

Visual Object Recognition

Computational Models and Neurophysiological Mechanisms

Neurobiology 230. Harvard College/GSAS 78454

Class 1 [09/01/2021]. Introduction to Vision

Note: no class on 09/06/2021

Class 2 [09/13/2021]. Natural image statistics and the retina

Class 3 [09/20/2021]. The Phenomenology of Vision

Class 4 [09/27/2021]. Learning from Lesions

Class 5 [10/04/2021]. Primary Visual Cortex

Note: no class on 10/11/2021

Class 6 [10/18/2021]. Adventures into *terra incognita*

Class 7 [10/25/2021]. From the Highest Echelons of Visual Processing to Cognition

Class 8 [11/01/2021]. First Steps into in silico vision [Will Xiao]

Class 9 [11/08/2021]. Teaching Computers how to see

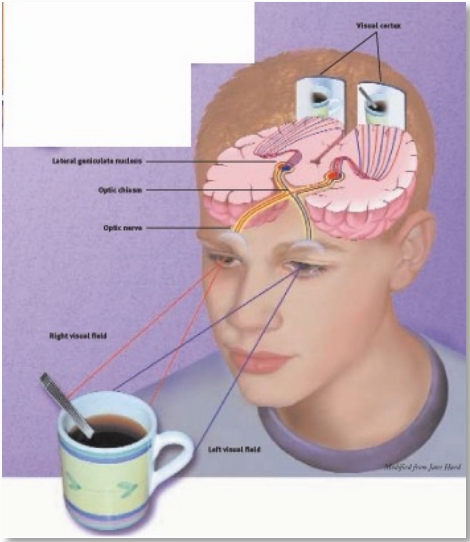
Class 10 [11/15/2021]. Computer Vision

Class 11 [11/22/2021]. Connecting Vision to the rest of Cognition

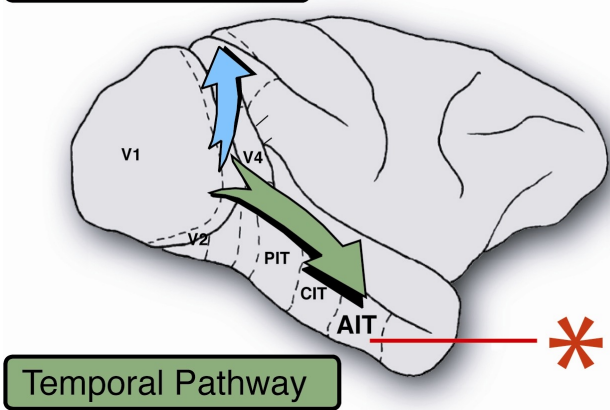
Class 12 [11/29/2021]. Visual Consciousness

FINAL EXAM, PAPER DUE 12/14/2021. No extensions.

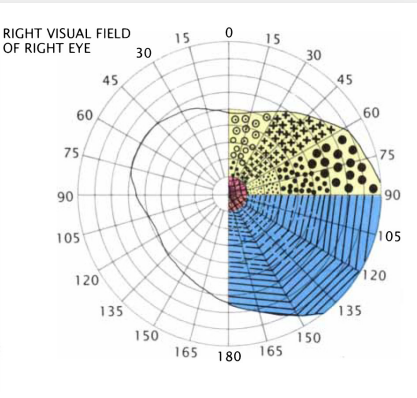
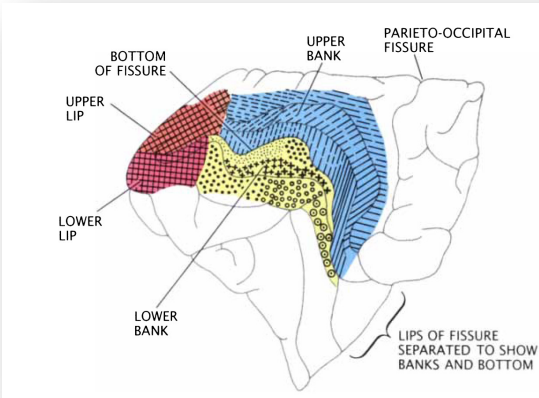
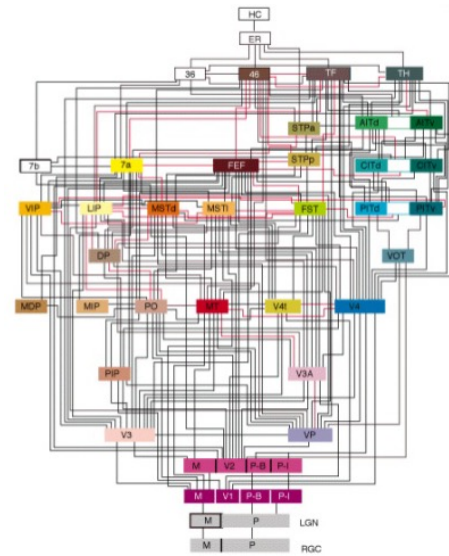
Quick recap



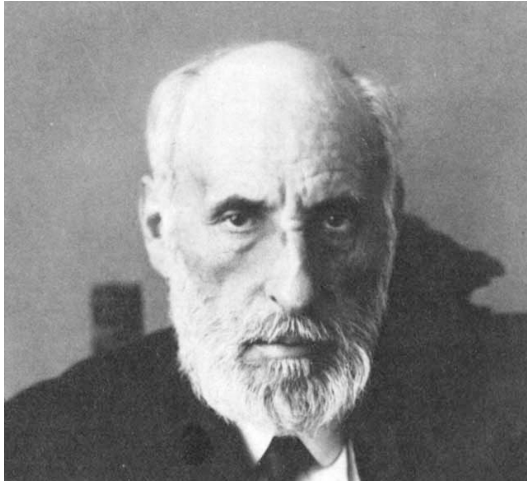
Parietal Pathway



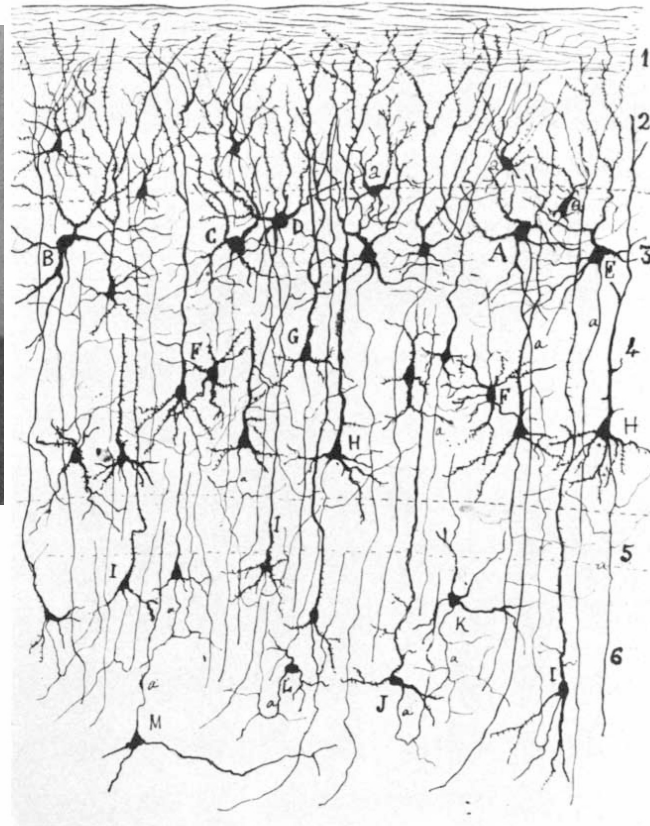
Temporal Pathway



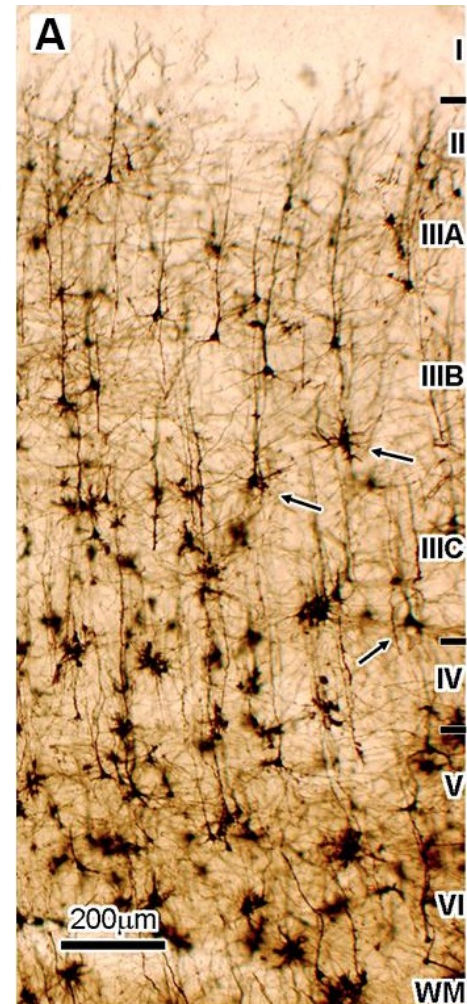
The complex circuitry of cortex as drawn by Ramon y Cajal



Ramon y Cajal
[1852-1934]

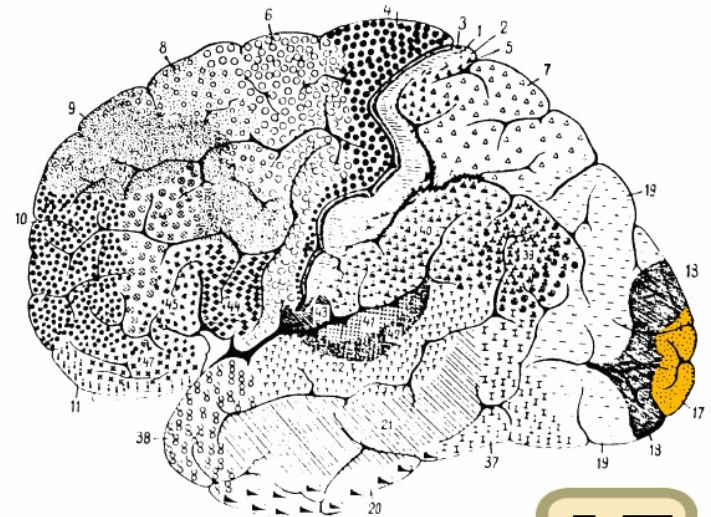


GOLGI-STAINED NERVE TISSUE from the visual cortex of a rat was sketched by Cajal in 1888. The numbers along the right-hand margin identify cellular layers; the capital letters label individual neurons. One of Cajal's most important contributions to neurobiology was to establish the neuron as a discrete, well-defined cell rather than as part of a continuous network.

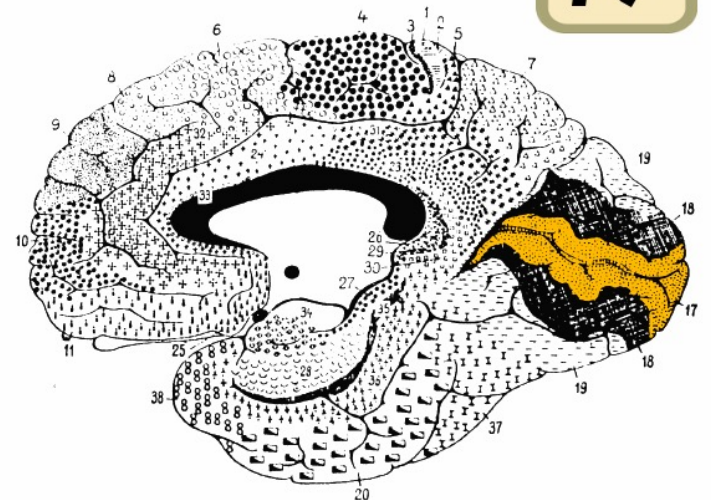


Primary visual cortex in Brodmann's map

Brain shown from the side, facing left.
Above: view from outside, below: cut
through the middle. Orange = Brodmann
area 17 (primary visual cortex)



17



You are here



How does a car work?



“Behavior”: it moves, it makes sounds, can also output music, different speeds, turns,

“Lesions”: no wheels, no steering wheel, no gas

“fMRI”: measure average temperature over 5 minutes, and every 3 inches

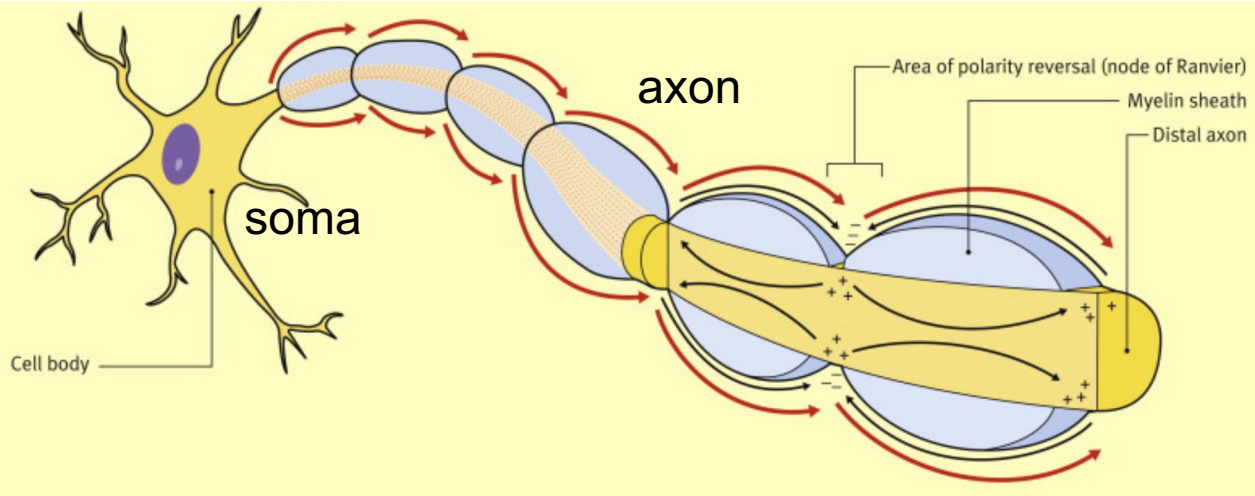
“EEG”: get frequency spectrum of sounds from the motor every second



“Neurophysiology”: Open the hood and study each component and how different parts interact

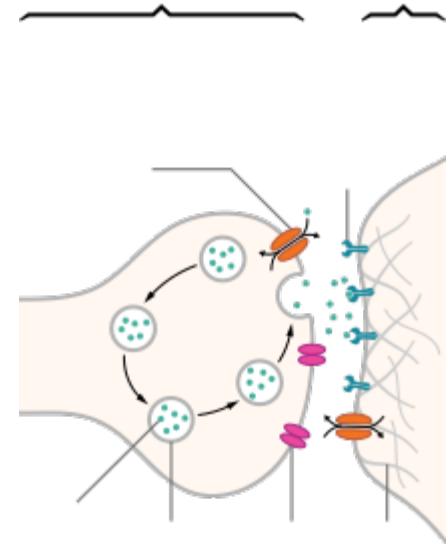
Basic Neuroscience

dendrites



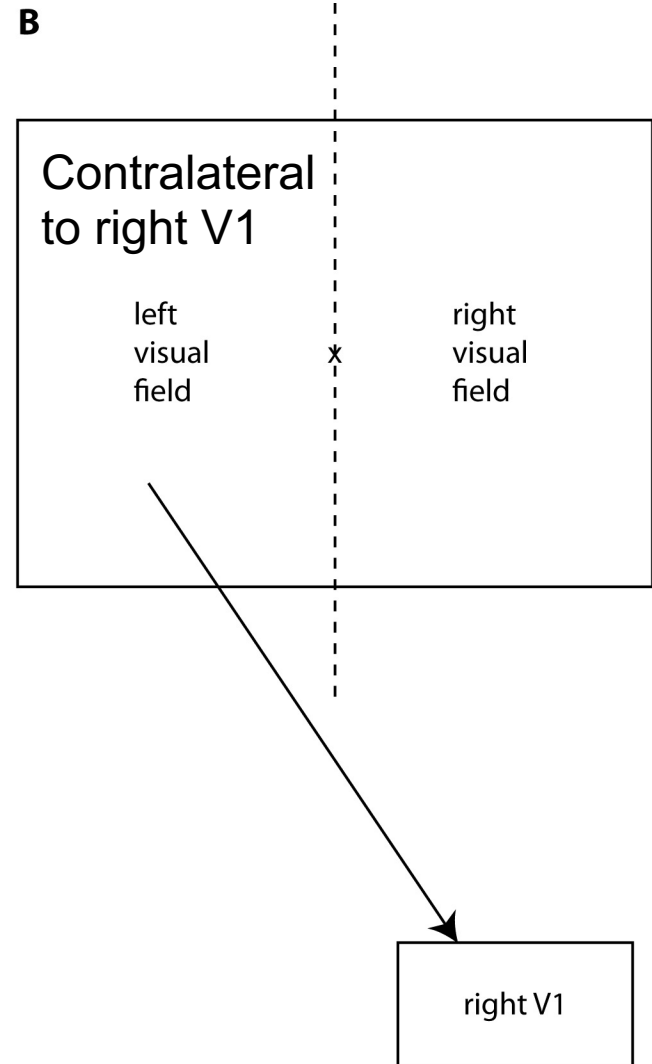
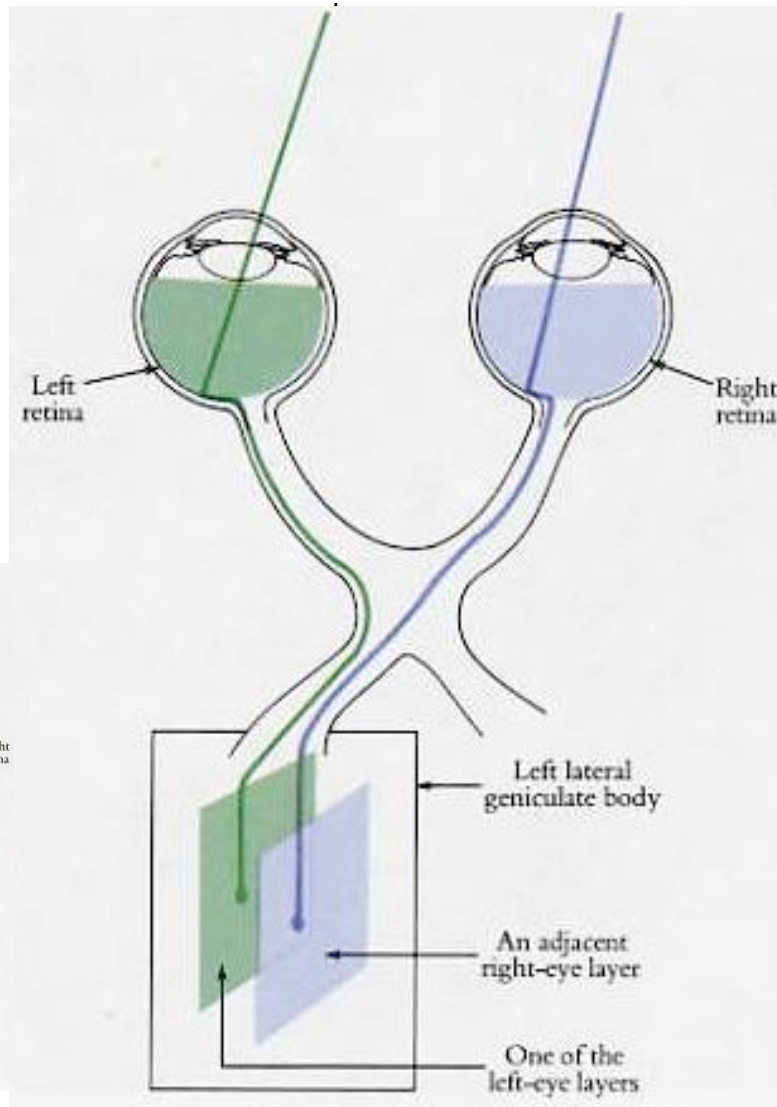
Pre-synaptic

Post-synaptic



Voltage changes inside the neuron
Voltage changes in the extracellular space

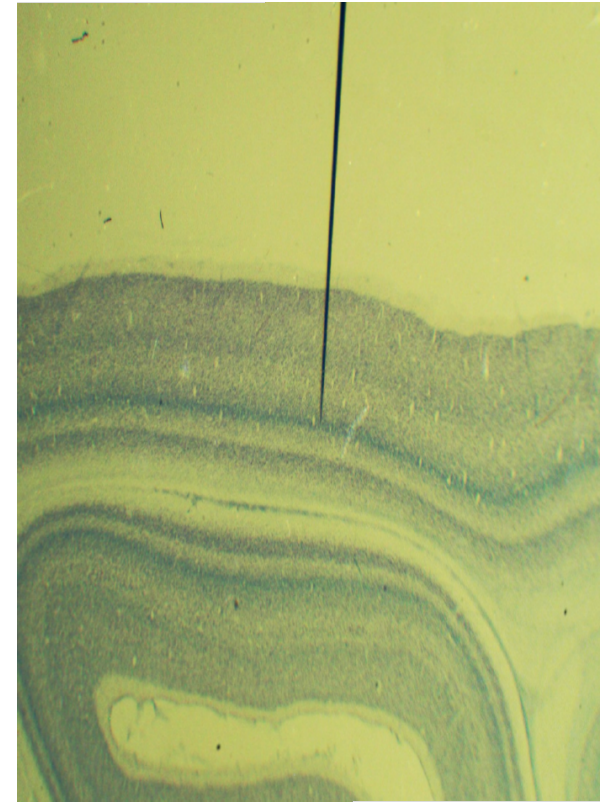
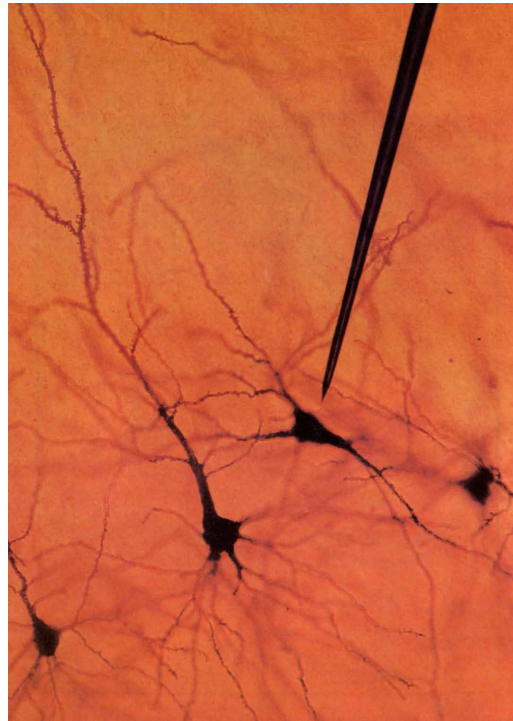
V1 in each hemisphere represents the *contralateral* visual field



The gold standard to examine neuronal activity: microelectrode recordings

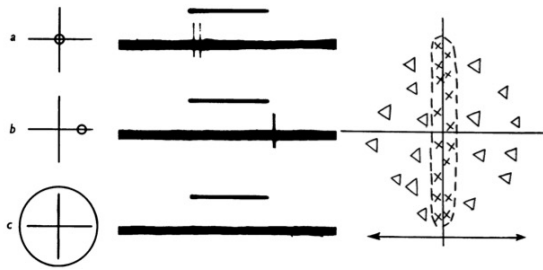
Edgar Adrian 1926

Neuronal resolution
Sub-millisecond temporal resolution
Direct examination of action potentials



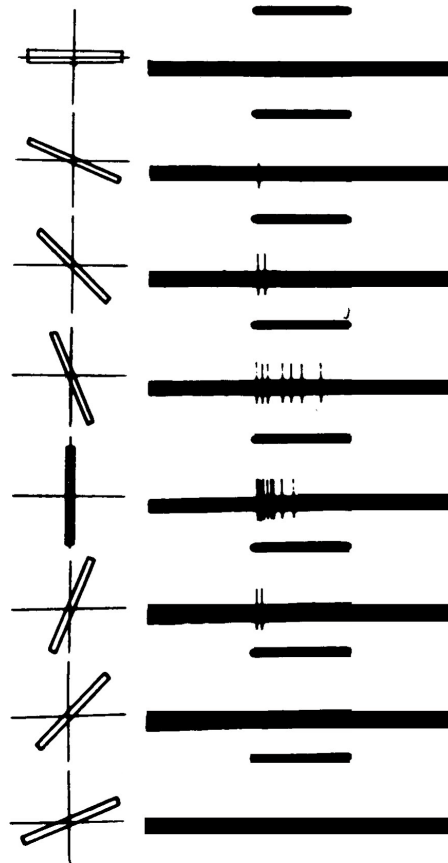
Hubel, D. (1979). The Visual Brain.
SCIENTIFIC AMERICAN 241, 45-53.

Neurophysiological recordings from primary visual cortex



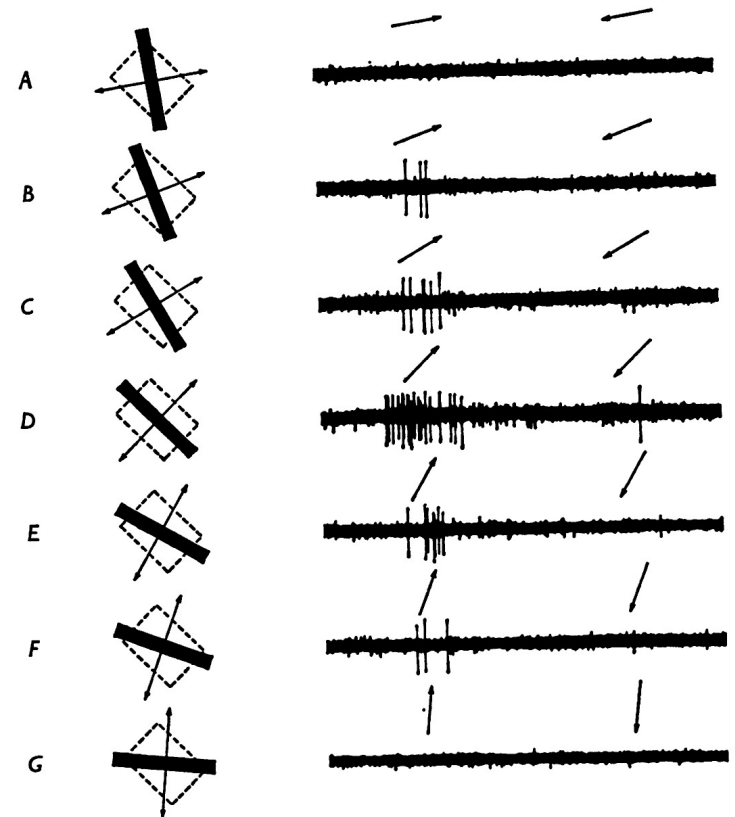
Hubel & Wiesel
J. Physiol. 1959

Orientation selectivity



Hubel – Nobel Lecture

Direction selectivity



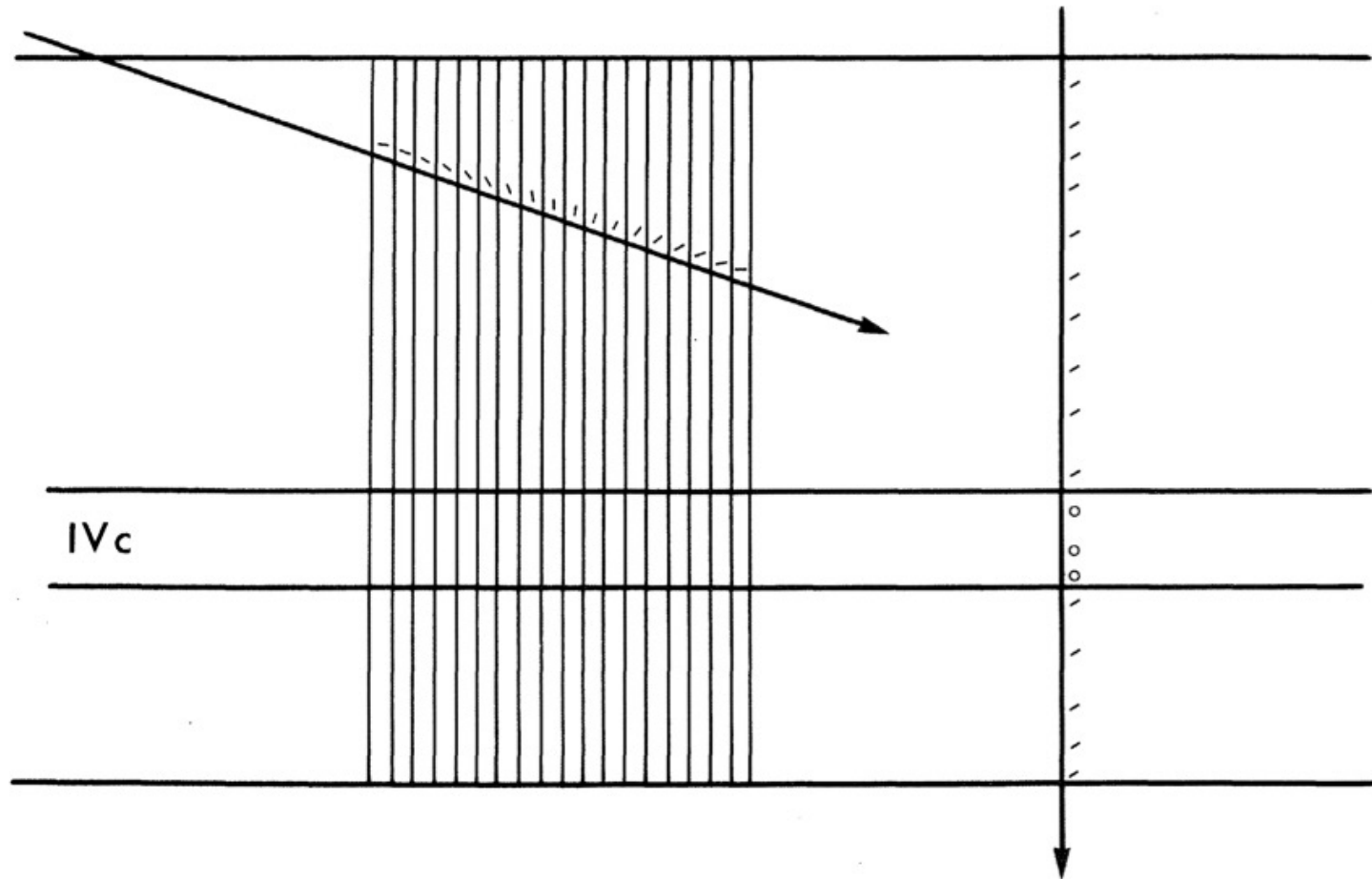
Hubel and Wiesel 1968

Simple Cells Video (Hubel and Wiesel)

<http://www.youtube.com/watch?v=8VdFf3egwfg>



Visual orientation columns

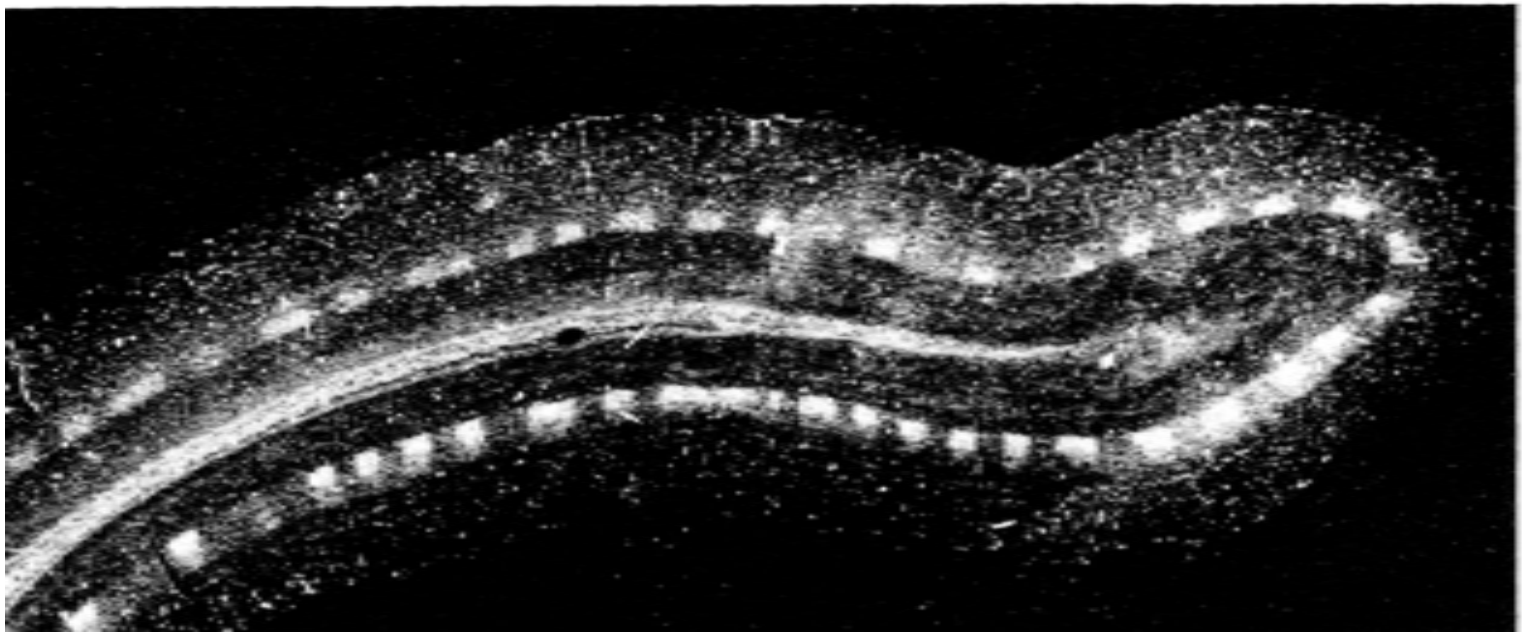
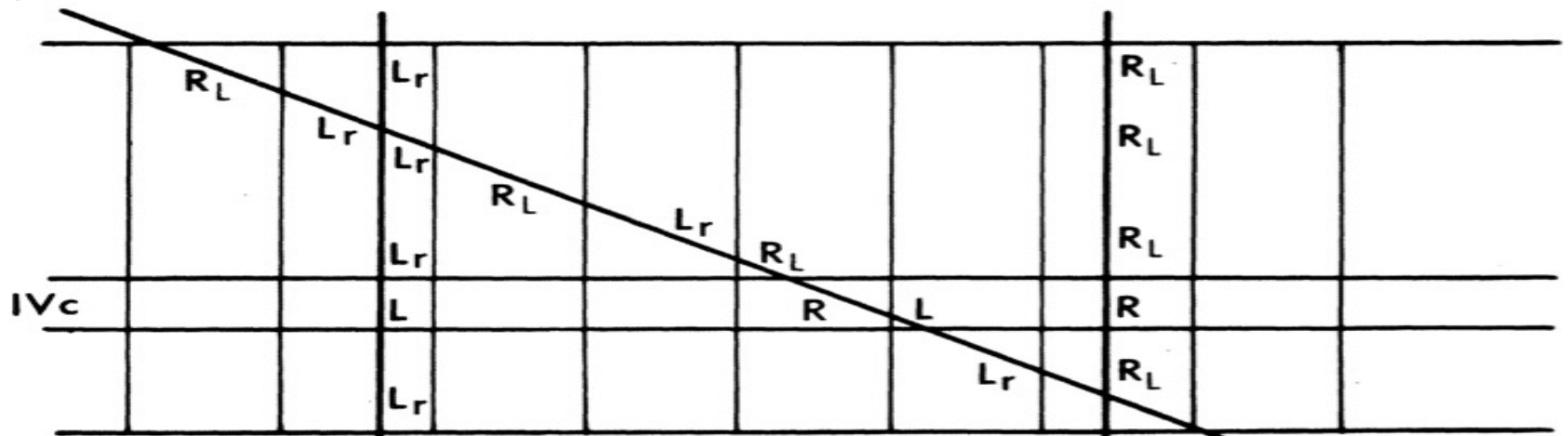


Hubel & Wiesel, Proc. R. Soc. Lond. B, 1977

Horton & Adams, Phil. Trans. R. Soc. B, 2005

Ocular dominance columns

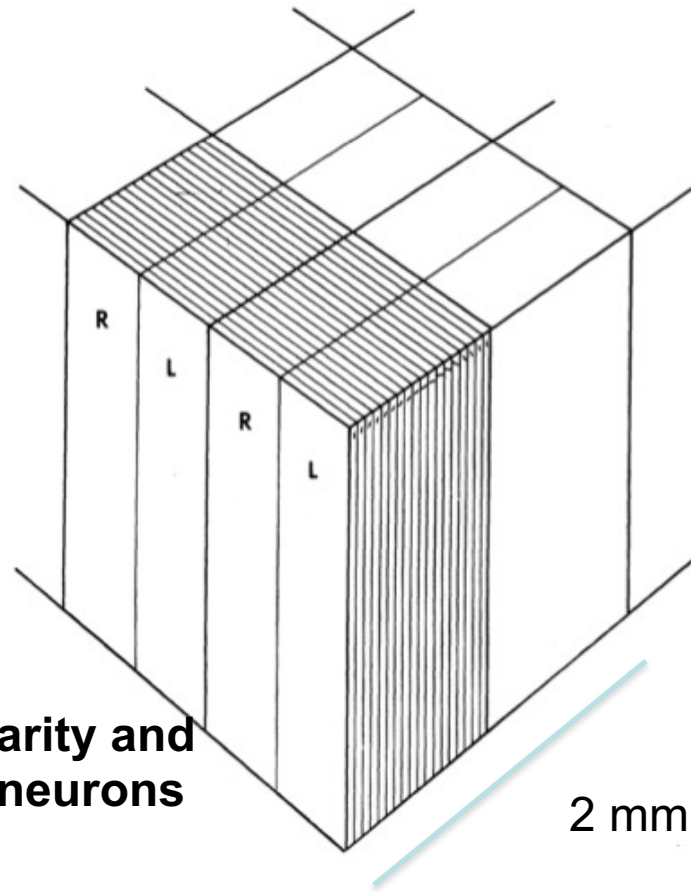
Hubel & Wiesel, Proc. R. Soc. Lond. B, 1977



Different primary visual cortex neurons show a variety of interests

- Orientation selectivity
- Direction selectivity
- Speed selectivity
- Typically monotonic response with contrast
- Spatial frequency preferences
- Color

Putting it all* together: the “hypercolumn”

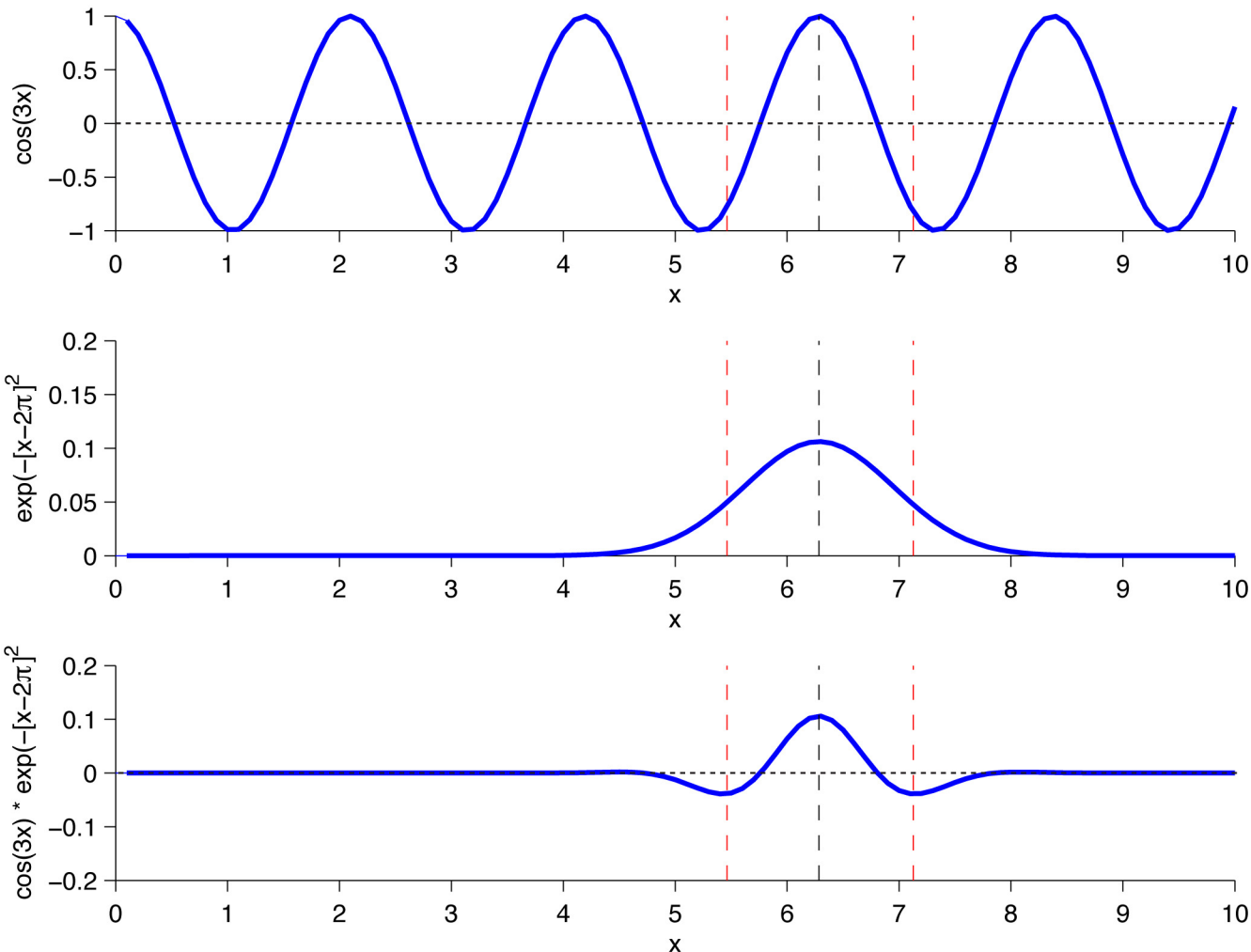


***all is more than ocularity and orientation. Many V1 neurons are also selective for:**

- Direction & speed**
- Depth**
- Color**

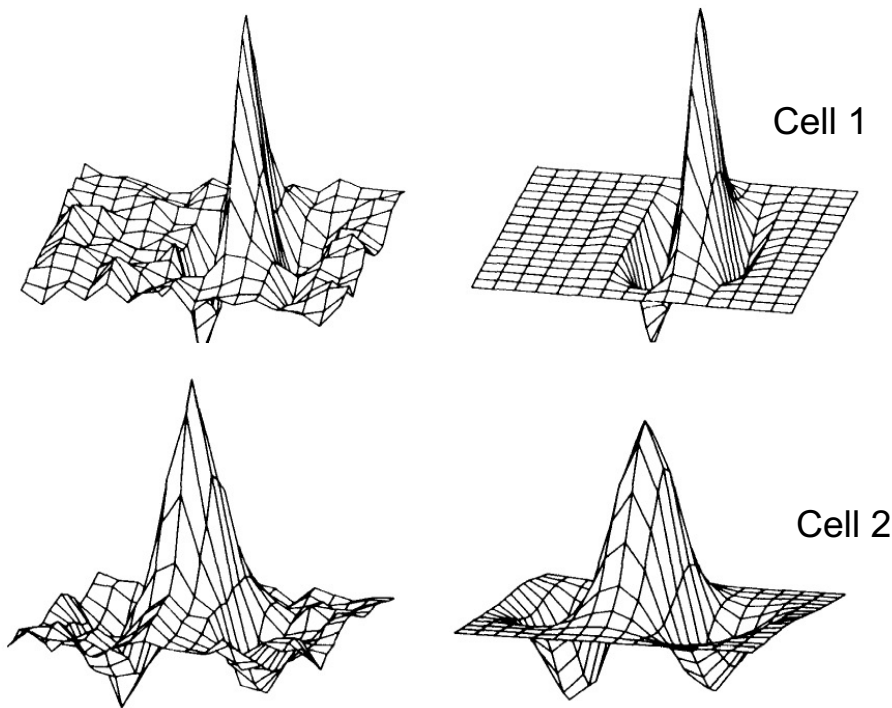
Hubel & Wiesel, Proc. R. Soc. Lond. B, 1977

Interlude 1: Multiplying a cosyne and a Gaussian function



Receptive fields for simple cells in V1

Spatial receptive field Gabor fit



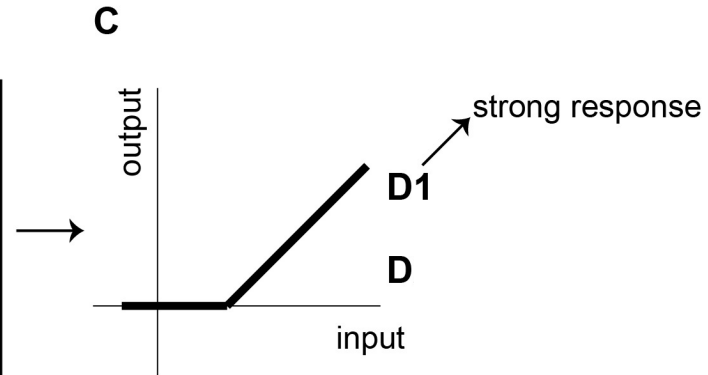
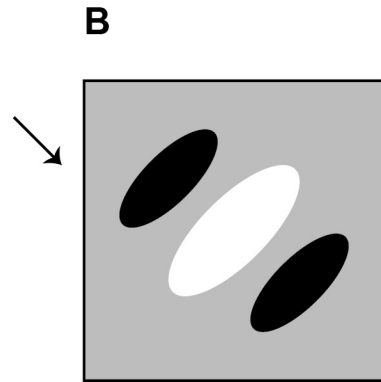
Gabor function

$$D(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left[-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right] \cos(kx - \phi)$$

Spatial receptive field
Cat primary visual cortex (area 17)
Jones and Palmer 1987

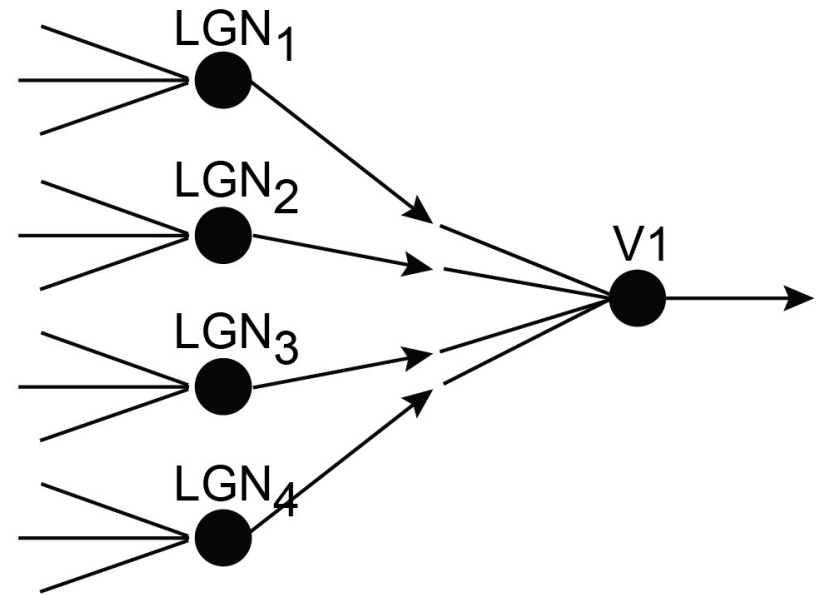
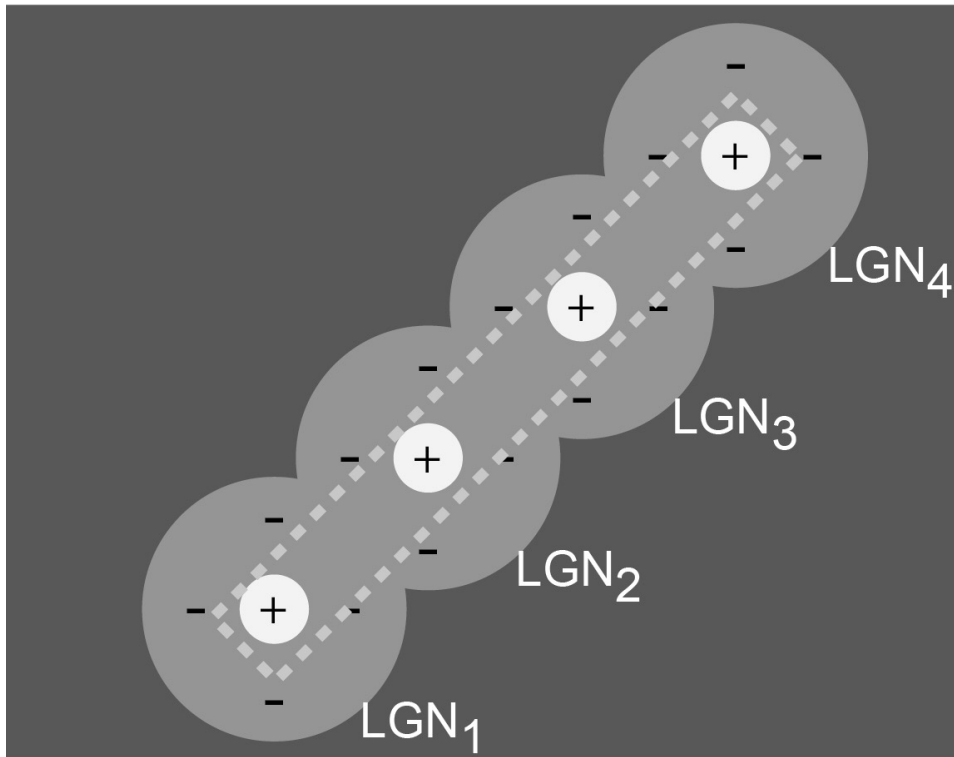
Unit computations in deep convolutional network models

A1 Fixation 1

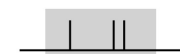
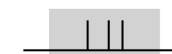
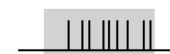
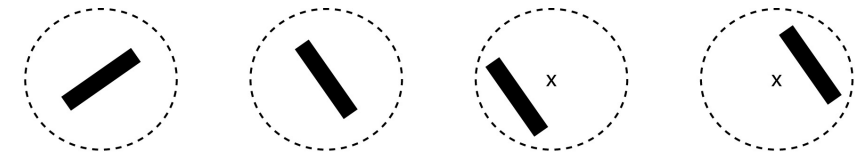
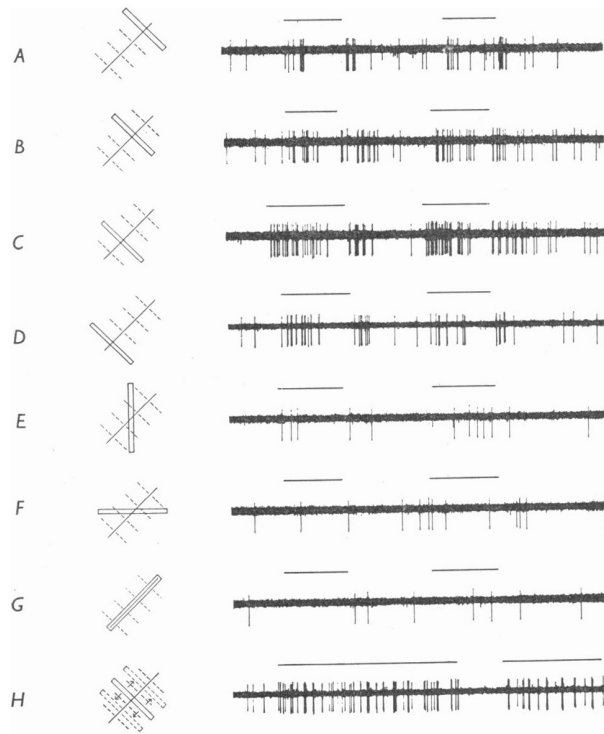


A model for orientation tuning in simple cells

Receptive fields



Complex cells show position tolerance



"Simple" Cell

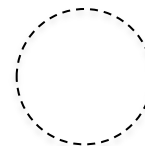


"Complex" Cell

Stimulus: black bar



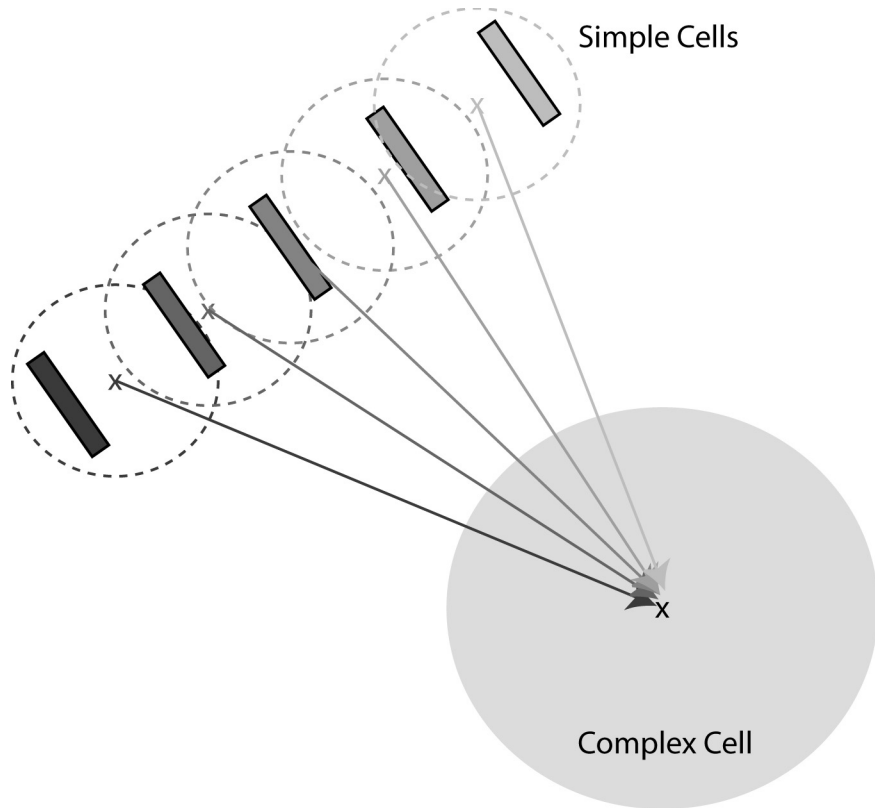
Stimulus presentation time



Receptive field

Text-fig. 4. Responses of a cell with a complex field to stimulation of the left (contralateral) eye with a slit $\frac{1}{8} \times 2\frac{1}{2}^\circ$. Receptive field was in the area centralis and was about $2 \times 3^\circ$ in size. A-D, $\frac{1}{8}^\circ$ wide slit oriented parallel to receptive field axis. E-G, slit oriented at 45 and 90° to receptive-field axis. H, slit oriented as in A-D, is on throughout the record and is moved rapidly from side to side where indicated by upper beam. Responses from left eye slightly more marked than those from right (Group 3, see Part II). Time 1 sec.

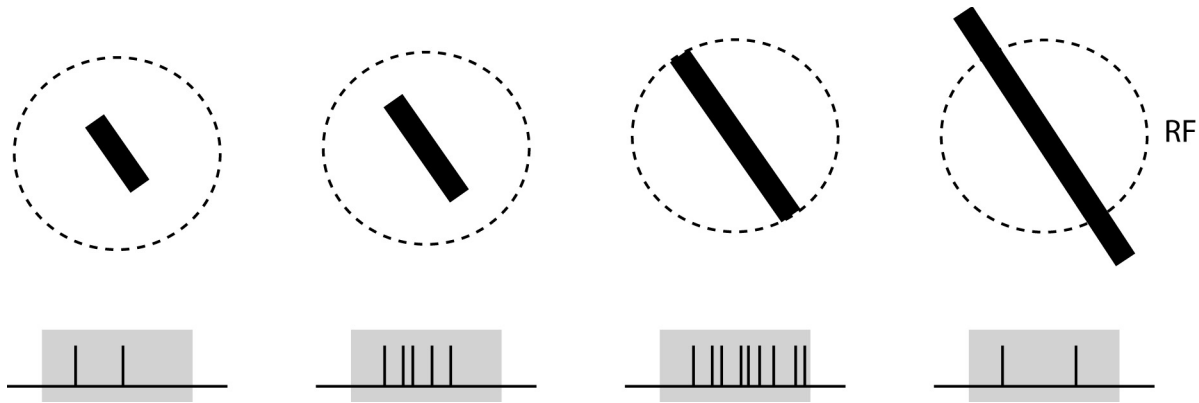
A model to describe tolerance in complex cells



A feed-forward model
describing the responses of
complex cells arising from
non-linear (e.g. OR) adding
of inputs from multiple simple
cells

(by no means the only model)

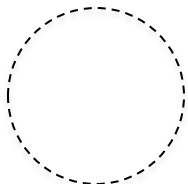
End stopping



Stimulus: bar with preferred orientation

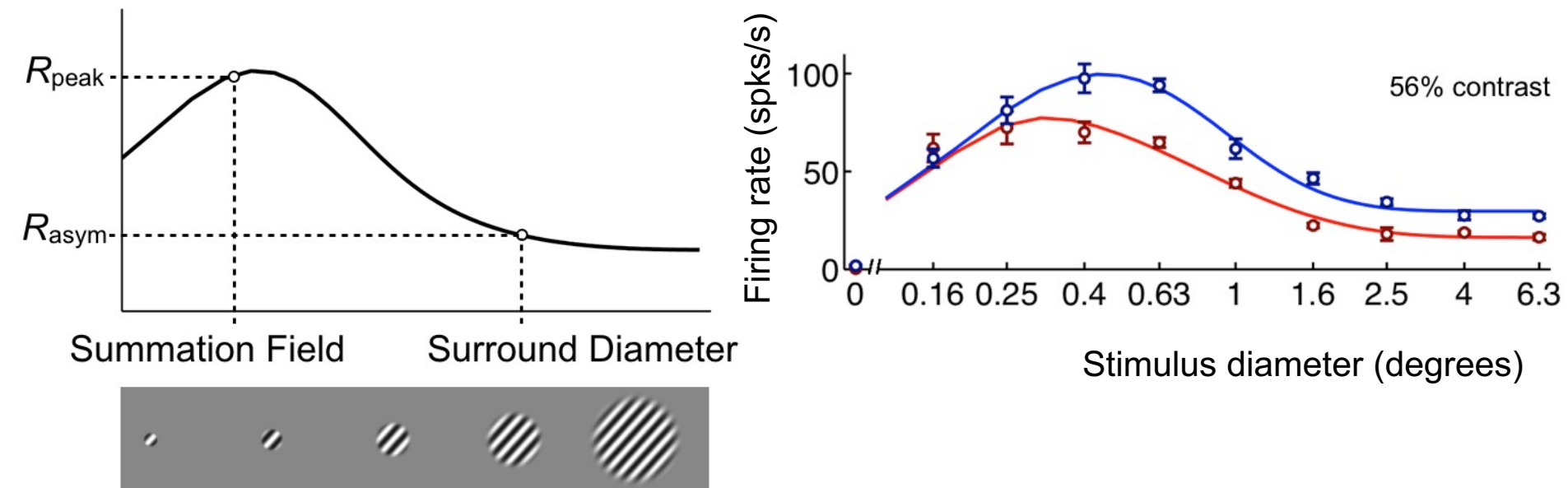


Stimulus presentation time



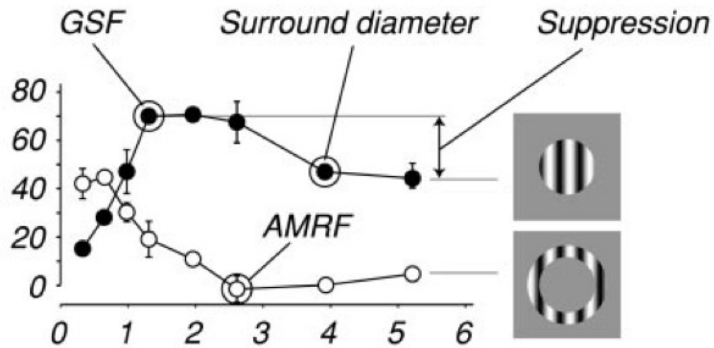
Receptive field

More is not necessarily better: the surround can inhibit the responses of neurons in V1

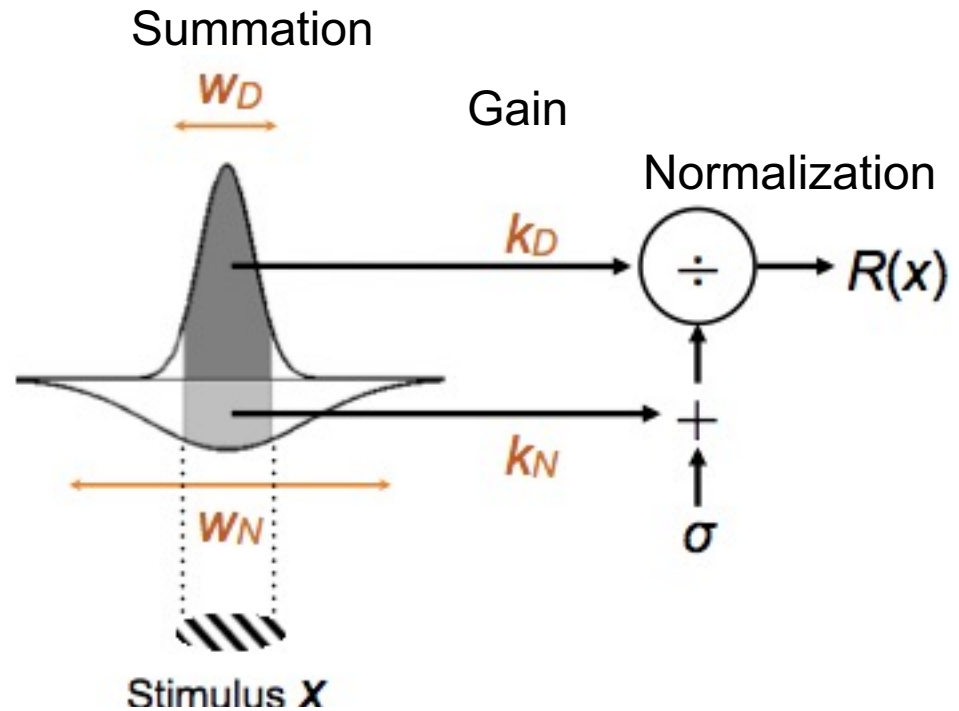


More is not necessarily better: the surround can inhibit the responses of neurons in V1

A



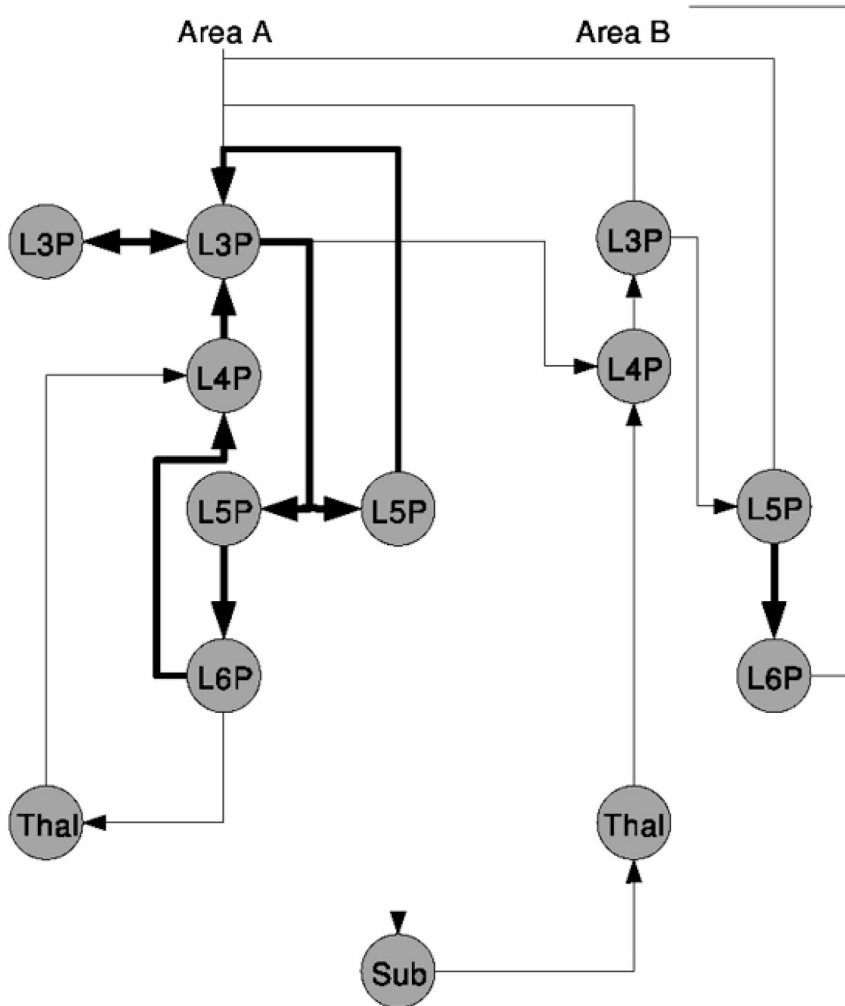
Cavanaugh et al J. Neurophys 2002



$$R_{\text{ROG}}(x) = R_0 + \frac{k_D [w_D \text{erf}(x/2w_D)]^2}{\sigma + k_N [w_N \text{erf}(x/2w_N)]^2}$$

Nassi et al Front. Syst. Neurosci. 2014

“Canonical” microcircuits in neocortex



Felleman and Van Essen 1991
Douglas and Martin 2004

Edges can take us a long way towards object recognition



1.9% of pixels > 0



MATLAB:

`I: image`

`I_edges = edge(I);`

Different methods:

Sobel, Prewitt, Roberts,
Laplacian of Gaussian,
Canny

(determining how the
gradients of I are
computed)



2.9% of pixels > 0



Note: this is a major
oversimplification. The output
of V1 does not simply
represent the image edges

Do we know what the early visual system does?

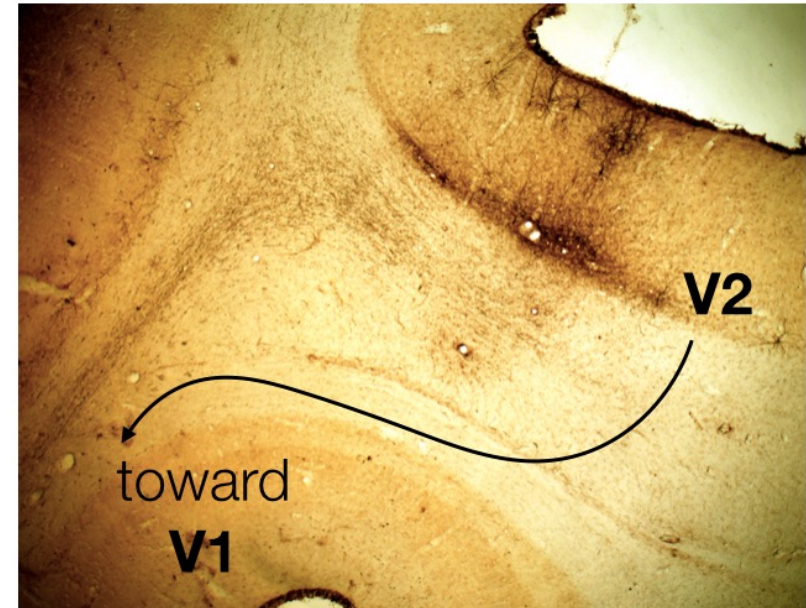
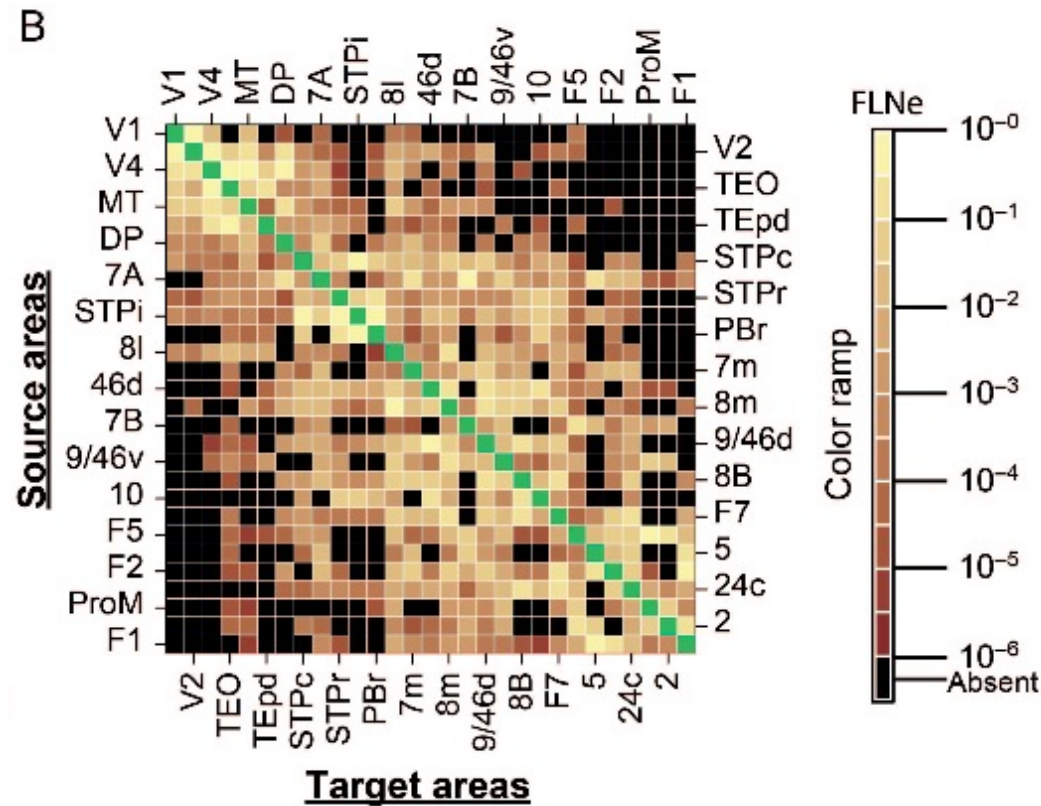
Up to 85% of “V1 function” has yet to be accounted for (Olshausen and Field 2005)

- Biased sampling of neurons
- Biased stimuli
- Biased theories
- Contextual effects
- Internal connections and feedback
- Joint activity

David and Gallant, J.L. Network (2005)

Carandini et al J. Neurosci. 2005

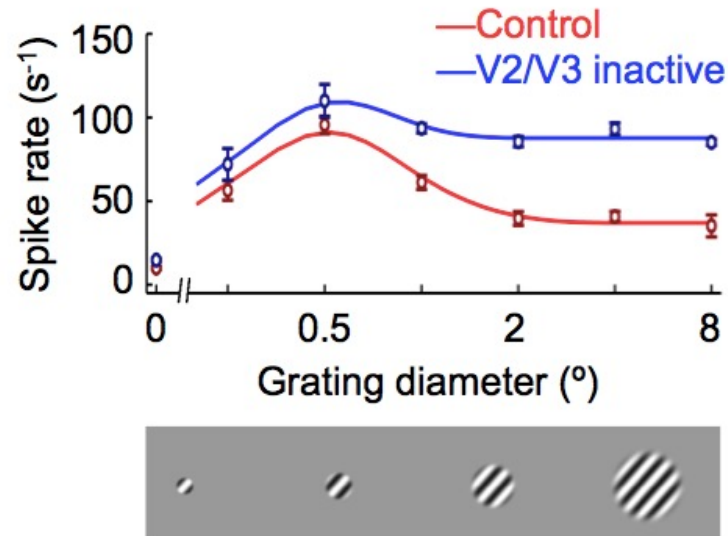
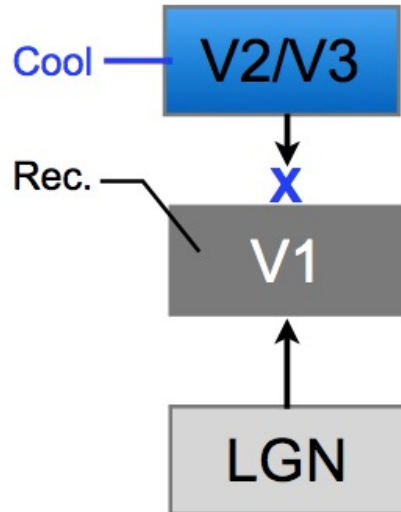
There are more top-down connections than bottom-up ones



Markov et al.

Cerebral Cortex 2014

Inactivating feedback to V1 leads to less surround suppression



Cited works

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- Yacoub, E., Harel, N., & Uğurbil, K. (2008). High-field fMRI unveils orientation columns in humans. *Proceedings of the National Academy of Sciences*, 105(30), 10607-10612.