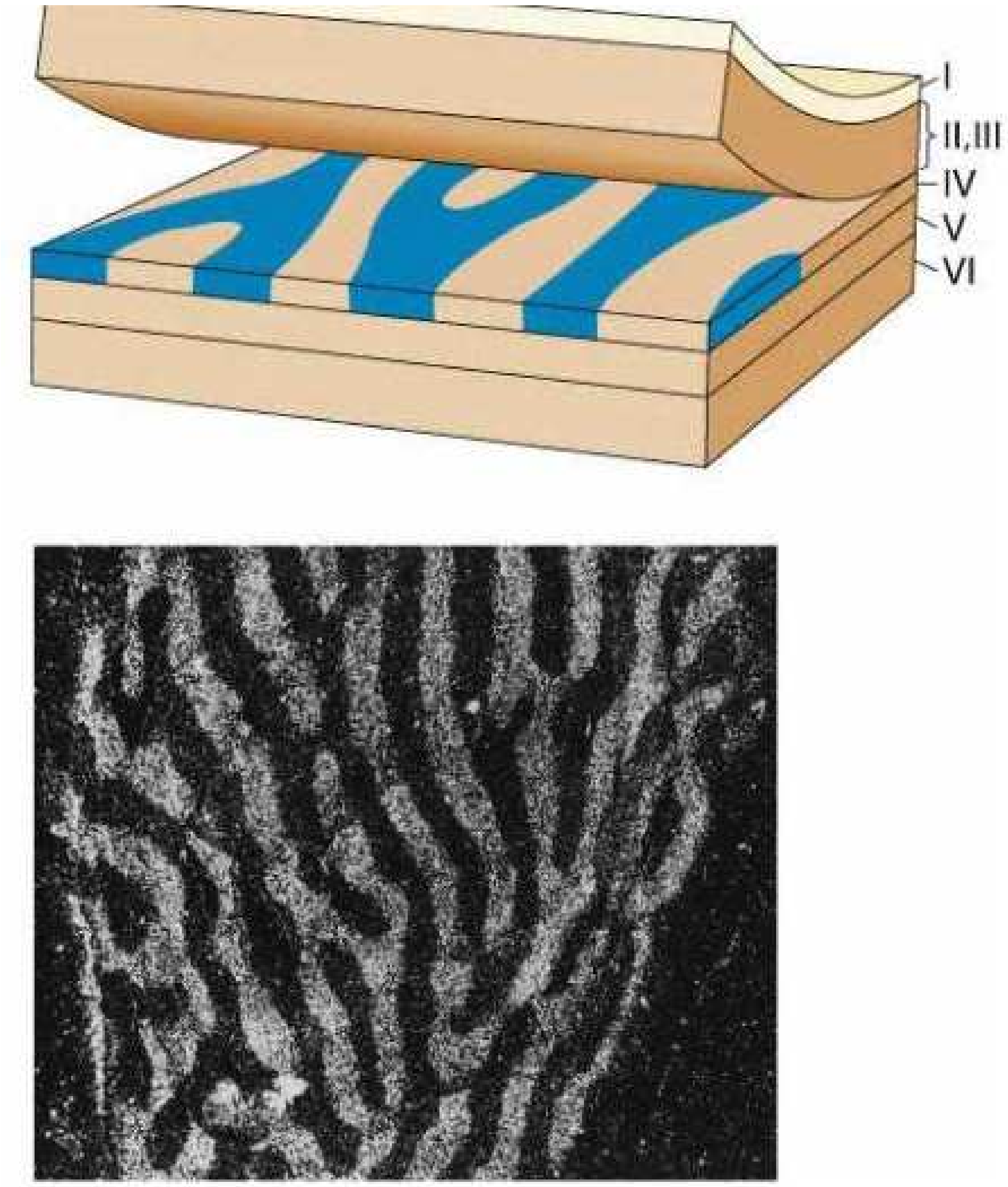
Neuroscience 5e Fig. 12.13

Speaker notes

No notes on this slide.

Ocular dominance bands in layer 4 of primary visual cortex (V1, area 17)

Histological stain of thalamocortical afferents, section through L4 of V1



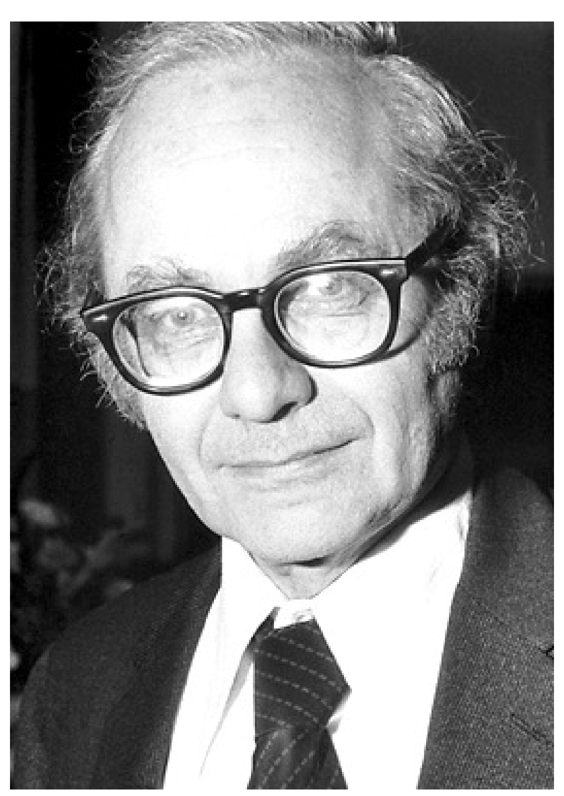
Hubel, Wiesel, and Levay 1976

Speaker notes

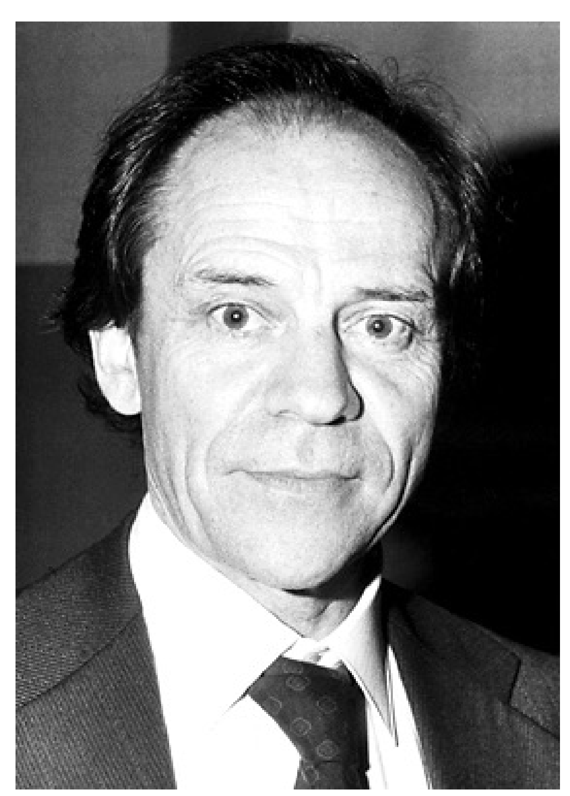
If we were to peer at layer 4 only and perform a histological procedure that labels thalamocortical inputs from only one eye we would see a pattern like this in primate cortex, resembling ocular dominance bands or stripes.

The Nobel Prize in Physiology or Medicine (1981)

> *"for their discoveries concerning information processing in the visual system"*



David H. Hubel



Torsten N. Wiesel

Speaker notes

Extrastriate visual areas

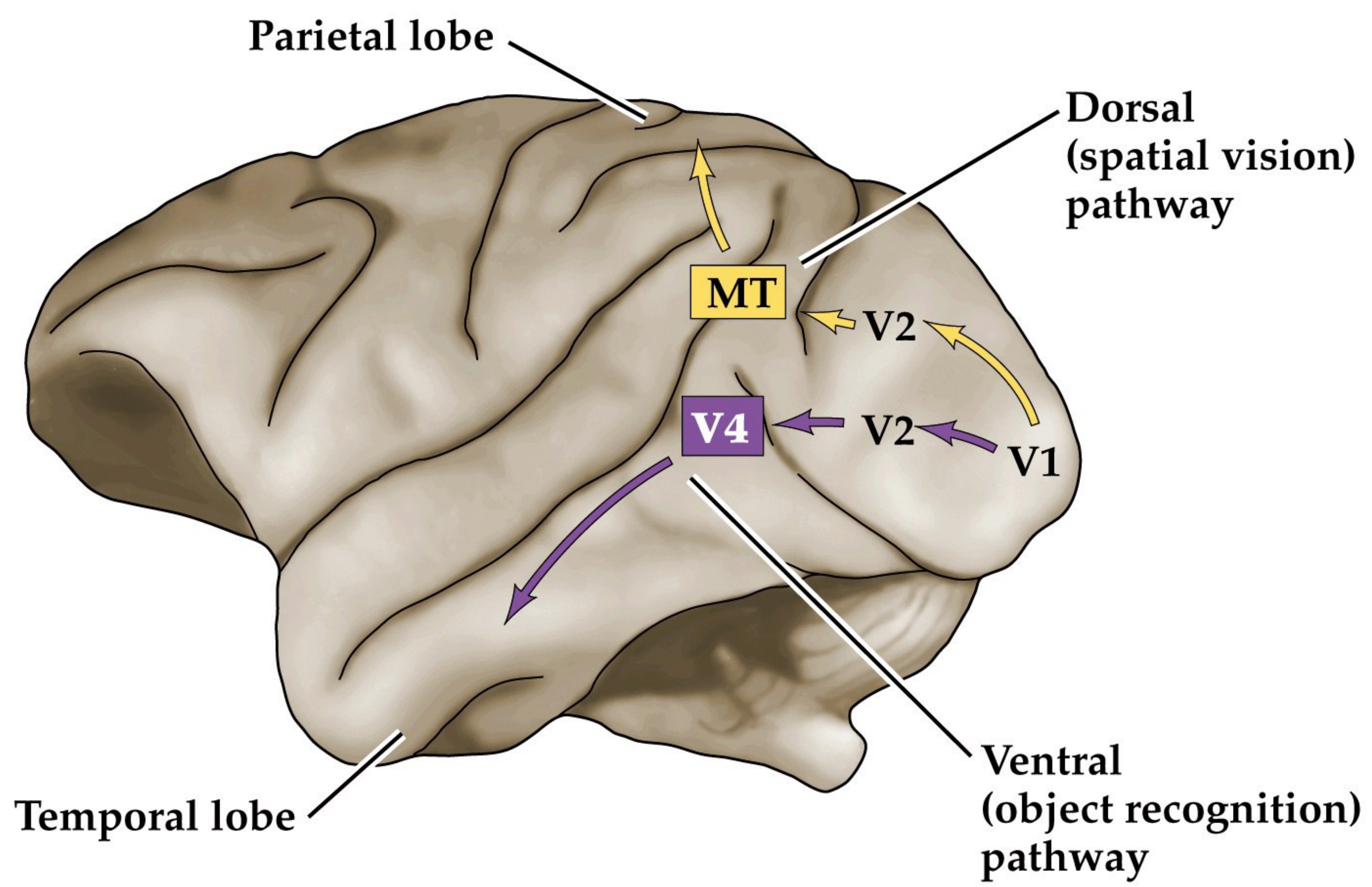
- There are many other areas of the brain that process visual information, each gets info derived from primary visual cortex (V1)
- Specialized for different functions
- MT middle temporal area, responds to direction of a moving edge without regard to its color
- V4, responds to color of a stimulus without regard to form
- 10 different visual areas, each with a topographic map
- Damage in these areas can really give weird experiences

Speaker notes

No notes on this slide.

Organization of the dorsal and ventral visual pathways

- **Dorsal stream**: object location (**Where**?)
  - Knowing location of objects in space. Linking visual data with movement/action
- **Ventral stream**: object recognition (**What**?)
  - Color: V4 (temporal-parietal junction)
  - Face recognition: fusiform gyrus



Neuroscience 5e Fig. 12.18

Speaker notes

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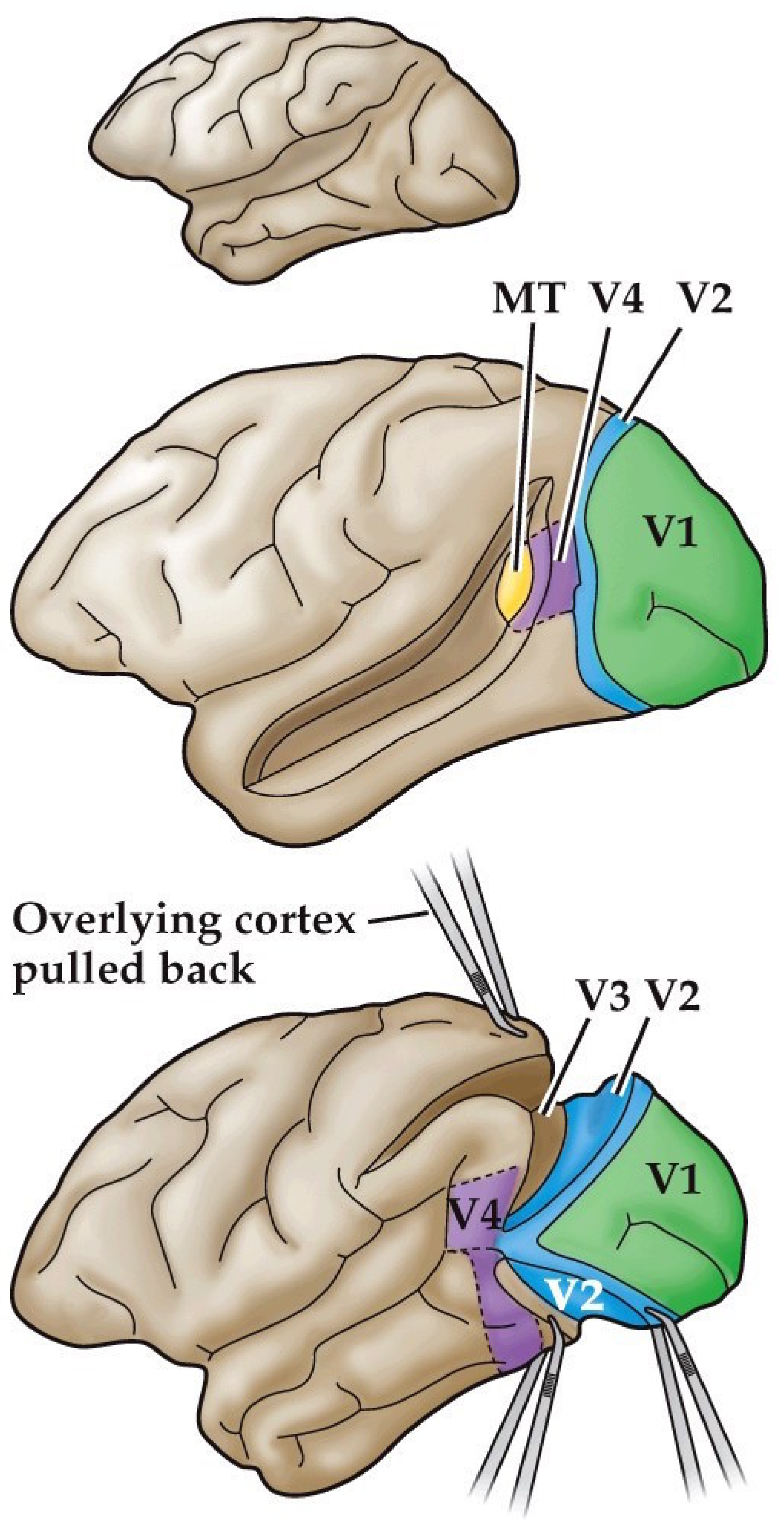
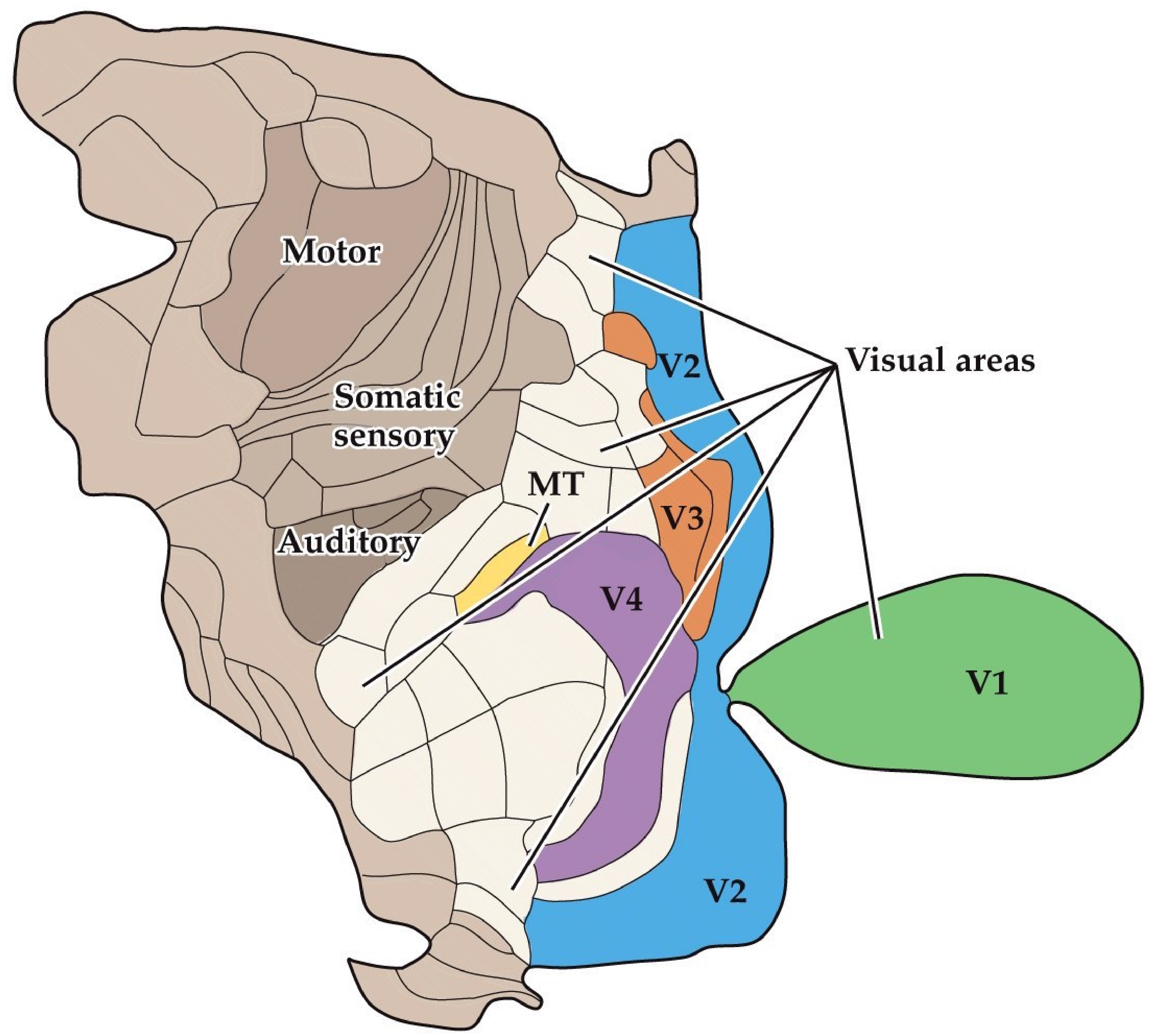
Subdivisions of the extrastriate cortex in the macaque monkey



Neuroscience 5e Fig. 12.16, Maunsell & Newsome 1987



Neuroscience 5e Fig. 12.16, Felleman & Van Essen 1991

Speaker notes

- extrastriate areas V2, V3, V4, MT

V2
: orientation, spatial frequency, and color like V1
: secondary visual cortex
: feedforward connections from V1 (direct and via the pulvinar)
: feedback to V1
: sends connections to V3, V4, and V5
: binocular disparity
: illusion contours
: some attentional modulation

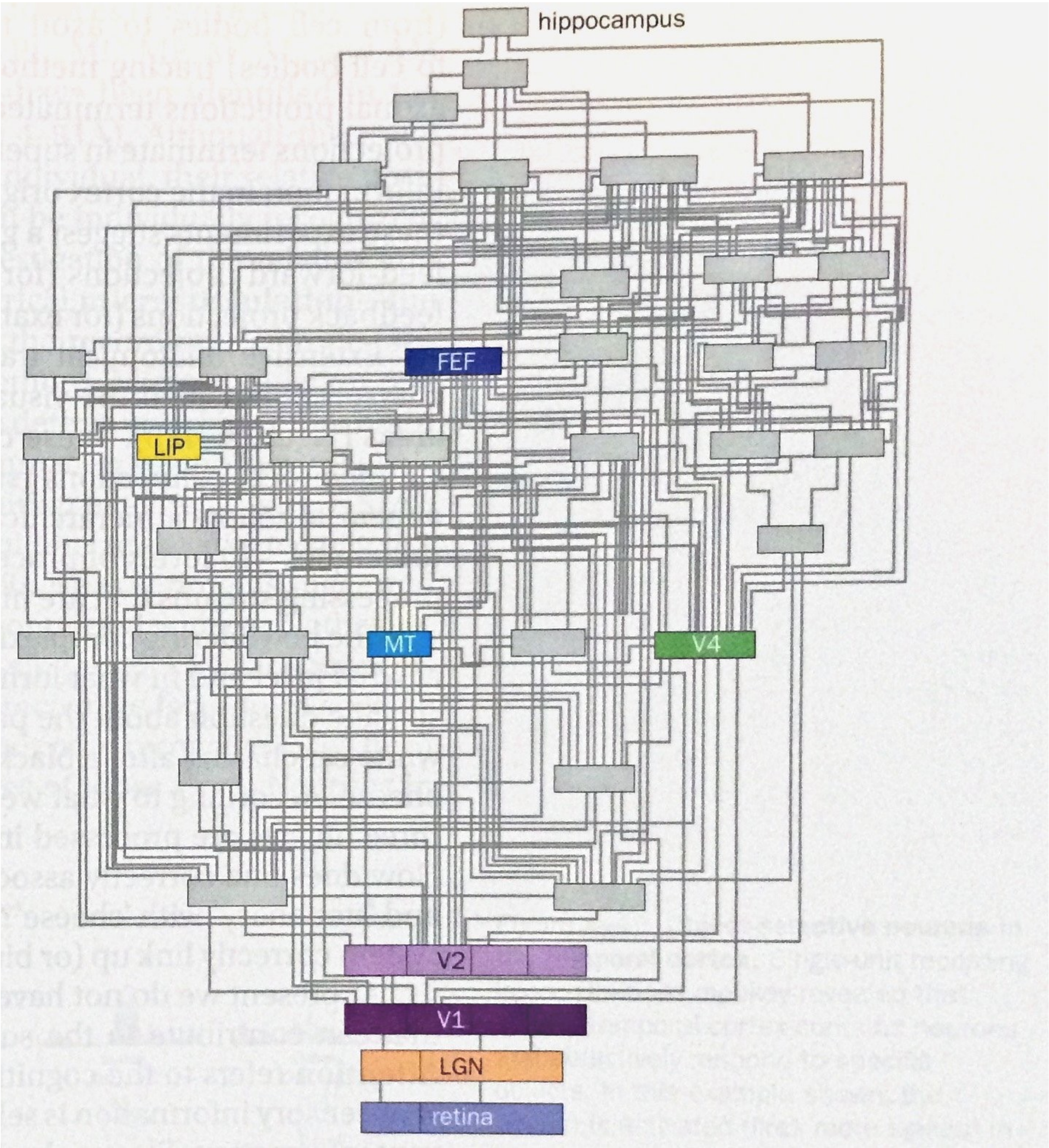
V3 : global motion

MT
: middle temporal area
: neurons responding selectively to direction of moving edge, but don't care about color

V4
: neurons that selectively respond to color, but don't care about direction of its movement

Hierarchical visual processing

MT– motion, V4– color, LIP, FEF– eye movements



adapted from Felleman, Van Essen 1991

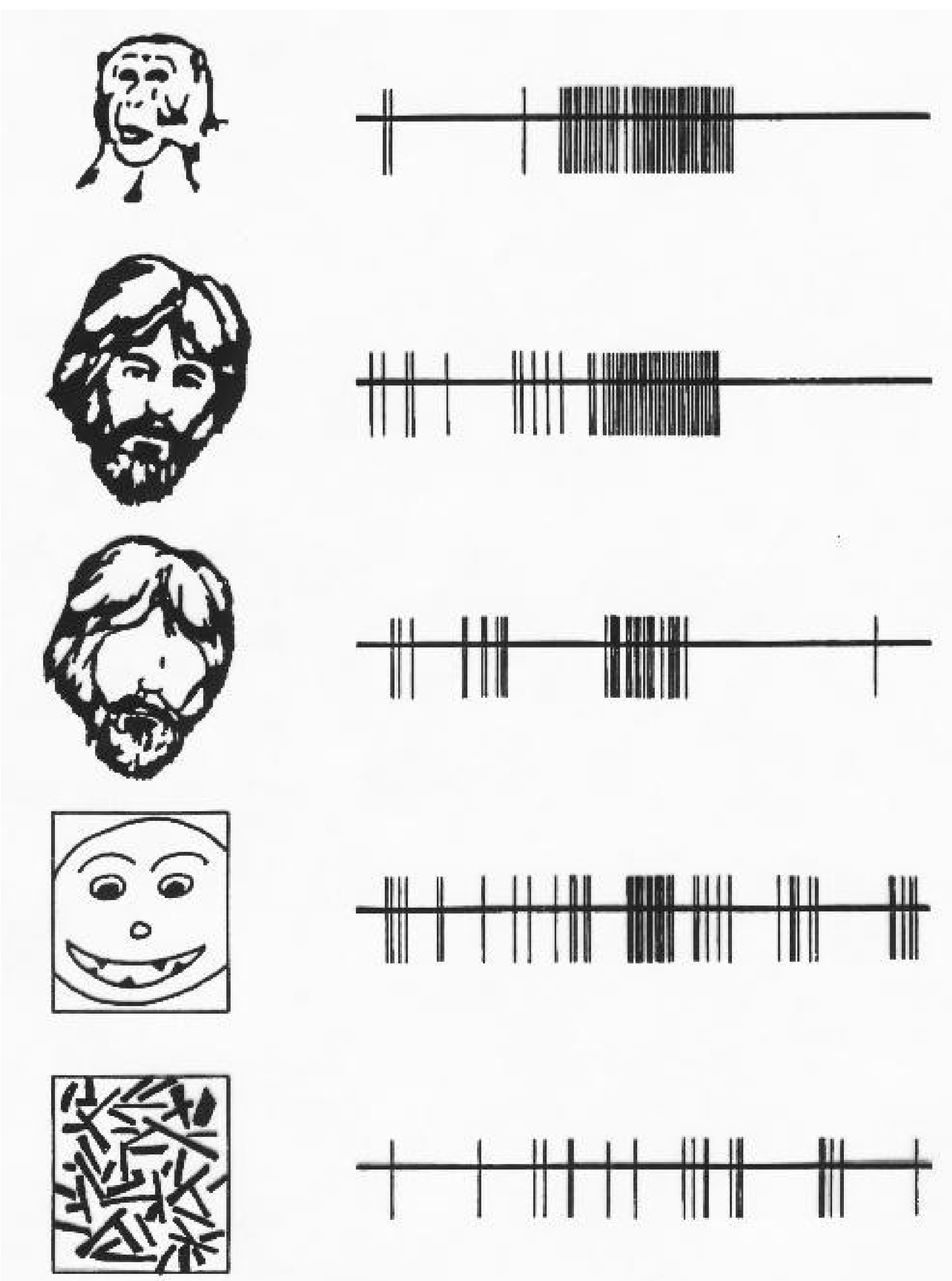
Speaker notes

“the brain is a complex of widely and reciprocally interconnected systems and that the dynamic interplay of neural activity within and between systems is the very essence of brain function” (V. Mountcastle). And indeed if you look at this—> anatomical wiring diagram for different visual areas represented by different colors you will notice that we use an organized constellation of brain regions to process and route different types of visual information

LIP
: lateral intraparietal area
: involved in eye movements
: electrical stimulation elicits saccades
: role in working memory as well

FEF : frontal eye field
: connections to superior colliculus
: important for saccades

Face recognition cells in the fusiform gyrus



Bruce, Desimone, & Gross, 1981

Speaker notes

responses of a monkey's neuron in their homologous area to the fusiform gyrus (area IT) to various facelike or non facelike stimuli.

fusiform gyrus : long strip of cortex in ventral temporal lobe, tracking along hippocampal gyrus in rostral-caudal extent, but separate from entorhinal or parahippocampal cortex

macaque monkey, https://jn.physiology.org/content/46/2/369

color synesthesia: association of colors with certain numbers, letters, or objects

prosopagnosia: face blindness. See the story of patient Dr. P from Dr. O. Sack's classic clinical tales book "The Man Who Mistook His Wife for a Hat"

Speaker notes

No notes on this slide.

Defects due visual cortex damage

- Cerebral achromatopsia
  - Do not see in color- only black and white. Lesions in extrastriate cortex areas such as V4/ventral stream
- Lesions in MT regions cause people to have defects in detecting motion (Hard to pour drinks accurately, see moving cars, etc)
- Blind sight
  - Disruptions in V1 cause blindness
  - However some patients can still "guess" what an object is. Implies that there are other projections from eye to brain (superior colliculus) that can somehow compensate for loss of V1