Lecture 5. More Introduction to Vision

Reading Assignments:

Chapters 5 and 6.

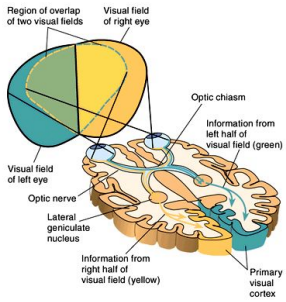
from the eye to V1

Image is decomposed and analyzed in terms of:

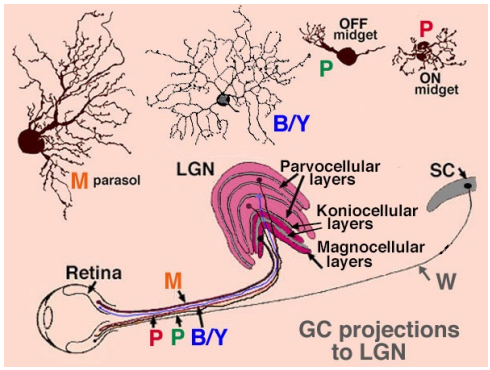
- orientation
- spatial frequency
- size
- color
- direction of motion
- binocular disparity

Visual Field Mapping

► The Primary Visual Pathway

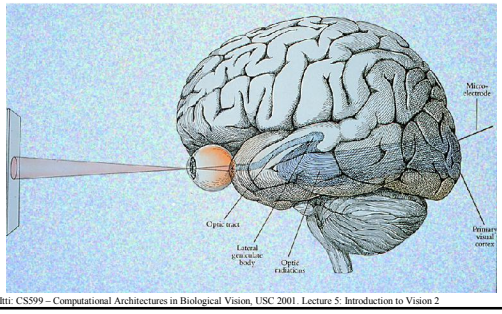


Retina to Lateral Geniculate Nucleus



Location of LGN in Brain

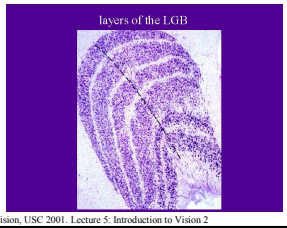
LGN = lateral geniculate nucleus of the thalamus.
Thalamus = deep gray-matter nucleus; relay station for all senses except olfaction.



Lateral Geniculate Nucleus

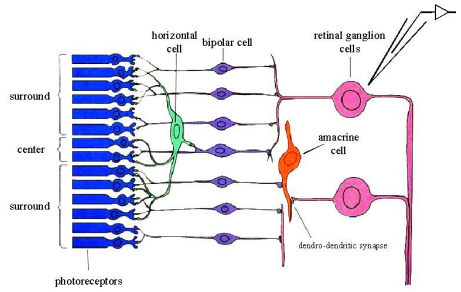
Receives input from both eyes, but these remain segregated (no binocular neurons).
LGN consists of 6 layers:

- 4 parvocellular (P-pathway): small RFs, input from cones, sensitive to color, fine detail and slow motion
- 2 magnocellular (M-pathway): large RFs, very sensitive to faster motion.



Origin of Center-Surround

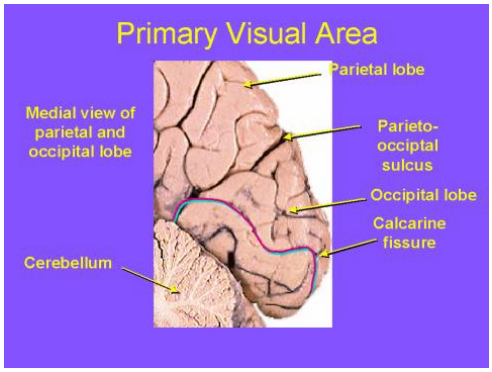
Neurons at every location receive inhibition from neurons at neighboring locations.



LGN to V1

- V1 = primary visual cortex = striate cortex (in contrast to higher, "extrastriate" areas).
- V1 is the first region where neurons respond to a combination of inputs from both eyes.
- Some neurons respond equally well to patterns presented on both eyes
- Some respond best to one eye

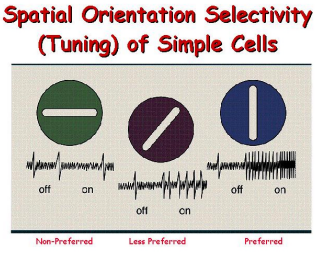
Calcarine sulcus



Neuronal Tuning

In addition to responding only to stimuli in a circumscribed region of the visual space, neurons typically only respond to some specific classes of stimuli (e.g., of given color, orientation, spatial frequency).

Each neuron thus has a preferred stimulus, and a tuning curve that describes the decrease of its response to stimuli increasingly different from the preferred stimulus.



Orientation Tuning in V1

First recorded by Hubel & Wiesel in 1958.

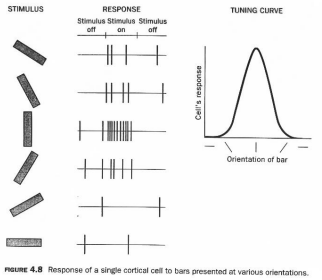
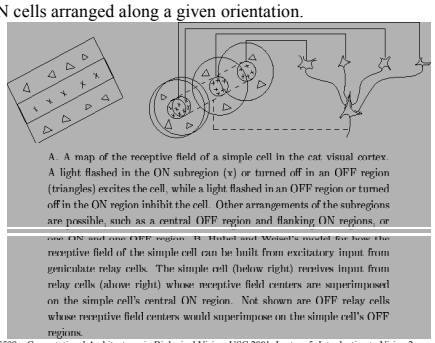


FIGURE 4.8 Response of a single cortical cell to bars presented at various orientations.

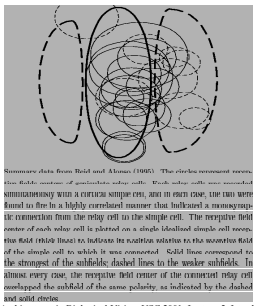
Origin of Orientation Selectivity

Feedforward model of Hubel & Wiesel: V1 cells receive inputs from LGN cells arranged along a given orientation.



A. A map of the receptive field of a simple cell in the cat visual cortex. A light flashed in the ON subregion (x) or turned off in an OFF region (triangles) excites the cell, while a light flashed in an OFF region or turned off in the ON region inhibit the cell. Other arrangements of the subregions are possible, such as a central OFF region and flanking ON regions, or one ON and one OFF region. B. Hubel and Wiesel's model for how the receptive field of the simple cell can be built from excitatory input from geniculate relay cells. The simple cell (below right) receives input from relay cells (above right) whose receptive field centers are superimposed on the simple cell's central ON region. Not shown are OFF relay cells whose receptive field centers would superimpose on the simple cell's OFF regions.

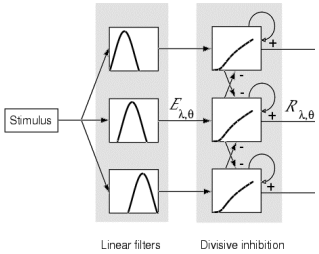
Feedforward model



But the feedforward model has shortcomings

E.g., does not explain independence of tuning with respect to contrast.

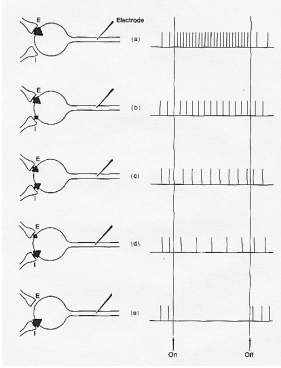
Hence, another model includes recurrent feedback (intra-cortical) connections which sharpen tuning and render it contrast-independent.



Excitatory vs. Inhibitory Input

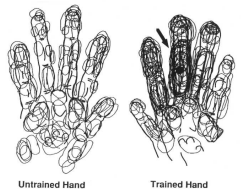
Activation of excitatory synapse increases activity of postsynaptic cell.

Activation of inhibitory synapse decreases activity of postsynaptic cell.



Tuning is General

It is also found, for example, in somatosensory cortex. Somatosensory neurons also have a receptive field, a preferred stimulus, and a tuning curve. Also note that these properties are highly adaptive and trainable.



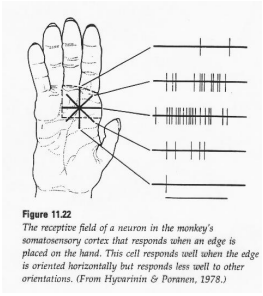
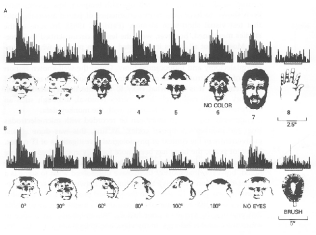


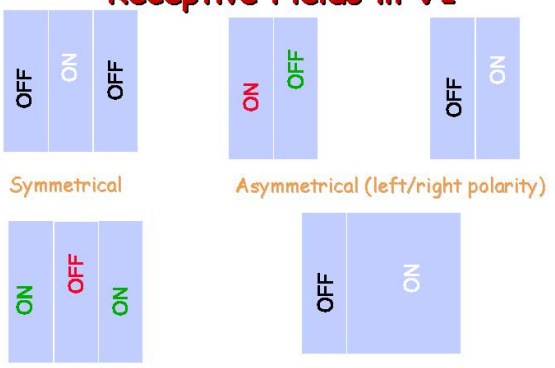
Figure 11.22
The receptive field of a neuron in the monkey's somatosensory cortex that responds when an edge is placed on the hand. This cell responds well when the edge is oriented horizontally but responds less well to other orientations. (From Hyvarinin & Poranen, 1978.)

More Complex Neuronal Tuning

"Face cells"



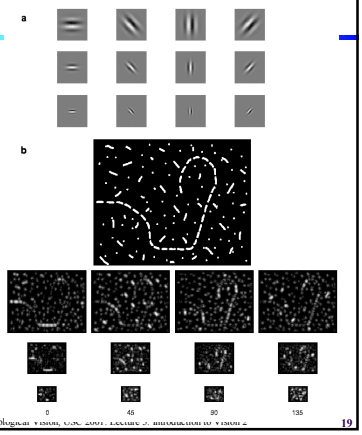
Receptive Fields in V1



Oriented RFs

Gabor function: product of a grating and a Gaussian.

Feedforward model: equivalent to convolving input image by sets of Gabor filters.



Receptive fields Summary

Retina: center-surround, circular, monocular
LGN: center-surround, circular, monocular
V1: oriented (Gabor): respond best to bar stimuli
sensitive to motion
monocular or binocular

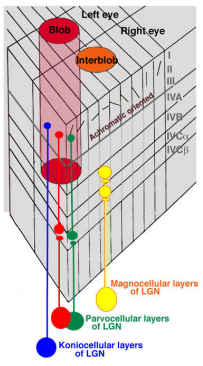
Simple cells: respond best to bars of given orientation at given location within receptive field.
Complex cells: less sensitive to stimulus position within RF, sensitive to stimulus motion.
Hypercomplex cells: like complex, but with inhibitory region at one end.

Cortical Hypercolumn

A hypercolumn represents one visual location, but many visual attributes.

Basic processing "module" in V1.

"Blobs": discontinuities in the columnar structure. Patches of neurons concerned mainly with color vision.

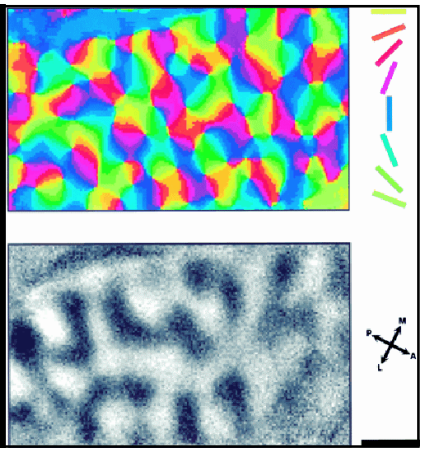


Optical Imaging

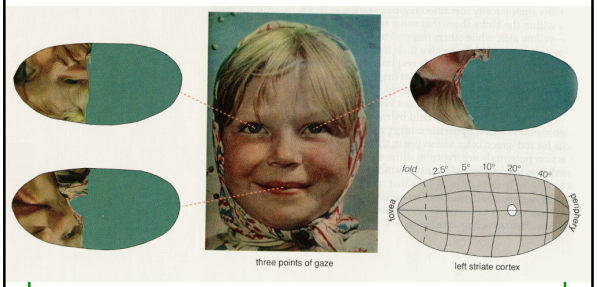
Orientation preference and ocular dominance maps from the same patch of cortex.

Black for contralateral and white for ipsilateral eye preference.

Scale bar, 1 mm.



Cortical Magnification

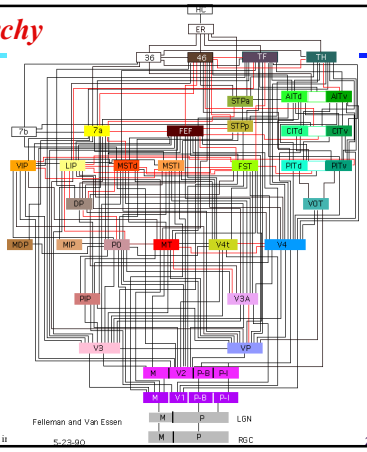


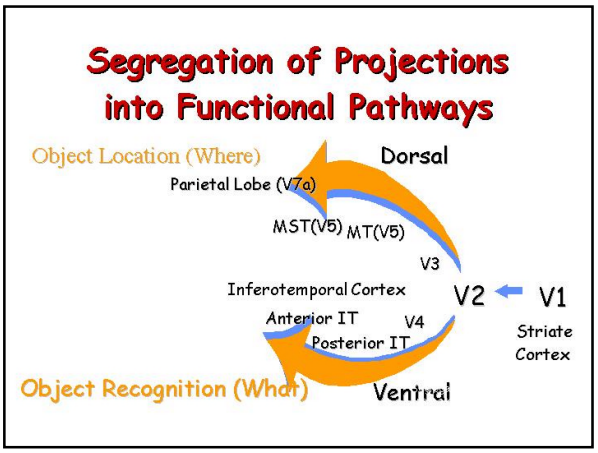
Much more neuronal hardware dedicated to the center of the field of view than to the periphery.
1000x more neurons in fovea than far periphery for same size input.

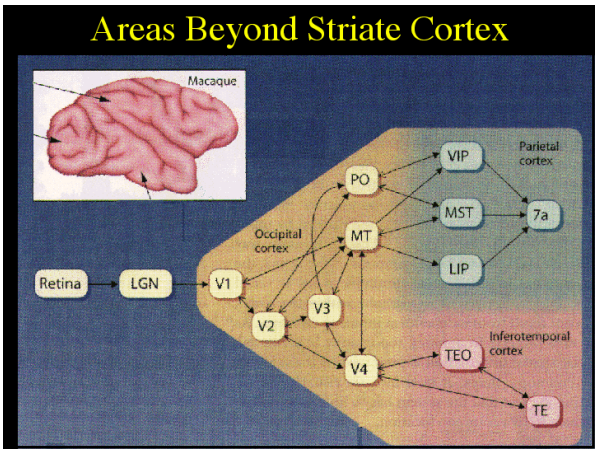
Cortical Hierarchy

Some highlights:

- more feedback than feedforward
- specialization by area
- what/where
- interactions





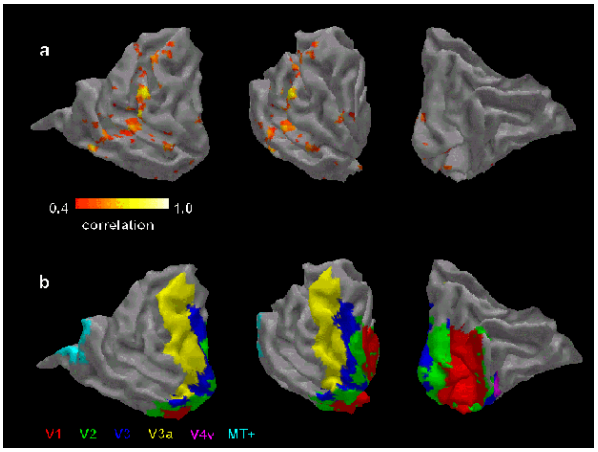


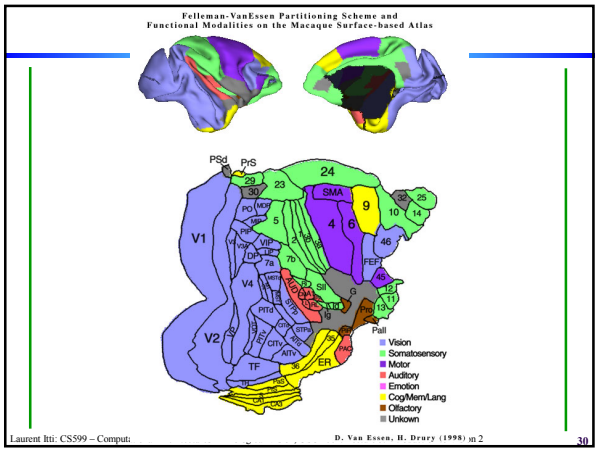
Extrastriate Cortex

- Over 25 visually responsive areas outside of striate cortex
- Many of visual areas have retinotopic maps
- Maps become less precise upstream from striate cortex
- Receptive fields increase upstream from striate cortex
- Many of these areas contain neurons selective for various stimulus dimensions (orientation, direction of motion, disparity, color)
- Two streams of processing through visual cortex: motion and "where" (occipito-parietal, magnocellular) and color & form (occipito-temporal; parvocellular) pathway.

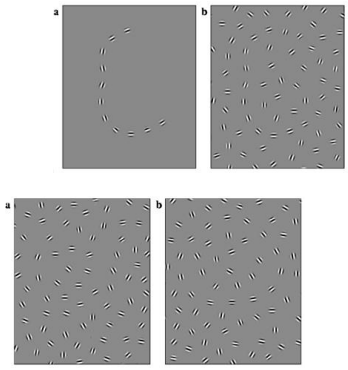
Area V2

- Located within the lunate sulcus; immediately adjacent to V1
- Orderly retinotopic map
- Receptive fields larger than those in V1
- A pattern of "thick", "thin" and "interstripes" perpendicular to the cortical surface with inputs from specific regions in V1 (interblob -->interstripe; layer 4B-->thick; blobs-->thin).
- Cells selective for orientation, direction, disparity, color (similar to V1); responses to subjective contours.





Contour Perception and V2



Area V3

- Inputs from layer 4B (with magnocellular inputs) of V1.
- Retinotopic map split into upper (VP) and lower field.
- Responses to lower spatial and higher temporal frequencies than in V2.
- Receptive fields larger than in V2; many selective for orientation, direction, disparity and color.
- Emergence of new properties: evidence for integration of complex motion ("pattern" motion; like MT).
- Possible site for interaction between color and motion.

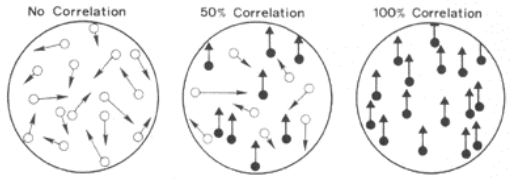
Area V4

- Inputs from V2 (thin stripes and interstripes) and V3. Projects to inferotemporal cortex (IT).
- Orderly retinotopic map; larger receptive fields than in V2 and V3
- Cells selective for orientation and color; some directionally selective cells.
- Lesions result in deficits in some aspects of complex form and/or color perception and not in motion perception.

Area V5 (MT)

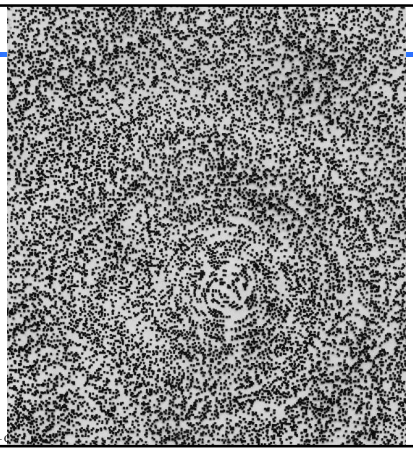
- Inputs from V1 (layer 4B) , V2 (thick stripes) and V3
- Projections to MST and parietal cortex
- Retinotopic map.
- Larger receptive fields selective for motion direction, disparity and stimulus orientation; no selectivity for color; responses to complex motion ("pattern" motion).
- Lesions: selectively affect direction and speed discrimination, as well as motion integration. deficits more pronounced in the presence of motion noise. Partial or complete recovery with training.

Response to Motion Stimuli in MT



Area MST

- Inputs from MT and V3
- Projections to parietal cortex
- Large receptive fields that include the fovea; no retinotopy
- Cells respond well to large-field motion; selective for direction of complex motion (rotation, contraction, expansion, spiral); responses to optic flow.
- Likely involvement in the analysis of optic flow



Area IT

- Inputs from V4
- Large receptive fields include the fovea and covering most of the visual field
- Selectivity to length, size, shape, faces and textures
- High selectivity for complex images (10% of cells selective to faces and hands).
- Evidence that stimulus selectivity can be acquired through learning
- Lesions in humans result in prosopagnosia (deficit in face recognition); lesions in monkeys result in deficits in learning of complex pattern discriminations.
- Involvement in short-term memory (delay related activity)

Face Cells

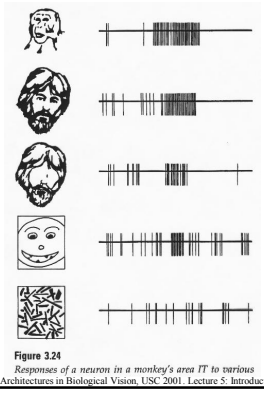


Figure 3.24
Responses of a neuron in a monkey's area IT to various