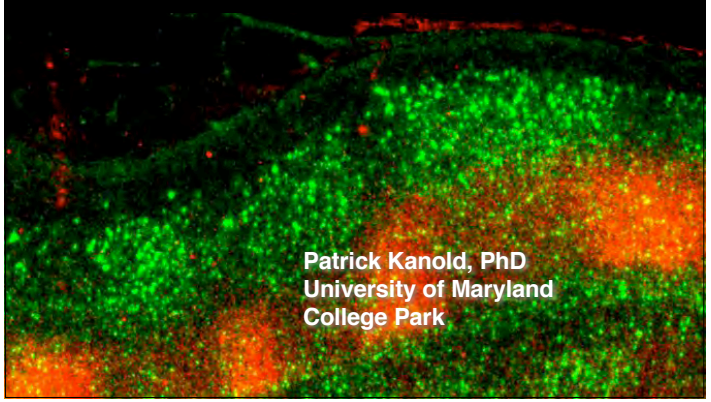
The Visual system part I

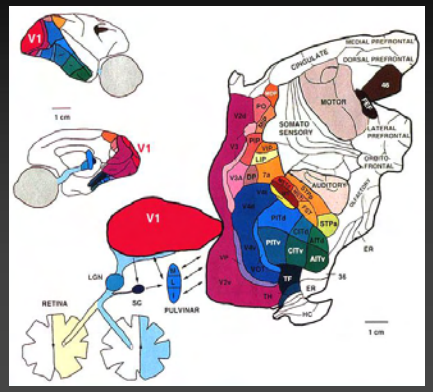


Patrick Kanold, PhD
University of Maryland
College Park

Outline

- Eye
- Retina
- LGN
- Visual cortex
  - Structure
  - Response properties
  - Cortical processing
- Topographic maps large and small
  - Retinotopy
  - Ocular dominance
  - Orientation
  - Sharp map borders

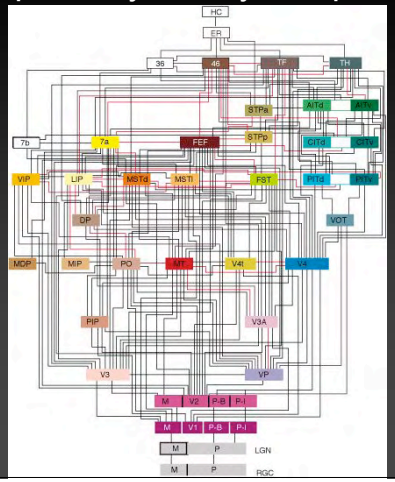
A large part of the brain is dedicated for vision



Van Essen 1992 Flattened primate brain

The visual pathway

The visual pathway is very complicated…



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The eye

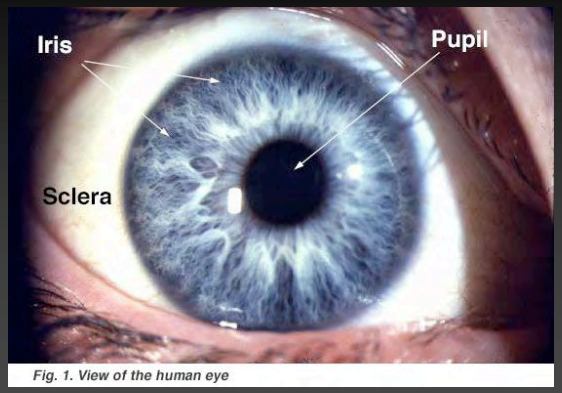
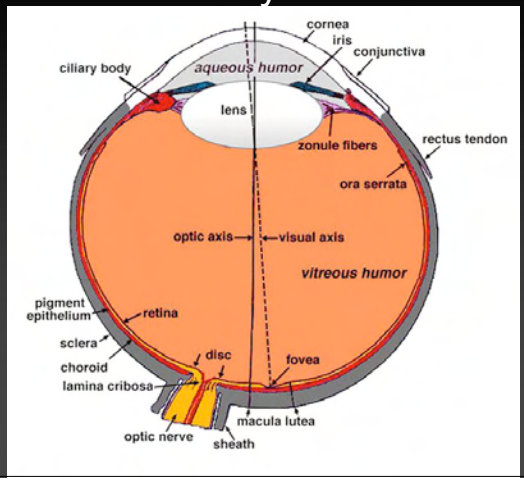
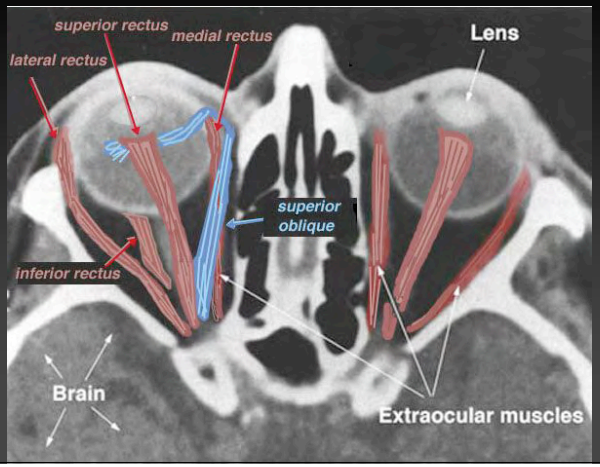


Fig. 1. View of the human eye

The eye



The eye



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The retina

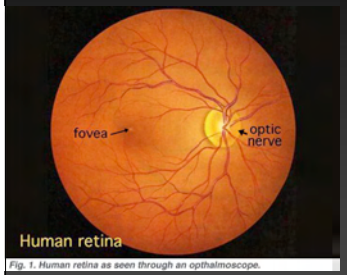
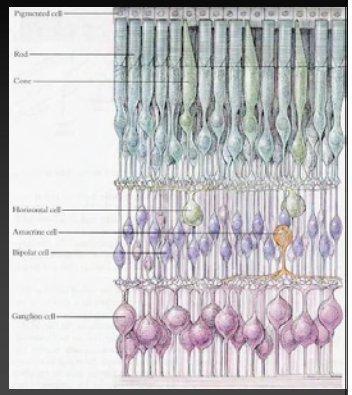
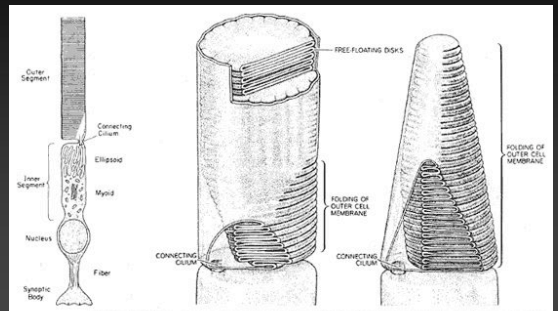


Fig. 1. Human retina as seen through an opthalmoscope.



light

2 kinds of photoreceptors: Rods and cones



At the left is a generalized conception of the important structural features of a vertebrate photoreceptor cell. At the right are shown the differences between the structure of rod (left) and cone (right) outer segments. These diagrams are from Young (1970) and Young (1971).

Rods can detect very dim stimuli (>=1 photon!)

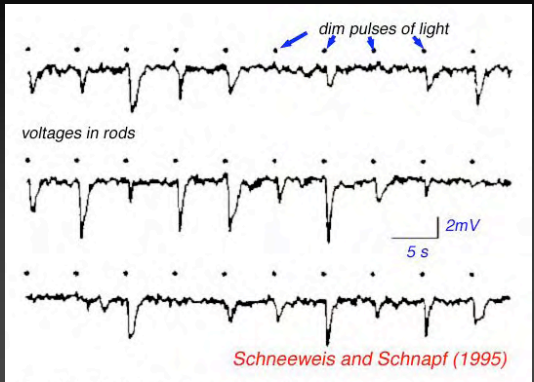


Fig. 22. Photovoltages recorded in monkey rods.

Cones come in 3 flavors

Some people and animals (cats&dogs) have only 2

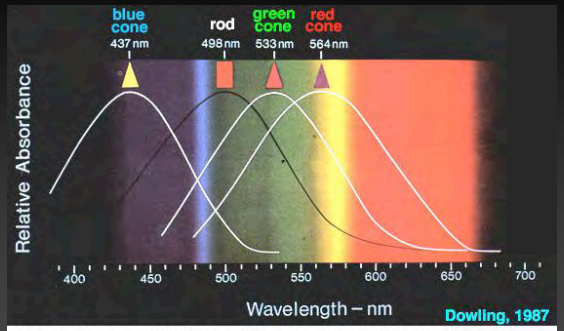
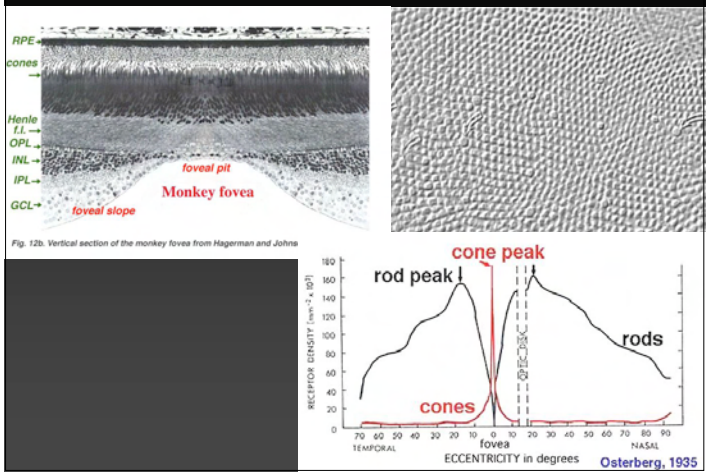


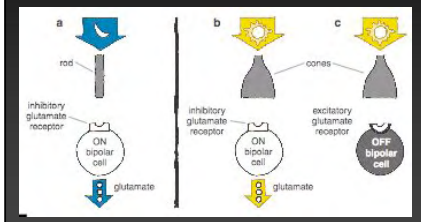
Fig. 14.The peak spectral sensitivities of the the 3 cone types and the the rods in the primate retina (Brown and Wald, 1963). From Dowling's book (1987).

High resolution vision by cones in the fovea

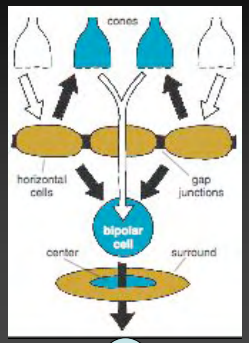


Retinal circuits

Photoreceptors release glutamate in dark
They STOP releasing glutamate in light

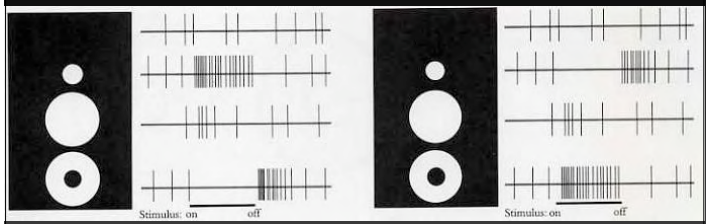


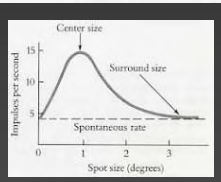
Light stimulates glutamate release in ON bipolar cells
Light reduces glutamate release in OFF bipolar cells



Ganglion cell

Responses of retinal ganglion cells





Kuffler 1950s

More variety for color!

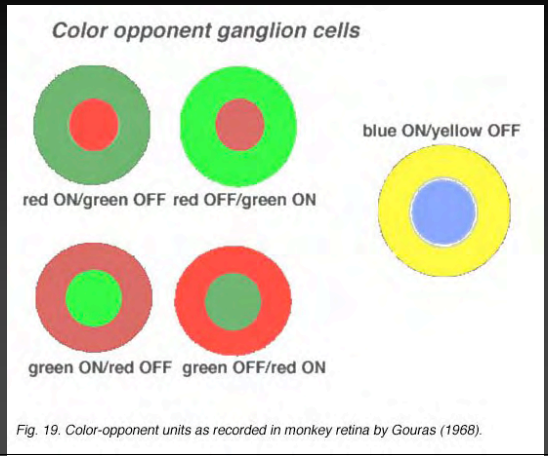


Fig. 19. Color-opponent units as recorded in monkey retina by Gouras (1968).

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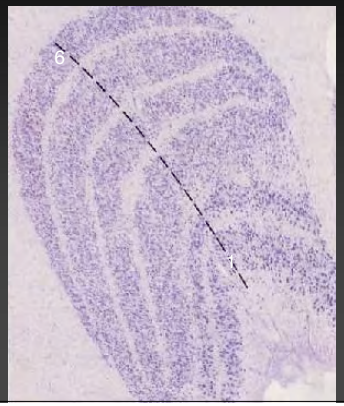
Lateral geniculate nucleus (LGN)

6 layers
psi eye: 2 3 5
Contra eye: 1 4 6

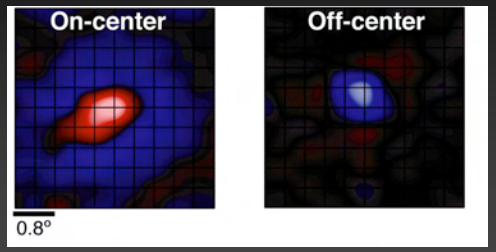
Magnocellular (BW): 1 2
Parvocellular (color): 3 6



Primate LGN

LGN responses (Hubel & Wiesel ~1960s)

LGN receptive fields mapped with white noise stimuli



Kanold et al

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The visual cortex

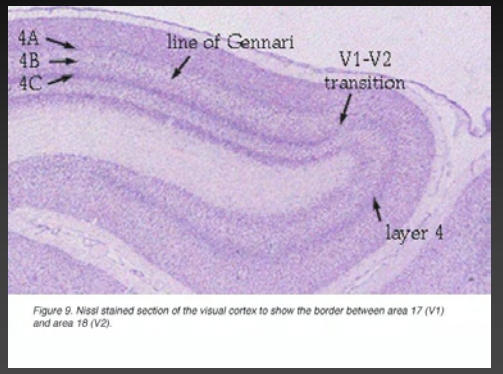
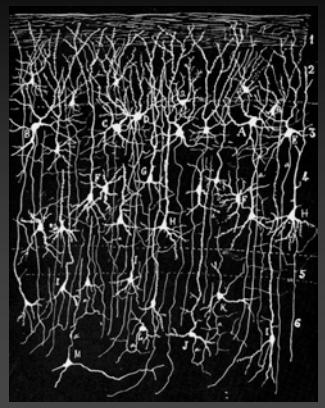


Figure 9. Nissl stained section of the visual cortex to show the border between area 17 (V1) and area 18 (V2).

Line of Gennari: myelinated axons from LGN

The visual cortex



V1 has a large neuronal diversity

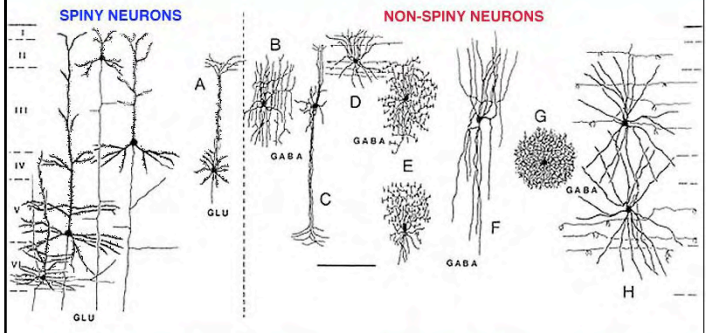
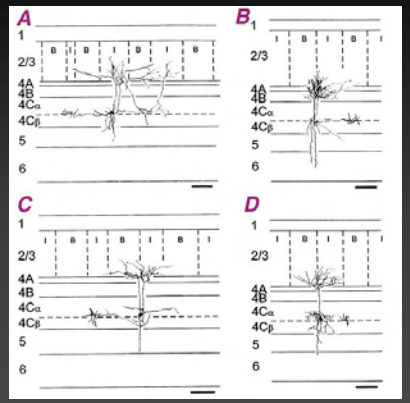
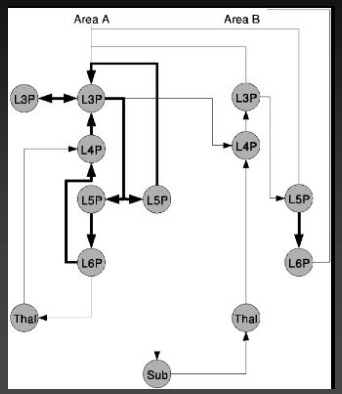


Figure 12. Basic cell types in the monkey cerebral cortex. Left: spiny neurons that include pyramidal cells and stellate cells (A). Spiny neurons utilize the neurotransmitter glutamate (Glu). Right: smooth cells that use the neurotransmitter GABA. B, cell with local axon arcades; C, double bouquet cell;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

Stereotyped connections
I.e: Layer 4c cells project to layer 2/3



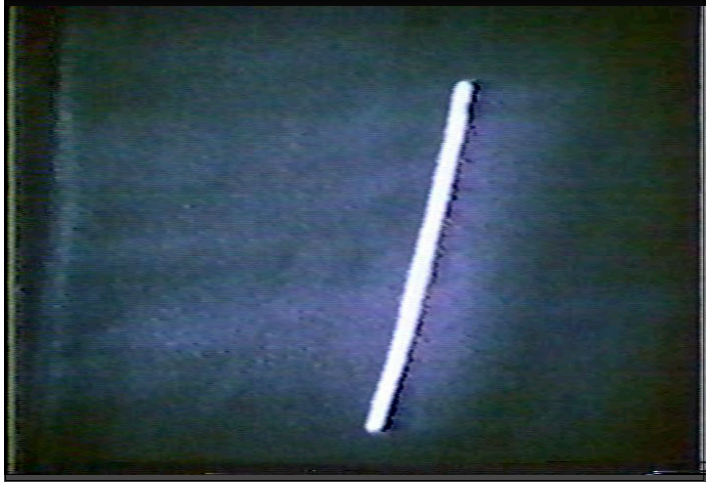
Stereotyped information flow through cortex



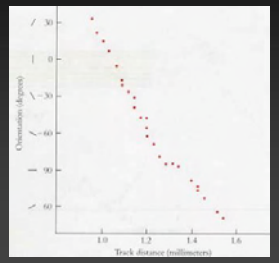
Douglas & Martin 2004

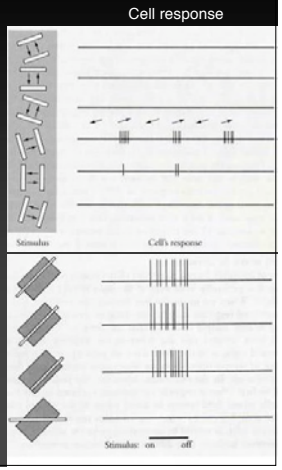
V1 responses I (Hubel & Wiesel ~1965)

V1 responses II (Hubel & Wiesel ~1965)



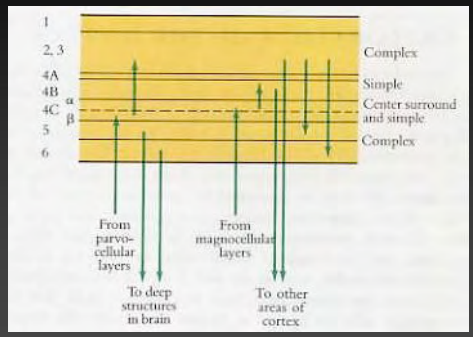
Orientation tuning: Simple and complex cells



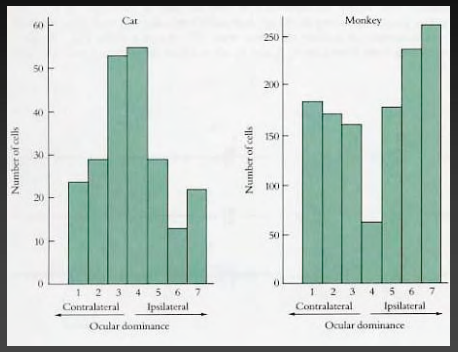


Hubel&Wiesel

Response types are distributed differently



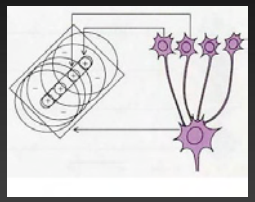
Binocular interactions (ocular dominance)



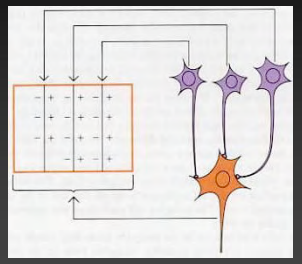
Hubel & Wiesel

How to make simple and complex cells? Feed-forward model

Simple cell



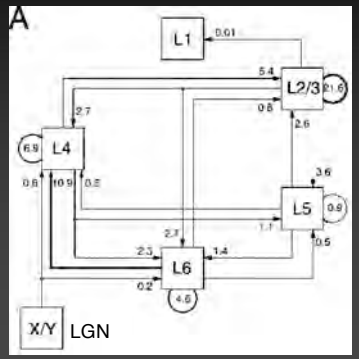
Complex cell



Hubel & Wiesel

How do these responses arise?

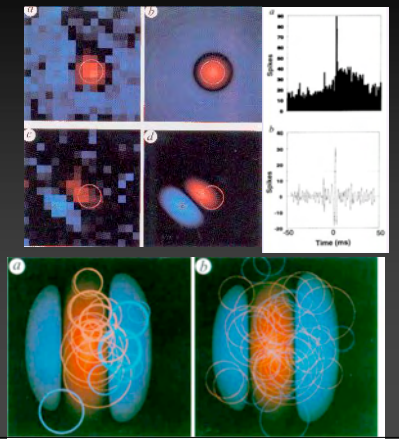
Problem: Only small fraction of synaptic inputs to layer 4 come from LGN



What about function?

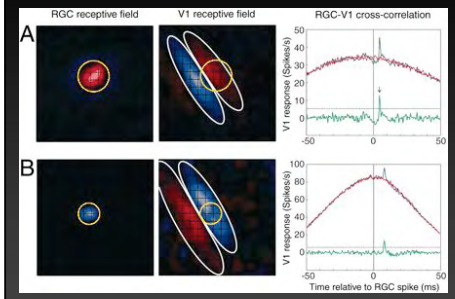
Binzegger et al 2004

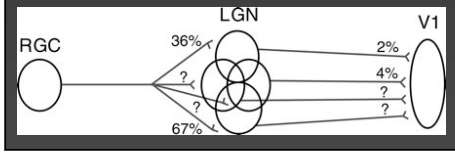
Simultaneous recordings in LGN and layer 4 reveal strong functional connections



Reid & Alonso 1995

Divergence and convergence

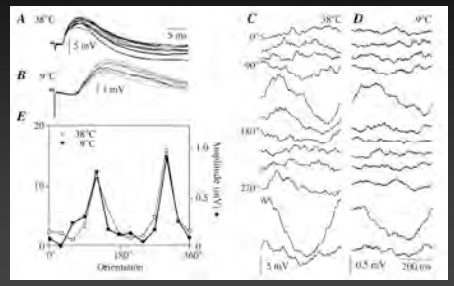




~3% of V1 spikes driven by single RGC!

Kara & Reid 2003

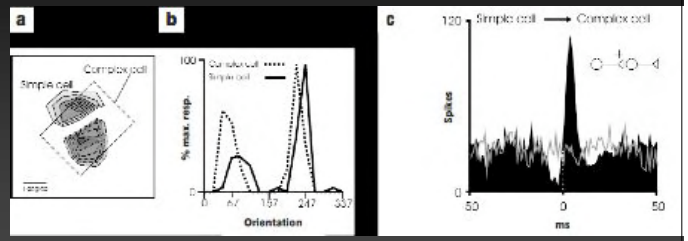
Silencing intracortical processing does not affect orientation tuning in layer 4



ntracellular recording!

Ferster 1996 Chung & Ferster 1998

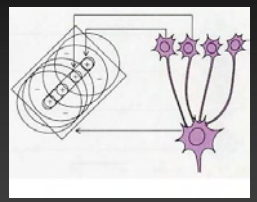
Simultaneous recordings in layer 4 and layer 2 reveal functional connections



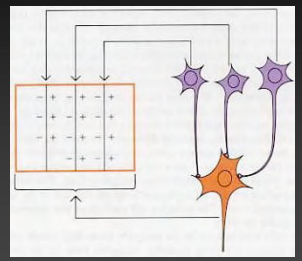
Alonso & Martinez 1998

Feed-forward model seems mostly correct!

Simple cell

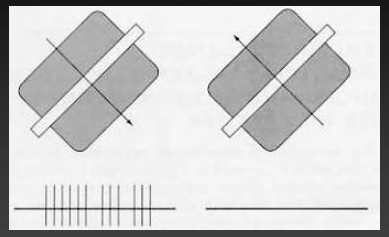


Complex cell



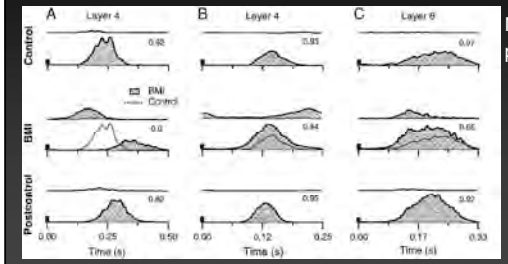
Hubel & Wiesel

Direction selective cells
(~30% of V1 cells)



Hubel & Wiesel 1968 (of course…)

Direction selectivity mediated by cortical inhibition

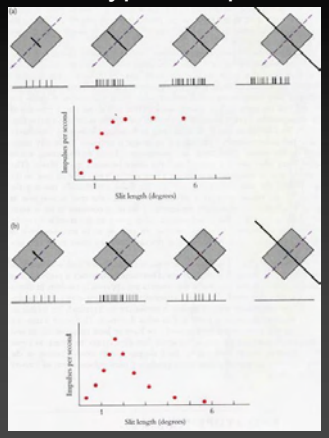


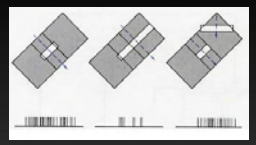
Non preferred direction
preferred direction

BM =GABA blocker

Murthy & Humphrey 1999

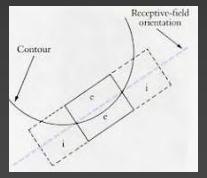
Hypercomplex cells: End stopping



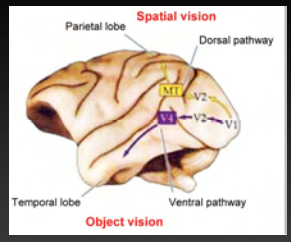


Hubel & Wiesel

Are these contour detectors?



Parallel pathways



Ventral (Color)

- LGN parvo layer
- V1 layer 4Cb
- V1 blobs
- V2 thin stripes

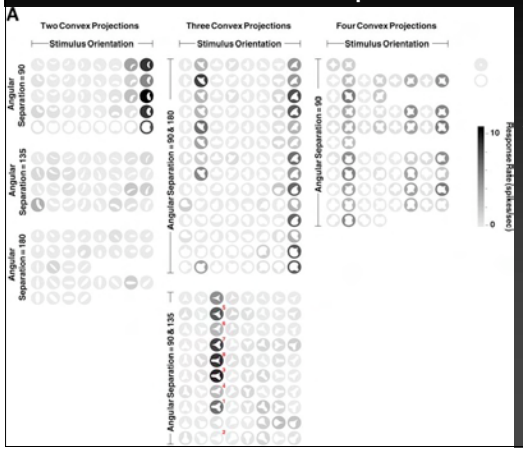
Ventral (Form)

- LGN parvo layer
- V1 layer 4Cb
- V1 interblobs
- V2 inter-stripes
- V4, MT

Dorsal (motion & disparity)

- LGN magno layer
- V1 layer 4Ca
- V1 layer 4B
- V2 thick stripes
- MT

At higher levels (I.e. V4) cells respond to shapes



V4 cell responding to concave curvature at the right

Pasupa hy & Conners 2001

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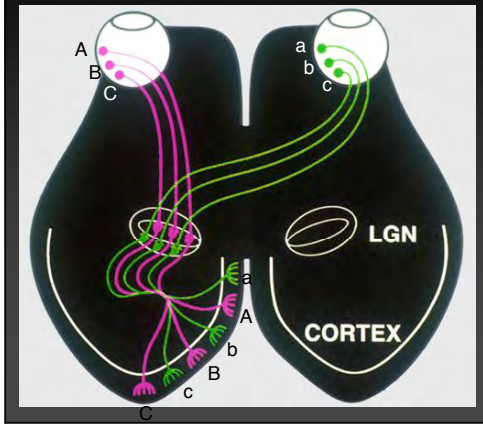
Topographic organization

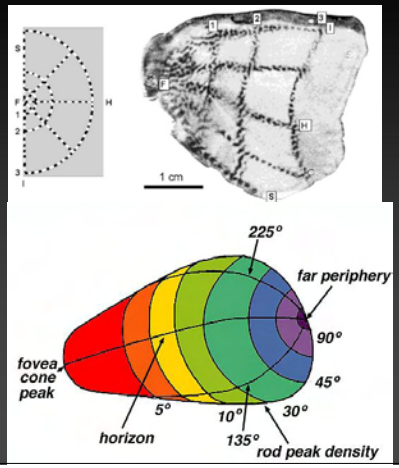


Eye specific segregation

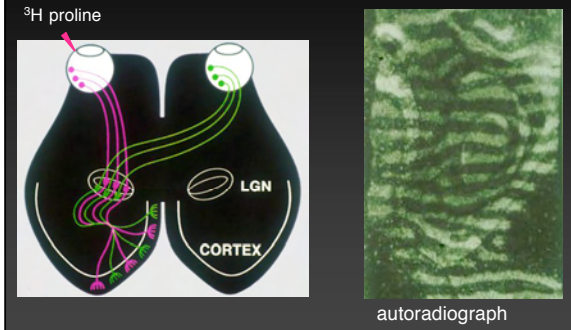
Topographic mapping

Retinotopic maps & magnification

R

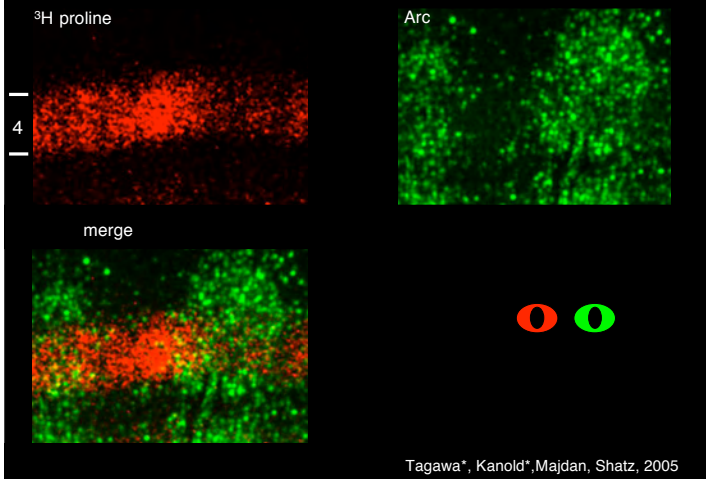


Inputs from 2 eyes are organized into ocular dominance columns in V1



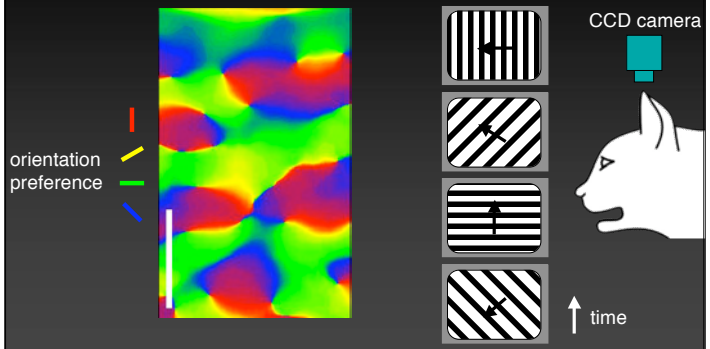
From Hubel & Wiesel

And now both eyes labeled…



Tagawa*, Kanold*,Majdan, Shatz, 2005

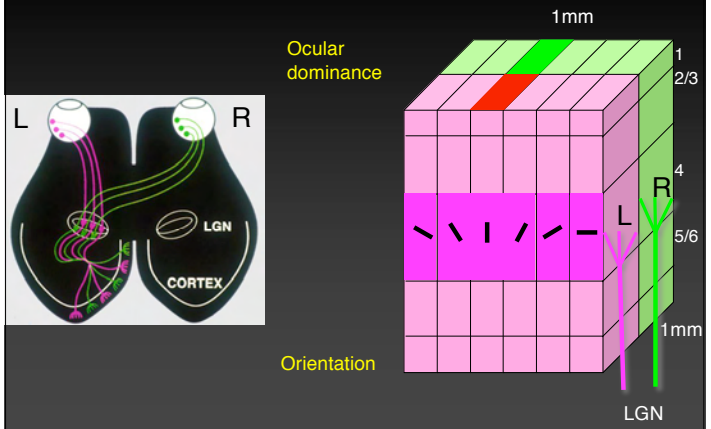
Optical imaging of orientation maps in vivo



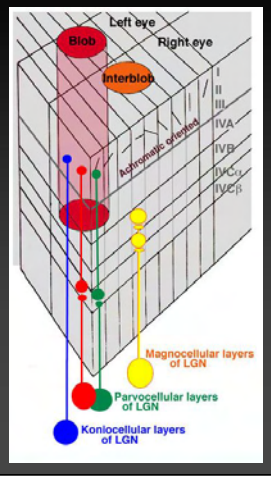
Kanold e al 2003

Low resolution (50 100um) technique!

Ocular dominance and orientation columns



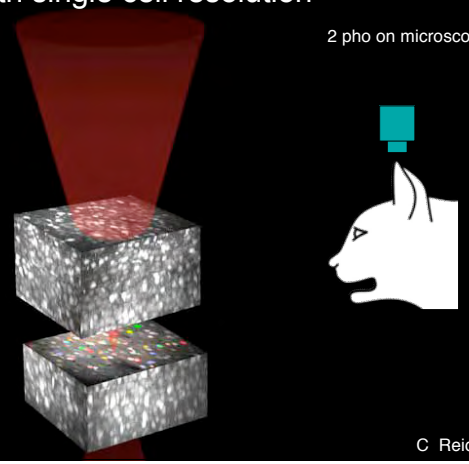
Hypercolumn



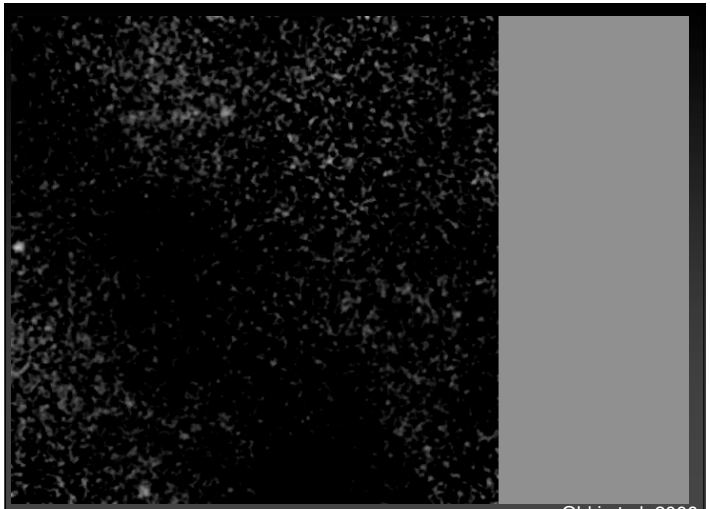
L

Imaging functional responses of many neurons with single cell resolution

2 pho on microscope

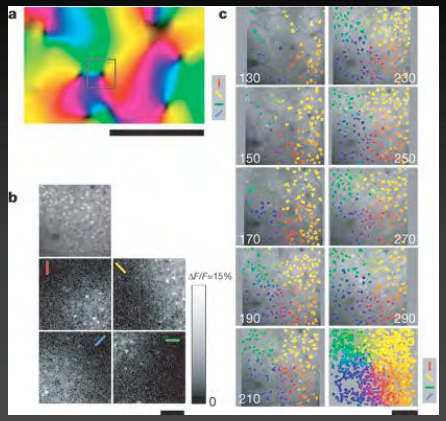


C Reid



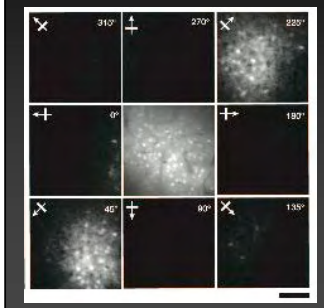
Ohki et al 2006

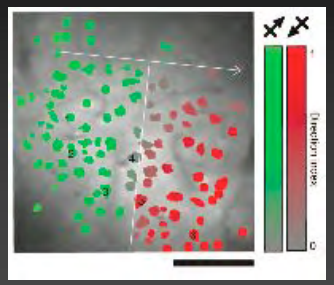
Tuning in pinwheel centers is sharp



Ohki et al 2006

Direction tuning maps are sharp





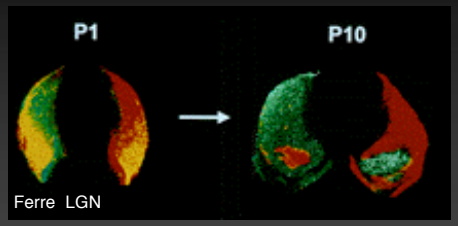
Ohki et al 2005

Summary

- Visual information is processed in multiple stages
- Visual receptive fields get more complex with subsequent processing stages
- Center/Surround at initial stages (retina, LGN), oriented bars etc in V1. Shapes in higher cortical areas.
- Within V1 receptive fields are more “complex” outside layer 4.
- Cells with similar receptive fields are organized in columns.
- Columnar tuning varies in an organized manner in many species (I.e. orientation maps in cat but NOT rat).

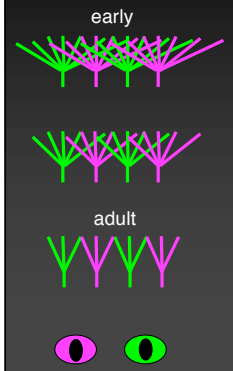
- How does this all get wired up?

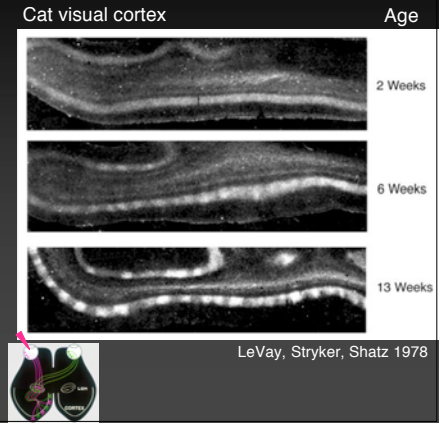
LGN layers form by refinement of retinal projections



Penn et al. Science 1998

Ocular dominance columns form by refinement of thalamocortical projections





LeVay, Stryker, Shatz 1978

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- How does this all get wired up? See part II on Thursday!