LISC-322 Neuroscience

THE VISUAL SYSTEM

Higher Visual Processing

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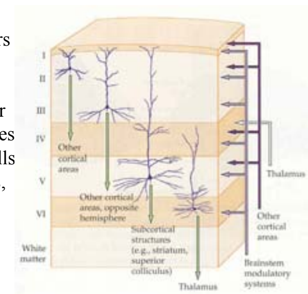
Cortical Organization

Most of the cortex that covers the cerebral hemispheres is *neocortex*, defined as cortex that has six cellular layers, or laminae. Each layer comprises distinctive populations of cells based on their different sizes, shapes, inputs, and outputs.

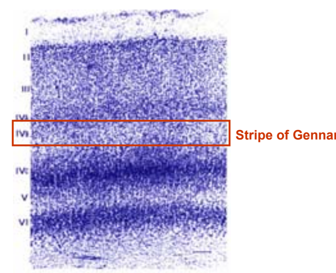


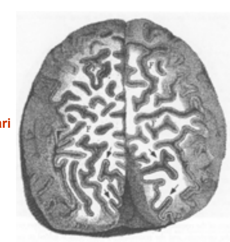
Primary Visual Cortex

The primary visual cortex is located in the occipital cortex. It receives visual information exclusively from the contralateral hemifield, which is topographically represented and wherein the fovea is granted an extended representation.

Like most cortical areas, primary visual cortex consists of *six layers*. It also contains a prominent stripe of white matter in its layer 4 - the *stripe of Gennari* - consisting of the myelinated axons of the lateral geniculate nucleus neurons. For this reason, the primary visual cortex is also referred to as the *striate cortex*.

Primary Visual Cortex

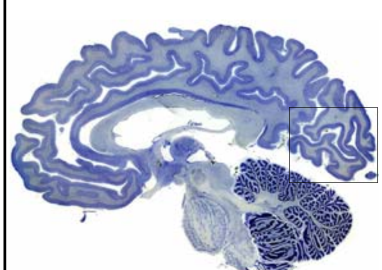


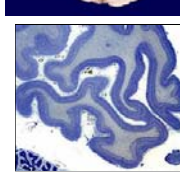


Francisco Gennari (1782)

Primary Visual Cortex

Primary Visual Cortex

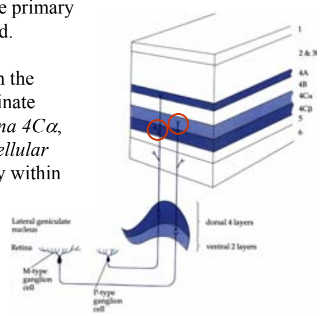




Primary Visual Cortex Inputs

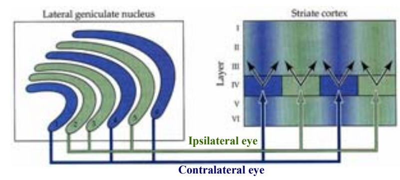
The LGN projections to the primary visual cortex are segregated.

The axons of the cells from the *magnocellular* layers terminate principally within *sublamina 4Cα*, and those from the *parvocellular* layers terminate principally within *sublamina 4Cβ*.



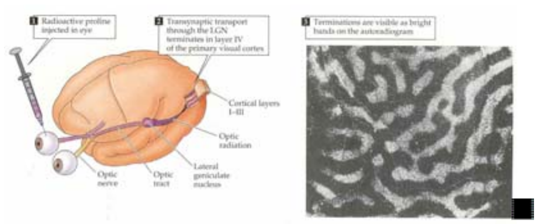
Ocular Dominance Columns

The inputs from the two eyes also are segregated within the input-receiving *layer 4* of primary visual cortex and form alternating *ocular dominance columns*.



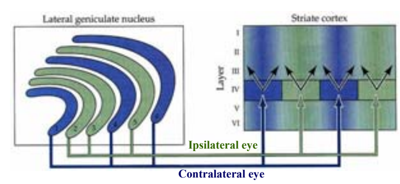
Ocular Dominance Columns

Alternating ocular dominance columns can be visualized with *autoradiography* after injecting radiolabeled amino acids into one eye that are transported transynaptically from the retina.



Ocular Dominance Columns

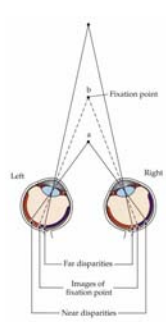
Although the neurons in layer 4 are monocular, neurons in the other layers of the same column combine signals from the two eyes, but their activation has the same ocular preference.



Binocular Disparity

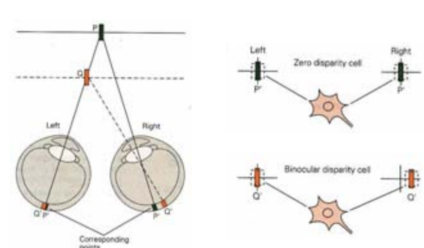
Bringing together the inputs from the two eyes at the level of the striate cortex provide a basis for *stereopsis*, the sensation of depth perception provided by binocular disparity, i.e., when an image falls on non-corresponding parts of the two retinas.

Some neurons respond to disparities beyond the plane of fixation (*far cells*), while others respond to disparities in front of the plane of the fixation (*near cells*).



Binocular Disparity

Disparity sensitive neurons are "*depth detectors*".



Binocular Disparity

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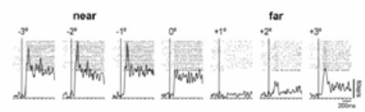
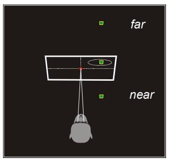




Receptive Fields

Compared to the small, concentric (center-surround) receptive fields of retinal and lateral geniculate nucleus cells, the receptive fields of primary visual cortex neurons are larger, rectangular and come in three main classes.

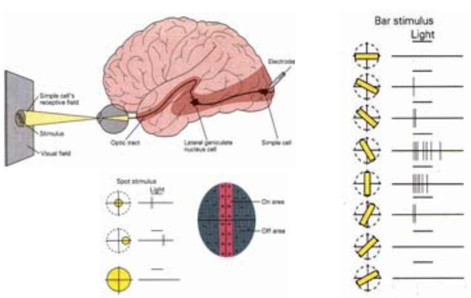
Retina

Lateral Geniculate Nucleus

Striate Cortex

1) *Simple*
2) *Complex*
3) *Hypercomplex*

Simple Cells

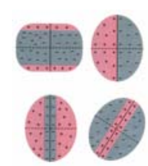


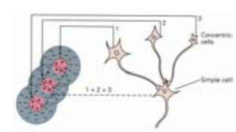
Simple Cells

Simple cells have narrow, elongated excitatory and inhibitory zones that have a specific axis of *orientation*.

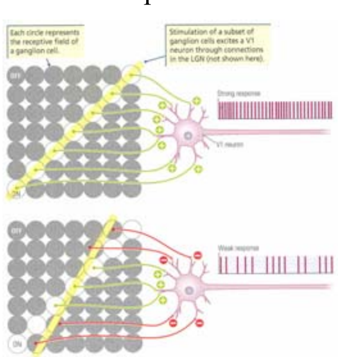
These cells are "*line detectors*".

Their receptive fields can be built from the *convergent connections* of lateral geniculate nucleus cells.





Simple Cells

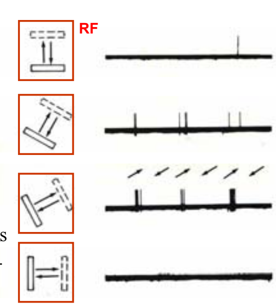


Complex Cells

Complex cells have large receptive fields without clear excitatory or inhibitory zones.

They respond best to a *moving edge* of specific orientation and direction of motion.

These direction selective neurons are powerful "*motion detectors*".

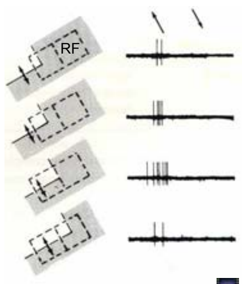


Hypercomplex Cells

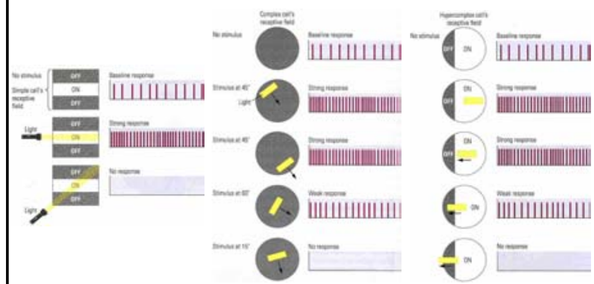
Hypercomplex cells have very large receptive fields that may combine complex cells' signals.

Many of them respond best to an oriented edge that is *stopped*, i.e., its end does not extend beyond a specific part of the receptive field.

Neurons with such a pattern of response act as "*angle detectors*".

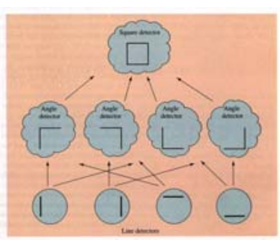


Primary Visual Cortex Cells



Visual Image Decomposition

Simple, complex and hypercomplex cells can work together to decompose the outlines of a visual image into short segments, the basis of simple and complex object recognition.



Functional Modules

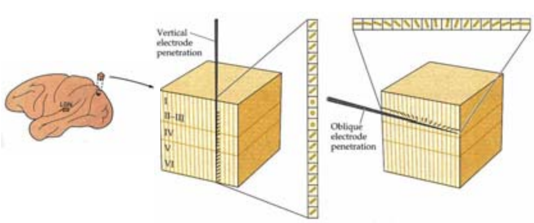
In addition to its representation of the visual field and its ocular dominance columns, the primary visual cortex organizes its neurons into two *functional modules*:

1) *Orientation columns*
2) *Blob regions*

The visual properties of each region of the visual field are ultimately represented within a *Hypercolumn*.

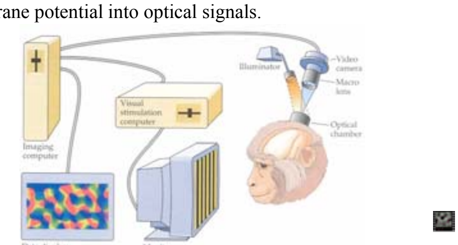
Orientation Columns

Within the topographical organization of visual field in the primary visual cortex, *simple cells* with the same orientation preference are grouped together into *orientation columns*, organized with an orderly shift in orientation preference.



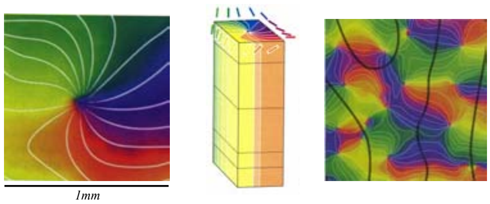
Orientation Columns

Map of orientation preference in the visual cortex can be visualized using optical imaging, in which a voltage-sensitive dye act as molecular transducers that transform changes in membrane potential into optical signals.



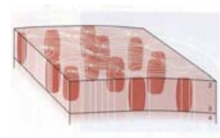
Orientation Columns

The orientation preference of neurons with similar receptive fields changes in a continuous fashion forming a pinwheel-like area (1-mm diameter). The map of orientation preference is then repeated for neurons with adjacent receptive fields.



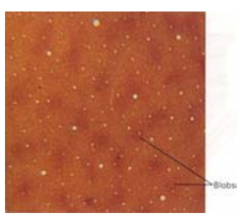
Blob Regions

The systematic shifts in orientation preference from one column to another is occasionally interrupted by *blobs*, peg-shaped regions of cells in layers 2-3, which contain neurons responsive to *brightness* and *color* but not to orientation.



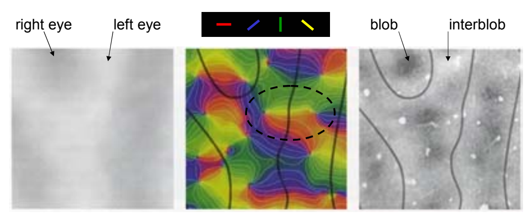
Blob Regions

Blobs can be revealed by examining the density of *cytochrome oxydase*, a mitochondrial enzyme involved in energy production. The heightened enzymatic activity in the blobs is thought to represent heightened neural activity.



Hypercolumns

A hypercolumn is a set of columns responsive to lines of all orientations from a particular region in the visual field and viewed by both eyes.



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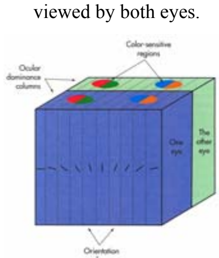
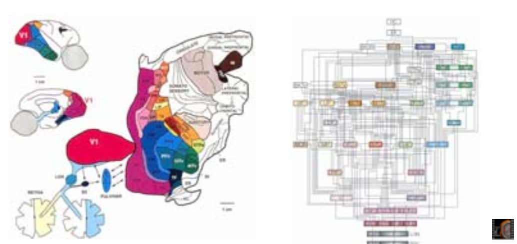


Organization of the Visual System

The parvocellular and magnocellular pathways that originate in the retina remains segregated within the striate cortex and feed into a collection of about 30 extrastriate visual areas.

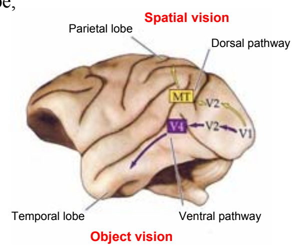


Ventral and Dorsal Processing Streams

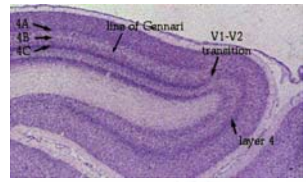
Extrastriate visual areas form two processing pathways:

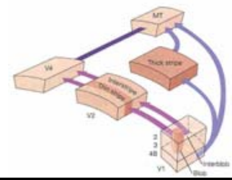
1) a ventral pathway concerns with object recognition, with neurons selective to shape, color and texture;

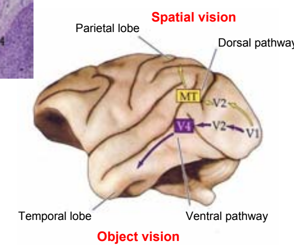
2) a dorsal pathway concerns with the spatial relationships of objects, with neurons that are selective to the speed and direction of movement as well as visual disparity.



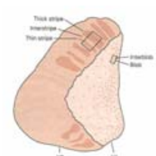
Cortical area V2

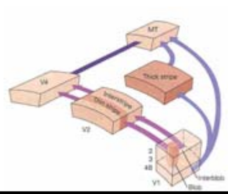


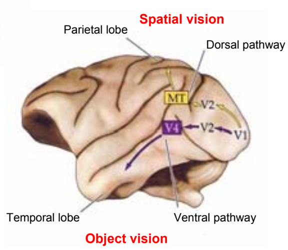


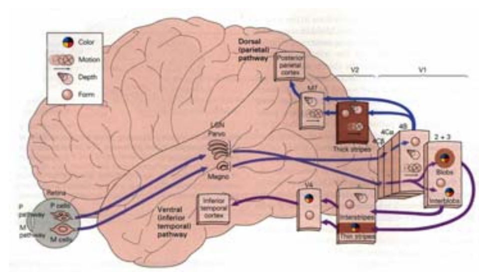


Visual Cortex Area V2









Ventral Pathway

color processing:
- LNG parvo layers
- V1 layer 4Cβ
- V1 blobs
- V2 thin stripes
- ↓ V4

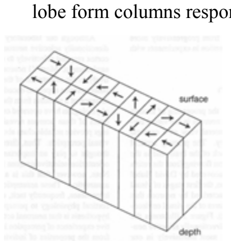
form processing:
- LGN parvo layers
- V1 layer 4Cβ
- V1 interblobs
- V2 interstripes
- ↓ V4, IT

Dorsal Pathway

motion & disparity:
- LGN magno layers
- V1 layer 4Cα
- V1 layer 4B
- V2 thick stripes
- ↓ MT

Columnar Organization

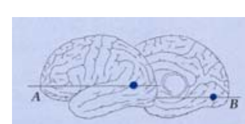
Just as the orientation columns in primary visual cortex, columns containing neurons that respond to directions of motion neurons exist in area MT while neurons in temporal lobe form columns responsive to categories of shapes.

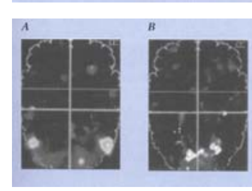


Human Motion and Color Centers

Positron emission tomographic (PET) scans in human subjects show increase in cerebral flow in: A) *area MT* (V5) while they view a monochromatic scene in motion, and B) *area V4* while they view a stationary colorful scene.

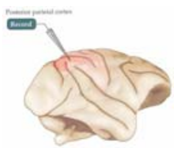
Severe disturbance of motion and color vision results from damage specific to these cortical areas.

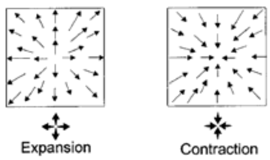




Monkey Visual Space Center

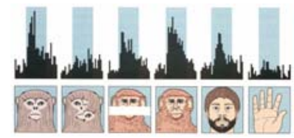
Neurons in the dorsal stream exhibit properties that are related to the spatial relationships of objects. At the highest levels in this pathway, visual neurons in the monkey posterior parietal cortex respond preferentially to *optic flow*.





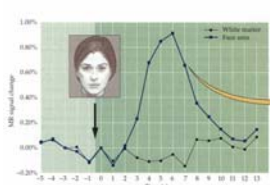
Monkey Face Center

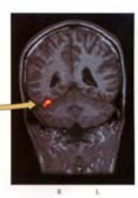
Neurons in the ventral stream exhibit properties that are important for object recognition. At the highest levels in this pathway, visual neurons in the monkey inferior temporal cortex respond preferentially to the presentation of *faces*.



Human Face Center

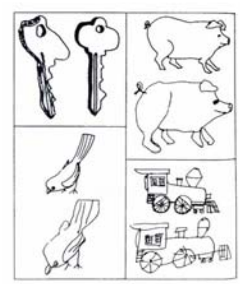
In humans, functional brain imaging shows activity change in the *right temporal lobe* of normal subjects presented with face stimuli. Lesions in this cortical region produce *prosopagnosia*, an inability to recognize and identify faces.





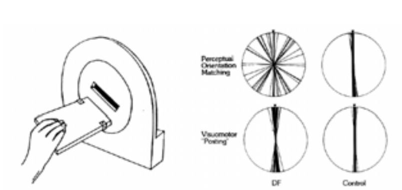
Temporal Cortex Damage

Damage to the temporal cortex generally results in poor object recognition. Some patients with *visual agnosia* can copy models well enough to reproduce them fairly accurately, but they are unable to recognize the objects in them!



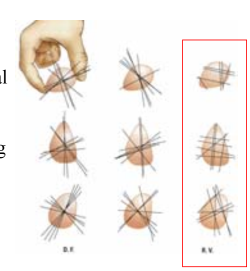
Temporal Cortex Damage

Nevertheless, the visually guided behavior of patients with *agnosia* is preserved. Thus, agnosic patients have difficulty identifying an object, but they can grasp and manipulate it.

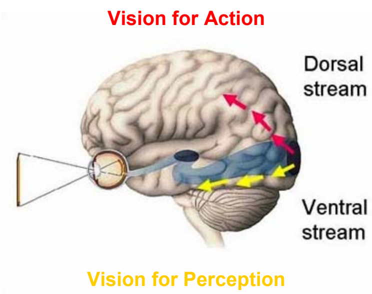


Parietal Cortex Damage (1)

Damage to the parietal cortex often results in low performance in spatial tasks, most often poor visuo-motor control. Some patients with *optic ataxia* have no difficulty identifying an object, but their visually guided behavior is so impaired that they cannot grasp it properly!

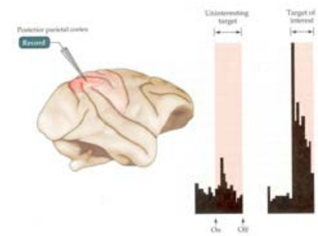


Two Visual Systems



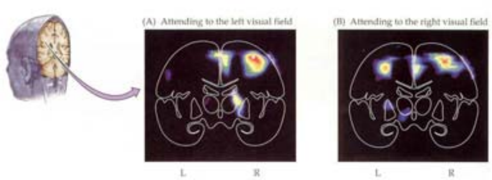
Visual Attention Center

At the highest level in the dorsal pathway, visual neurons in the monkey parietal cortex are selectively activated by stimuli that are behaviorally relevant, e.g., for an action.



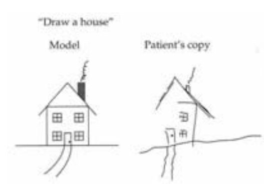
Visual Attention Center

In humans, functional brain imaging shows that the *right parietal lobe* of normal subjects is highly active during tasks requiring attention.



Parietal Cortex Damage (2)

Damage to the right parietal cortex often results in an inability to attend to objects in their left hemifield, or to the left part of objects. Patients with *hemineglect* cannot copy models to reproduce them accurately, but they are nonetheless able to recognize the objects in them!



Visual System: Higher Visual Processing

Reference for this Lecture:

- Neuroscience, 2nd edition (2001) by Purves et al., Chapter 12 & 26.

Reference for next Lecture:

- Neuroscience, 2nd edition (2001) by Purves et al., Chapter 20.

Lectures are posted:

- http://brain.phgy.queensu.ca/pare

Office Time:

- Tuesday & Thursday (15:00-17:00)
  Botterell Hall, Room 438