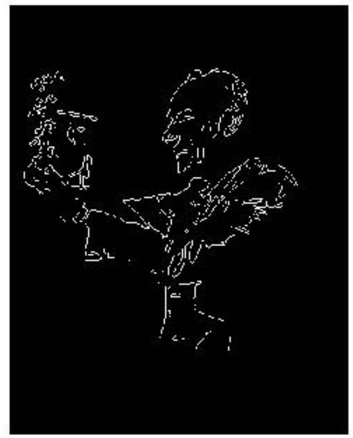
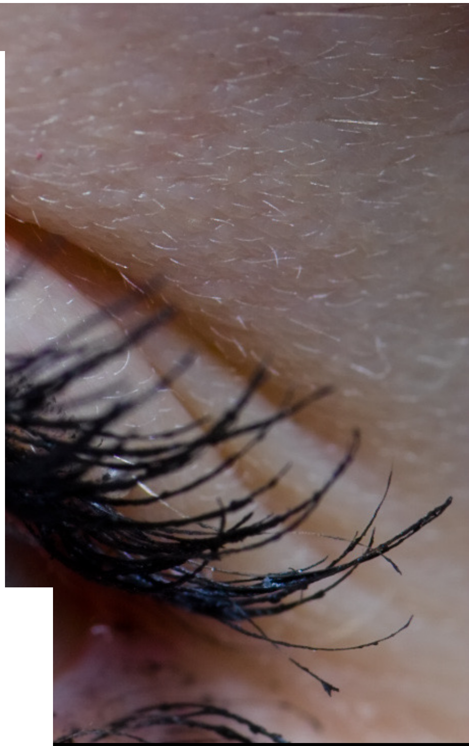
# Visual Object Recognition
# Computational Models and Neurophysiological Mechanisms
Neuro 130/230. Harvard College/GSAS 78454

**Who are these two people?**





# Visual Object Recognition
# Computational Models and Neurophysiological Mechanisms
## Neurobiology 130/230. Harvard College/GSAS 78454

Note: no class on 09/04/2023 (Labor Day)

Class 1 [09/11/2023]. Introduction to Vision

Class 2 [09/18/2023]. The Phenomenology of Vision

Class 3 [09/25/2023]. Natural image statistics and the retina

Class 4 [10/02/2023]. Learning from Lesions

Note: no class on 10/09/2023 (Indigenous Day)

**Class 5 [10/16/2023]. Primary Visual Cortex**

Class 6 [10/23/2023]. Adventures into *terra incognita*

Class 7 [10/30/2023]. From the Highest Echelons of Visual Processing to Cognition

Class 8 [11/06/2023]. First Steps into in silico vision

Class 9 [11/13/2023]. Teaching Computers how to see

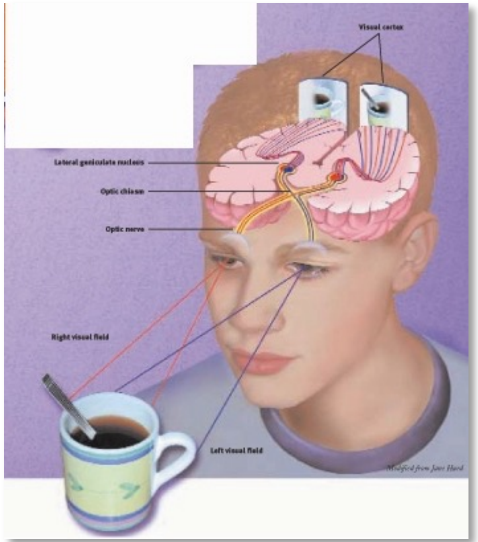
Class 10 [11/20/2023]. Computer Vision

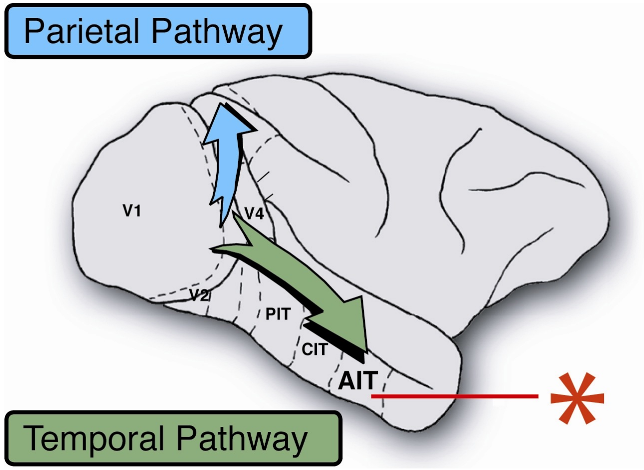
Class 11 [11/27/2023]. Connecting Vision to the rest of Cognition [Dr. Will Xiao]

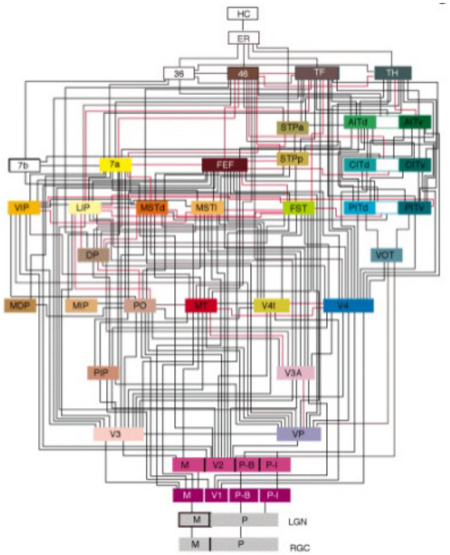
Class 12 [12/06/2023]. Visual Consciousness

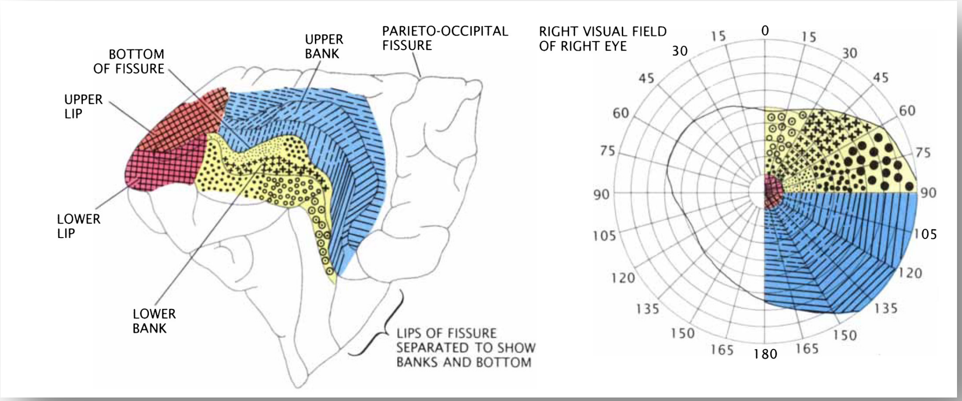
**FINAL EXAM, PAPER DUE 12/11/2023. No extensions.**

# Quick recap

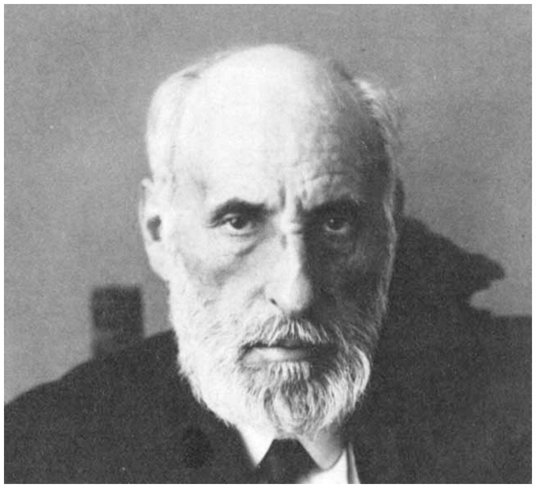

Visual cortex
Lateral geniculate nucleus
Optic chiasm
Optic nerve
Right visual field
Left visual field


Parietal Pathway
V1
V4
V2
PIT
CIT
AIT
Temporal Pathway

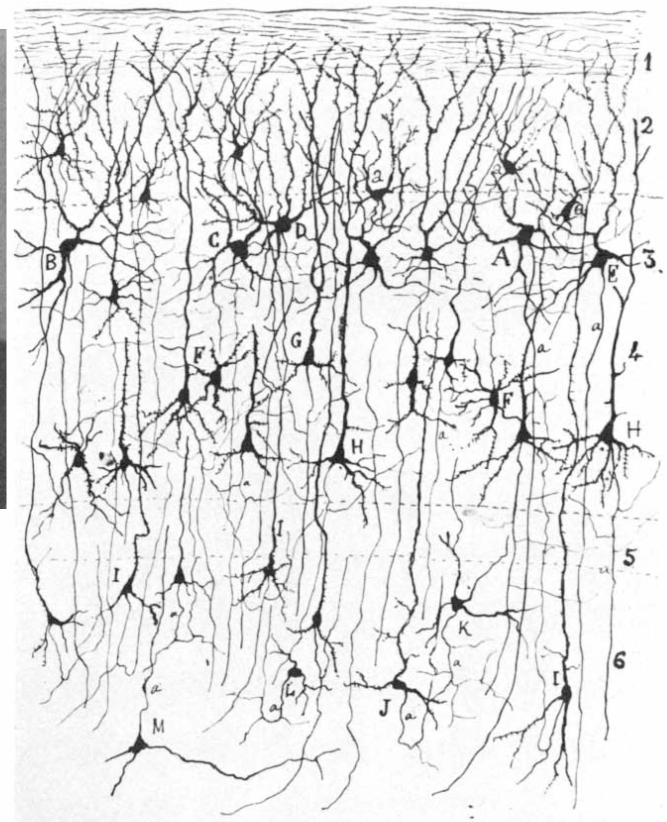



BOTTOM OF FISSURE
UPPER LIP
UPPER BANK
PARIETO-OCCIPITAL FISSURE
LOWER LIP
LOWER BANK
LIPS OF FISSURE SEPARATED TO SHOW BANKS AND BOTTOM
RIGHT VISUAL FIELD OF RIGHT EYE

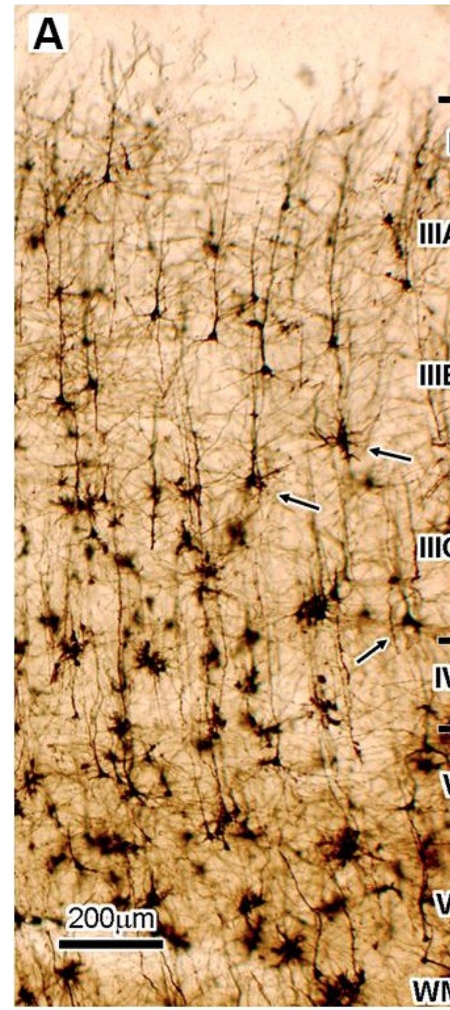
# The complex circuitry of cortex as drawn by Ramon y Cajal



Ramon y Cajal
[1852-1934]



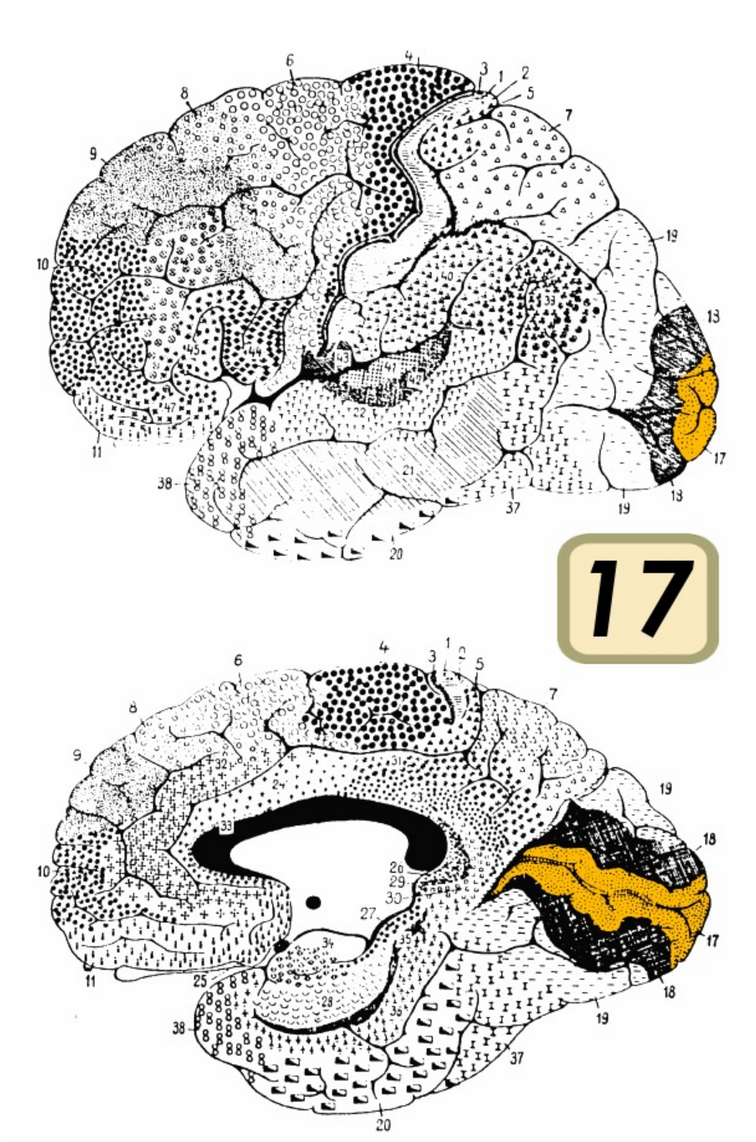

GOLGI-STAINED NERVE TISSUE from the visual cortex of a rat was sketched by Cajal in 1888. The numbers along the right-hand margin identify cellular layers; the capital letters label individual neurons. One of Cajal's most important contributions to neurobiology was to establish the neuron as a discrete,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



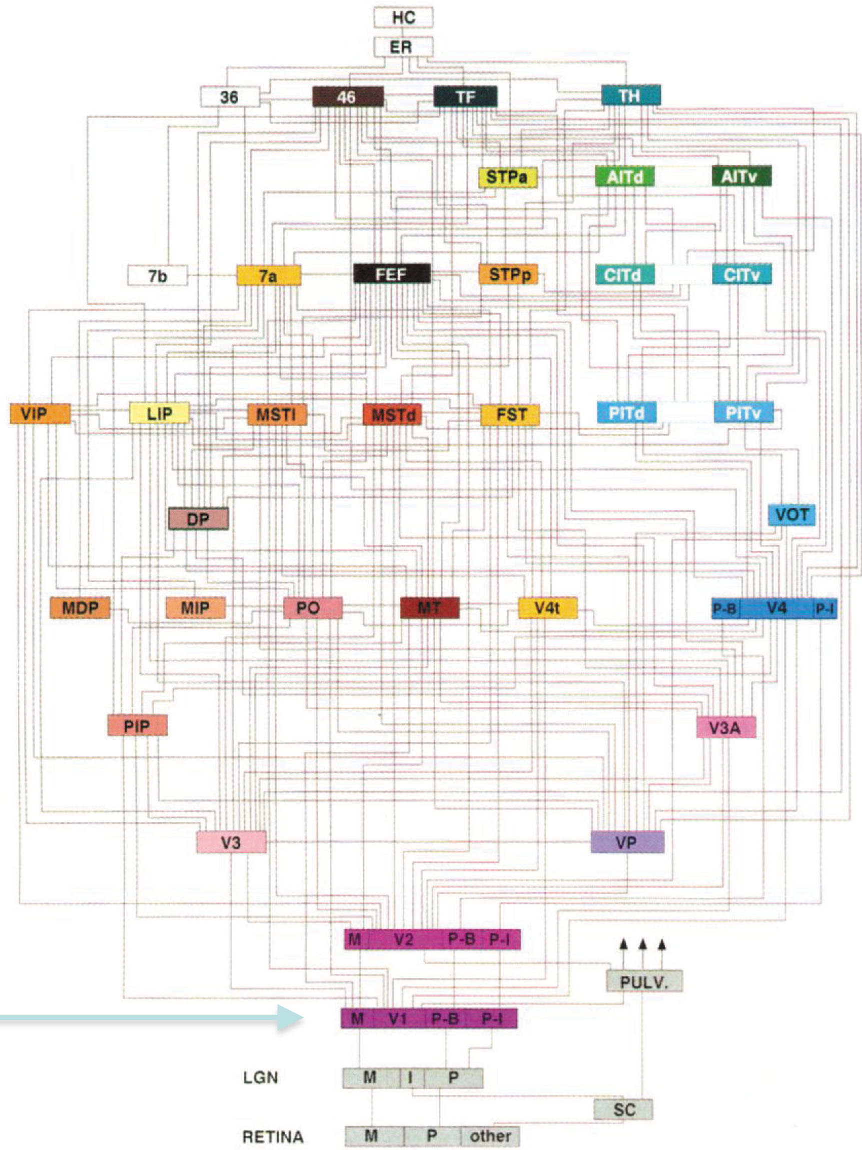

Dzaja et al, Frontiers in Neuroanatomy 2014

# 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)



# Visual system circuitry




You are here

Felleman and Van Essen. *Ce*

# How does a car work?

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

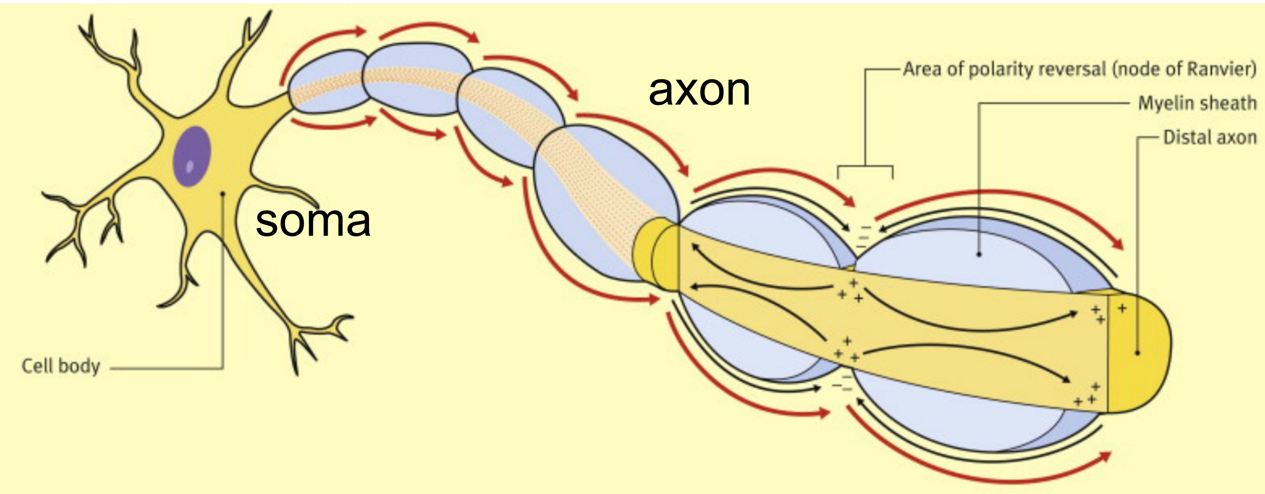
“Lesions”: no wheels, no steering wheel, no gas

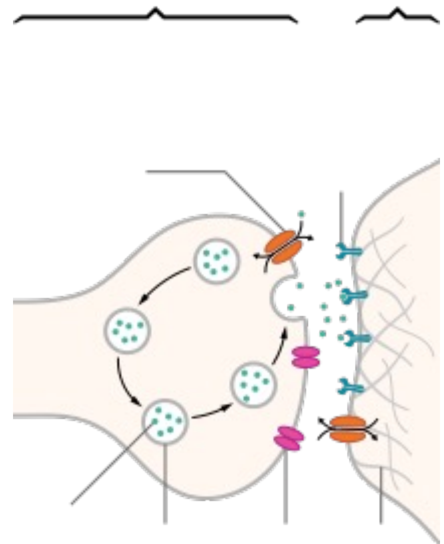
“fMRI”: measure average temperature over 5 minutes, and every 3 inches

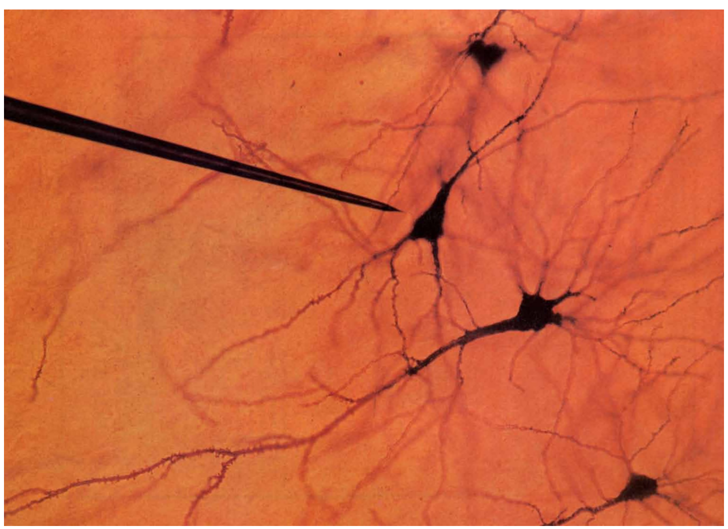
“EEG”: get frequency spectrum of sounds from the motor every second

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

# Basic Neuroscience

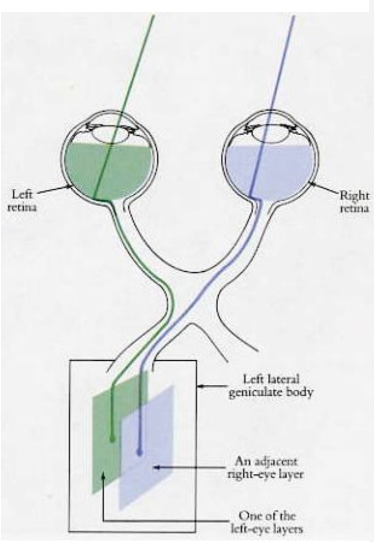


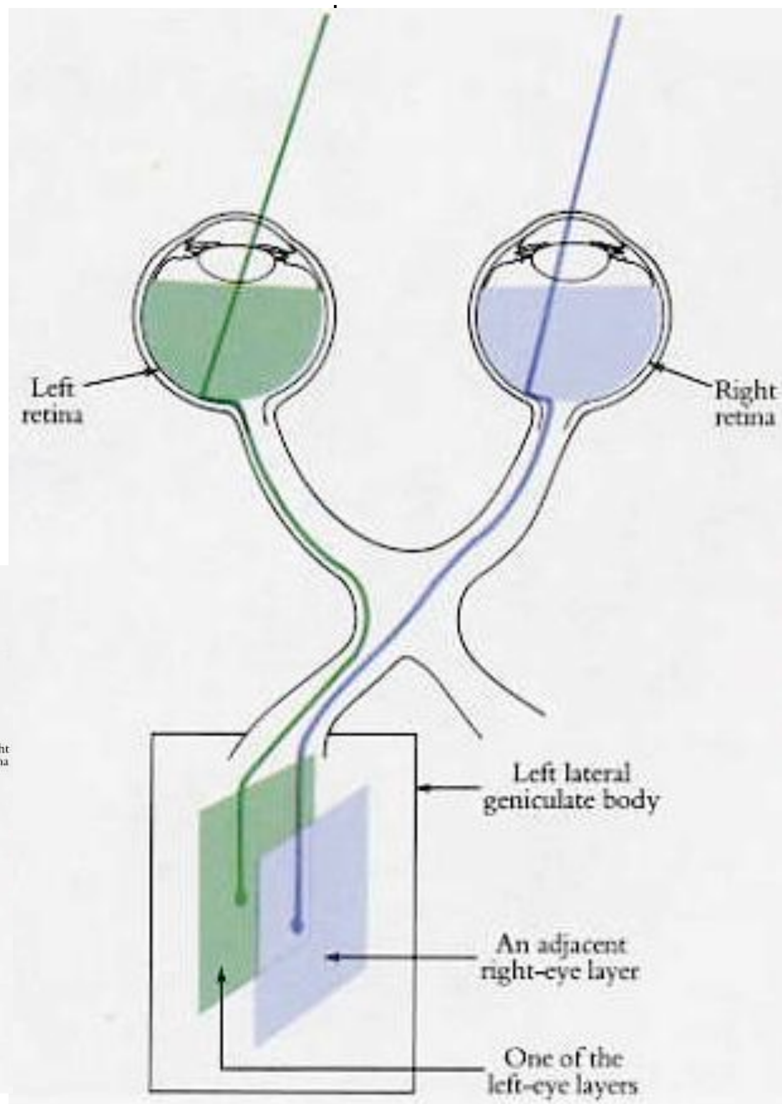



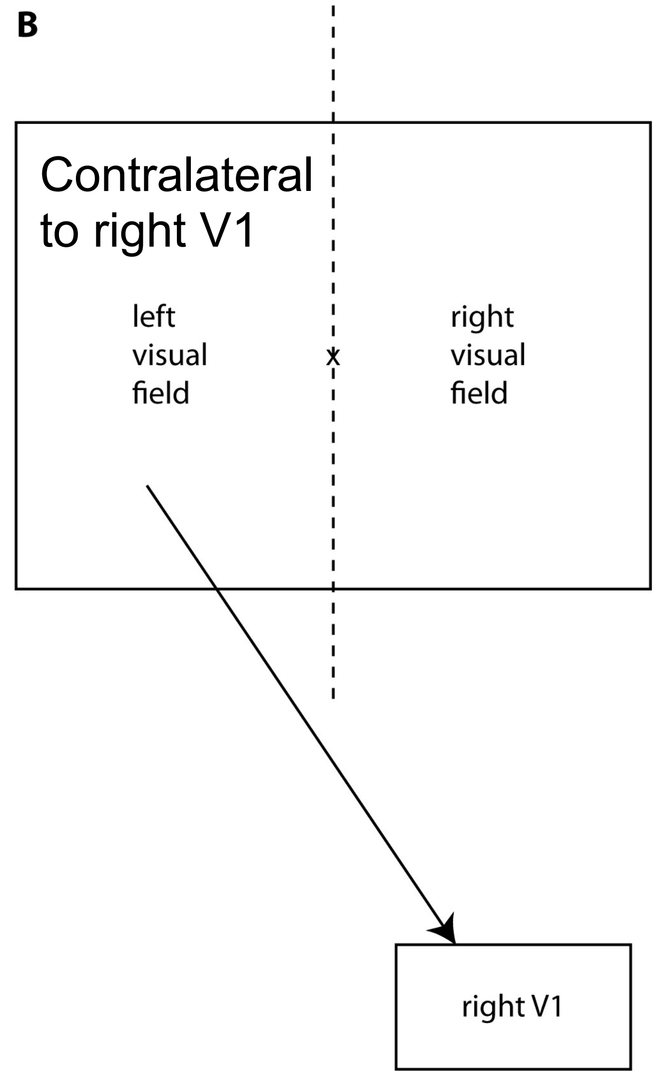



Voltage changes inside the neuron
Voltage changes in the extracelllular space

# V1 in each hemisphere represents the *contralateral* visual field



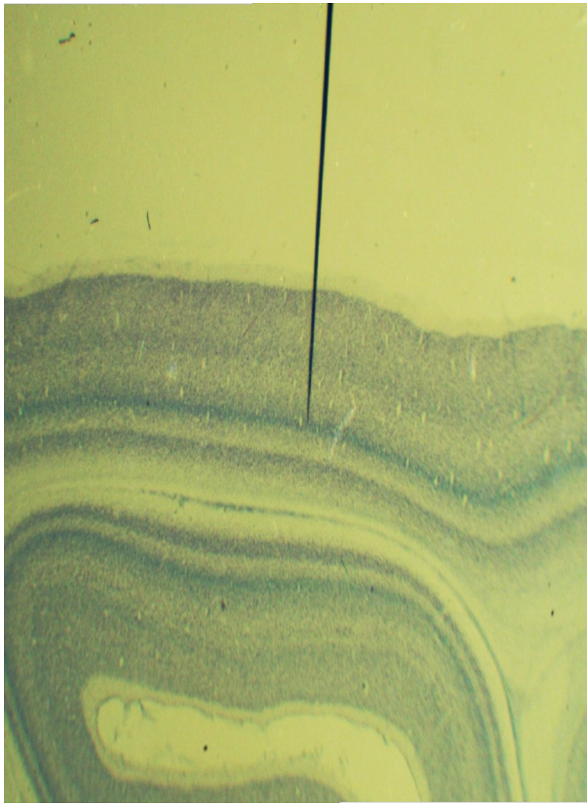



# The gold standard to examine neuronal activity: microelectrode recordings

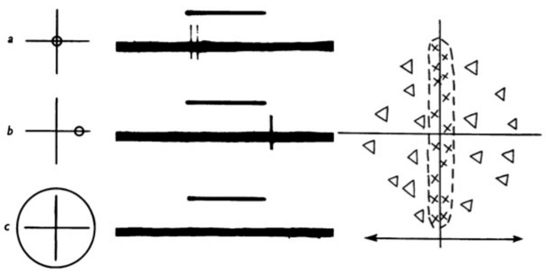
Edgar Adrian 1926

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

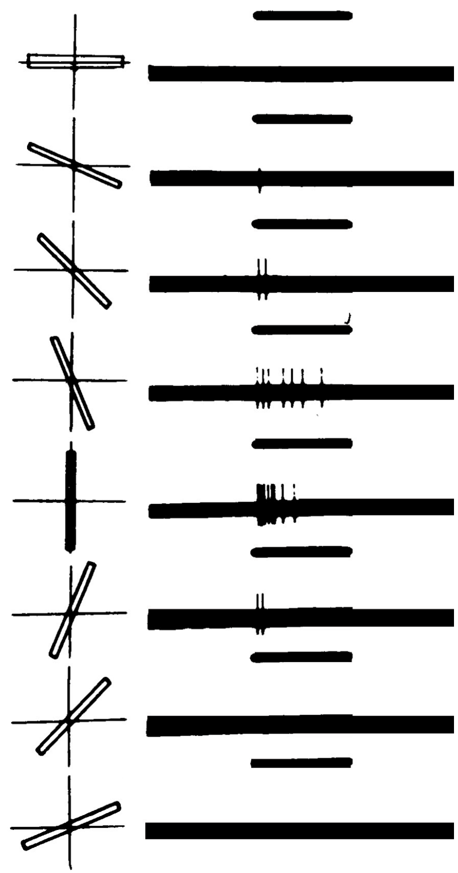
Hubel, D. (1979). The Visual Brain.
SCIENTIFIC AMERICAN 241, 45-53.

# Neurophysiological recordings from primary visual cortex



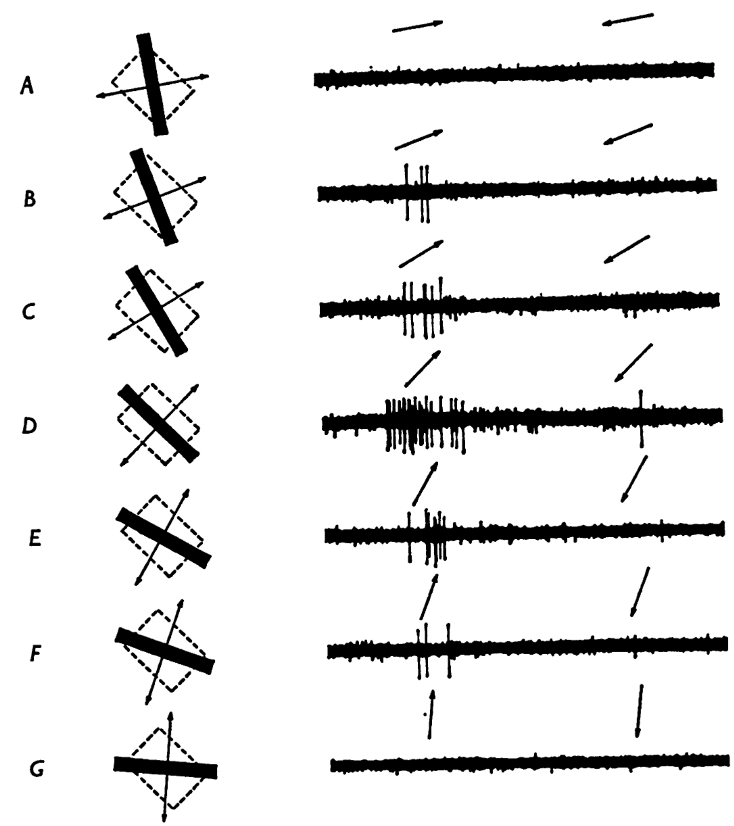
Hubel & Wiesel
J. Physiol. 1959

Orientation selectivity



Hubel – Nobel Lecture

Direction selectivity

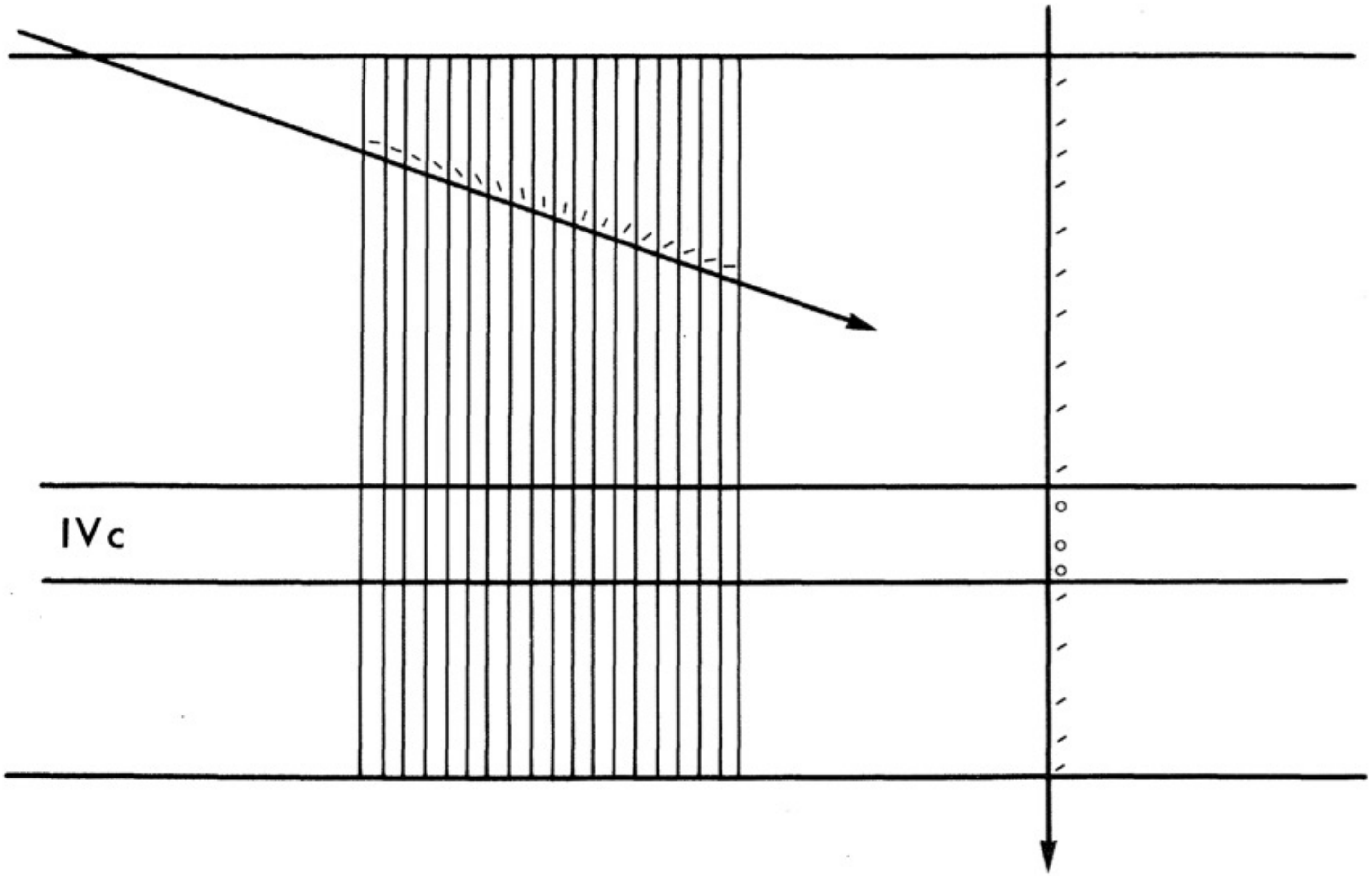



Hubel and Wiesel 1968

# Simple Cells Video (Hubel and Wiesel)

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

# Visual orientation columns

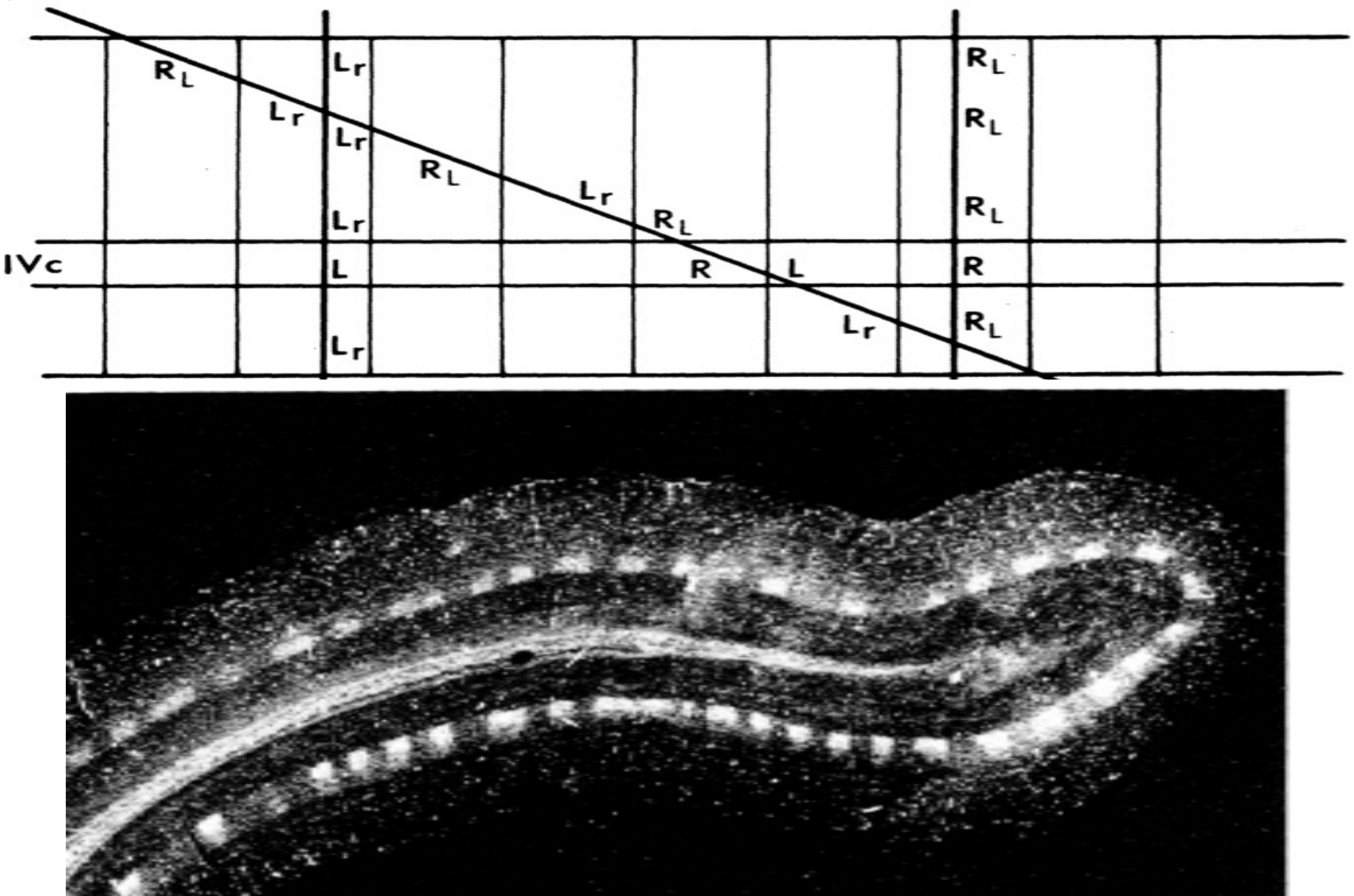



Hubel & Wiesel, Proc. R. Soc. Lond. B, 1977

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

# Ocular dominance columns

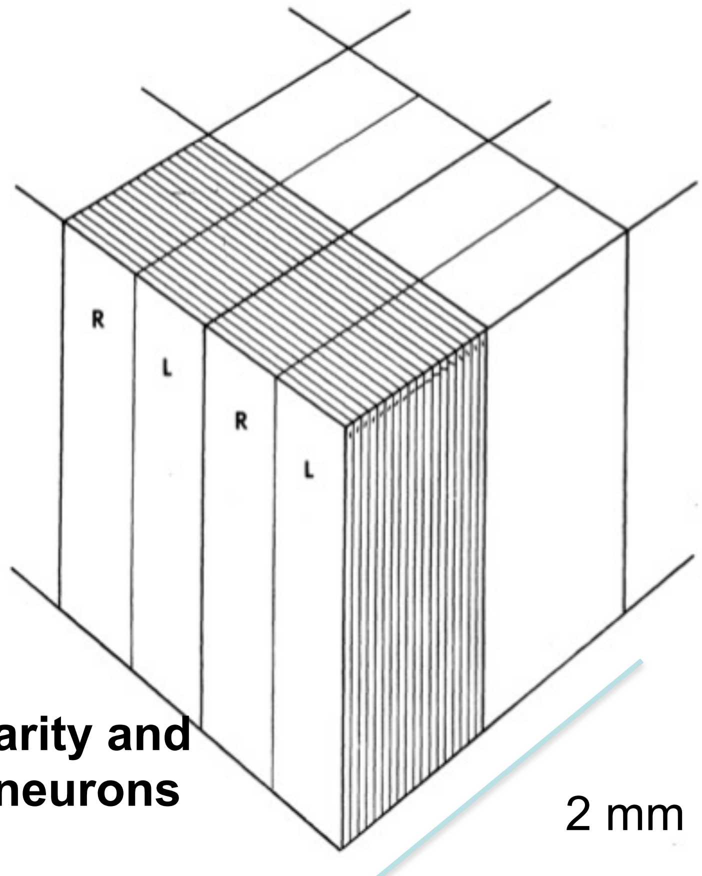
Hubel & Wiesel, Proc. R. Soc. Lond. B, 1977



# 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

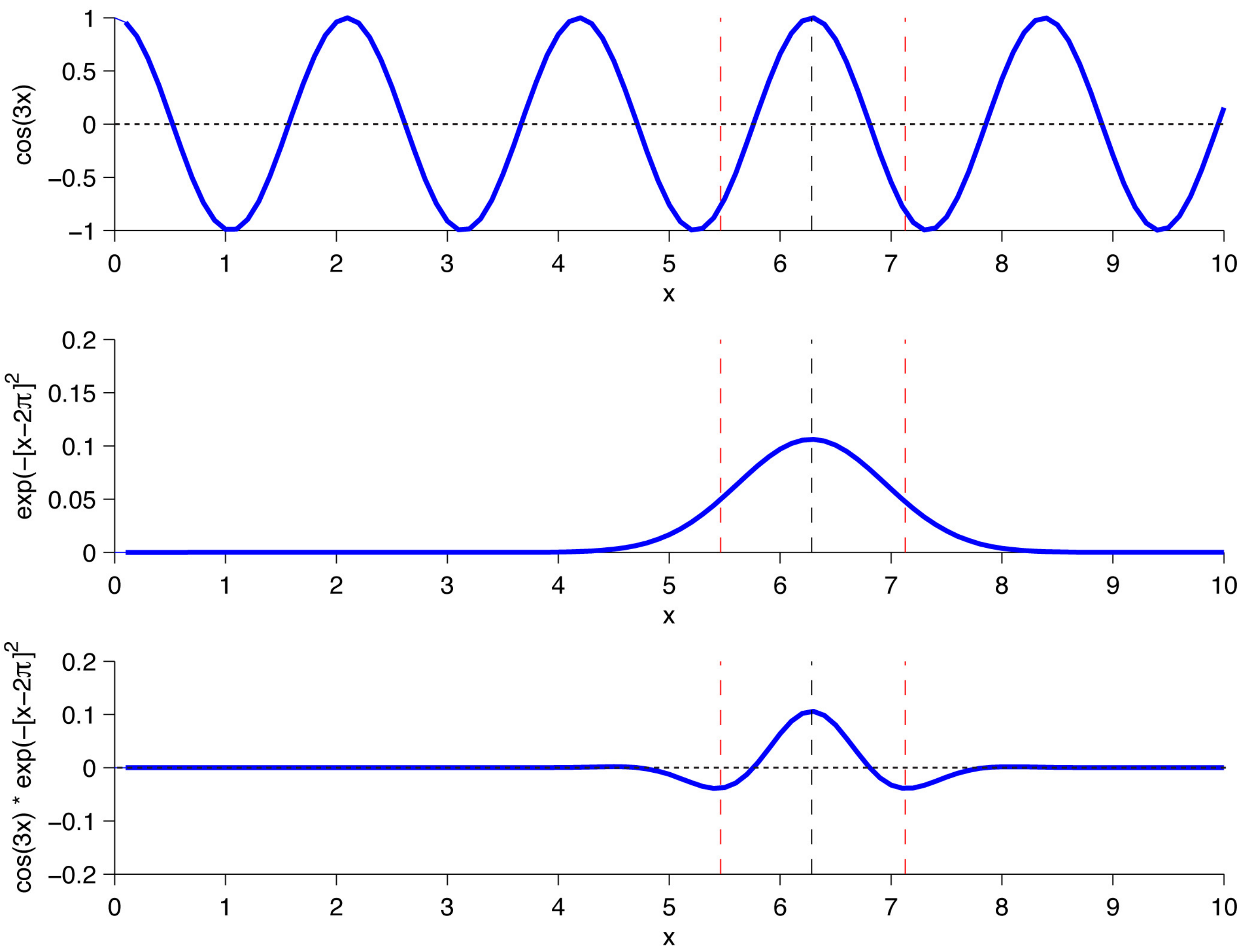
# Putting it all* together: the “hypercolumn”



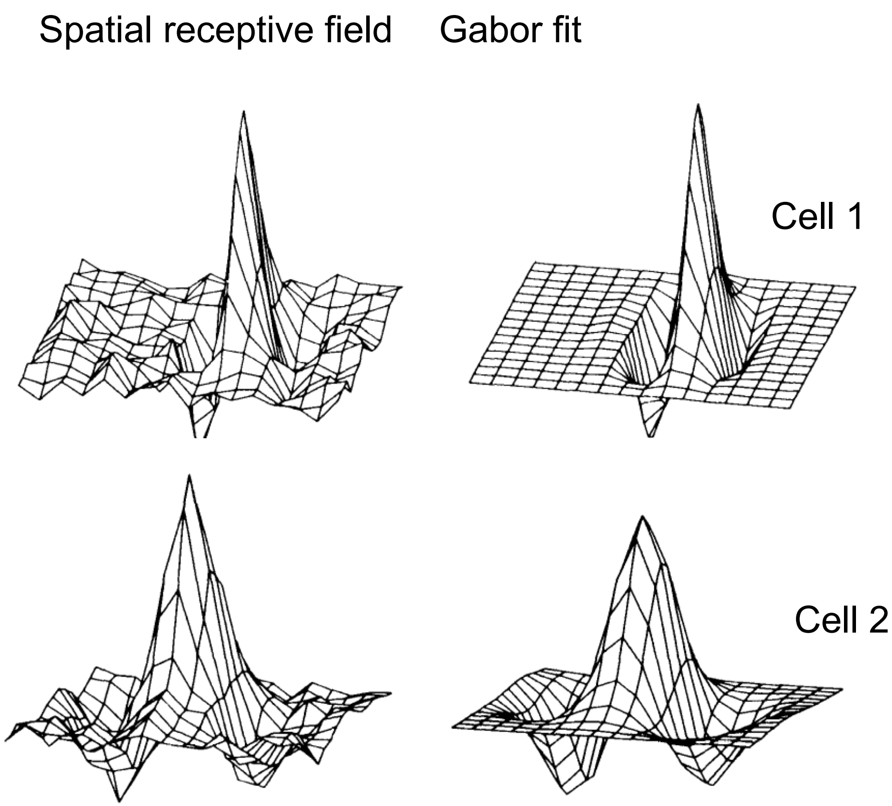

***all is more than ocularity and orientation. Many V1 neurons are also selective for:**
**- Direction & speed**
**- Depth**
**- Color**

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

# Interlude 1: Multiplying a cosyne and a Gaussian function



# Receptive fields for simple cells in V1

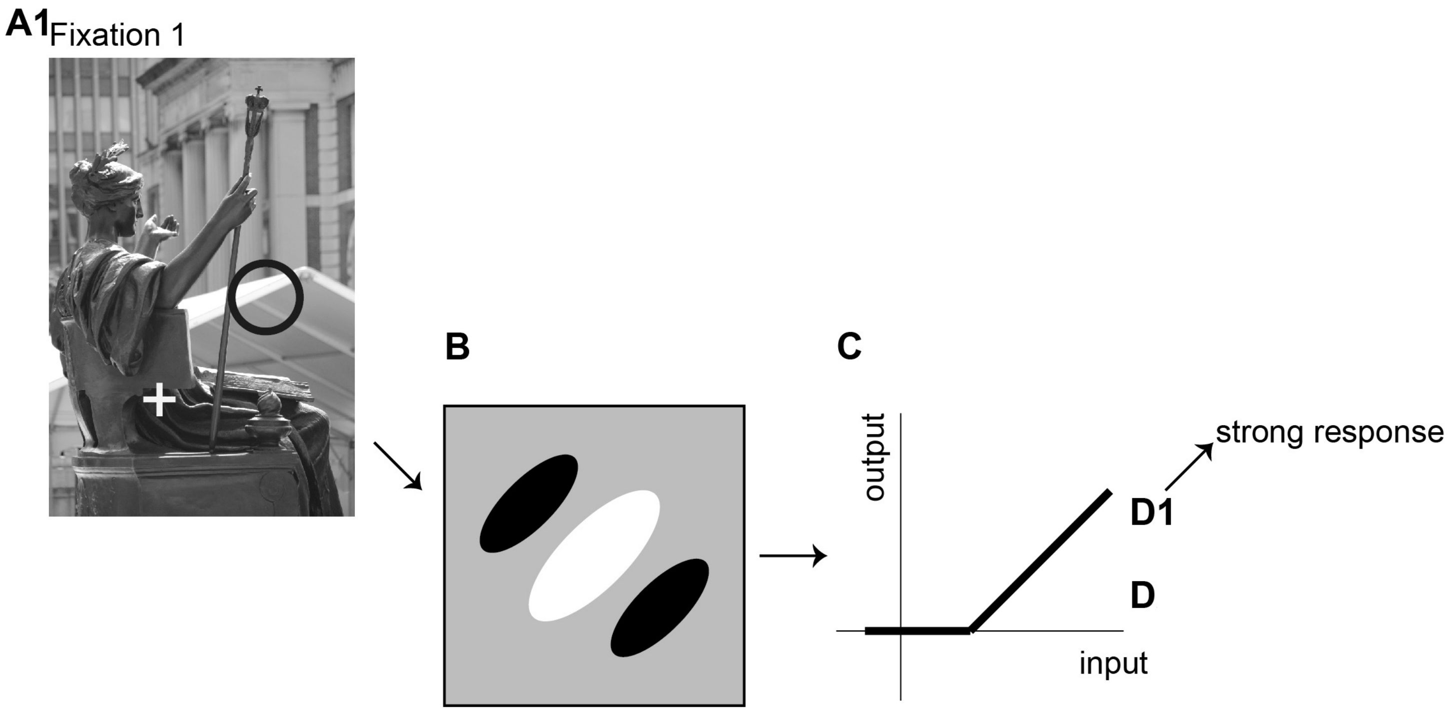



Gabor function

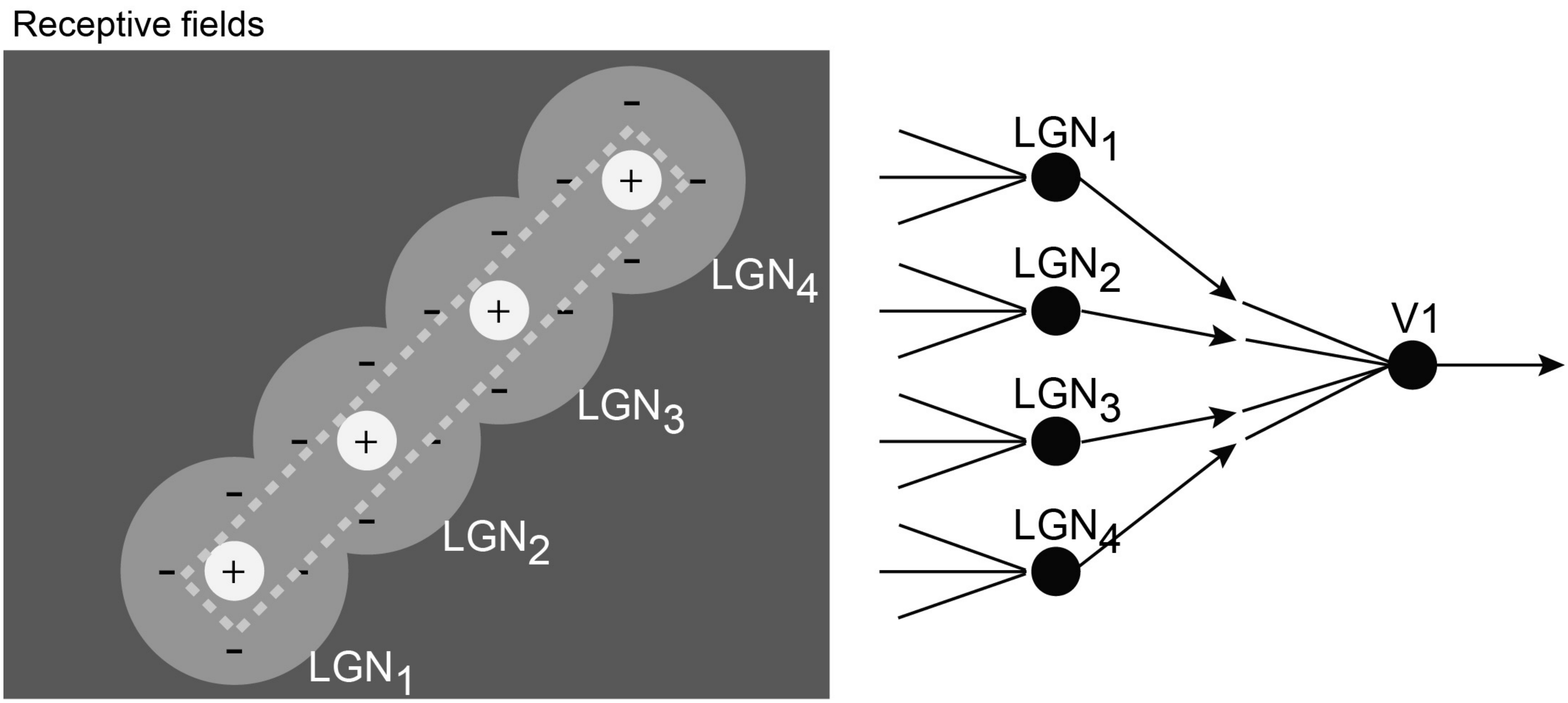
$$D(x,y) = \frac{1}{2\pi\sigma_x\sigma_y}\exp\left[-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right]\cos(kx-\phi)$$

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

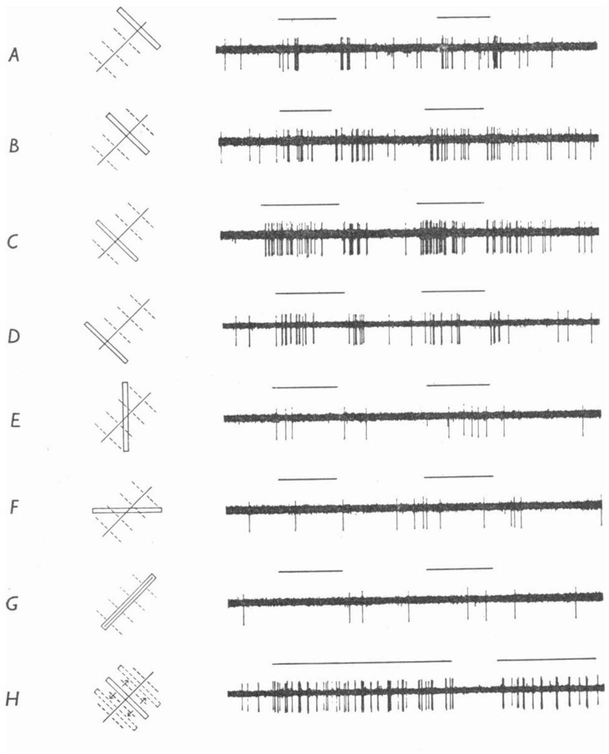
# Unit computations in deep convolutional network models



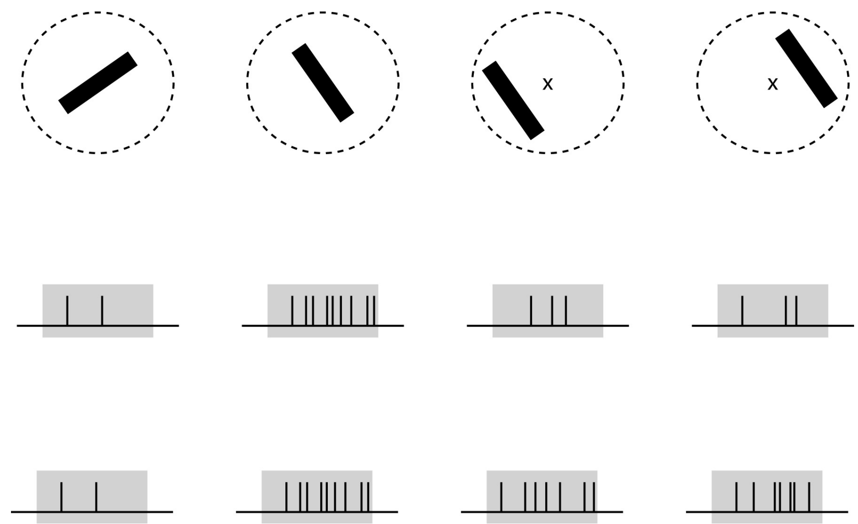
# A model for orientation tuning in simple cells



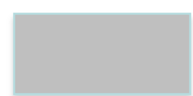
# Complex cells show position tolerance



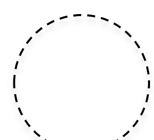

Text-fig. 4. Responses of a cell with a complex field to stimulation of the left (contralateral) eye with a slit $\frac{1}{8} \times 2\frac{1}{2}°$. Receptive field was in the area centralis and was about $2 \times 3°$ in size. *A–D*, $\frac{1}{8}°$ wide slit oriented parallel to receptive field axis. *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.




Stimulus: black bar



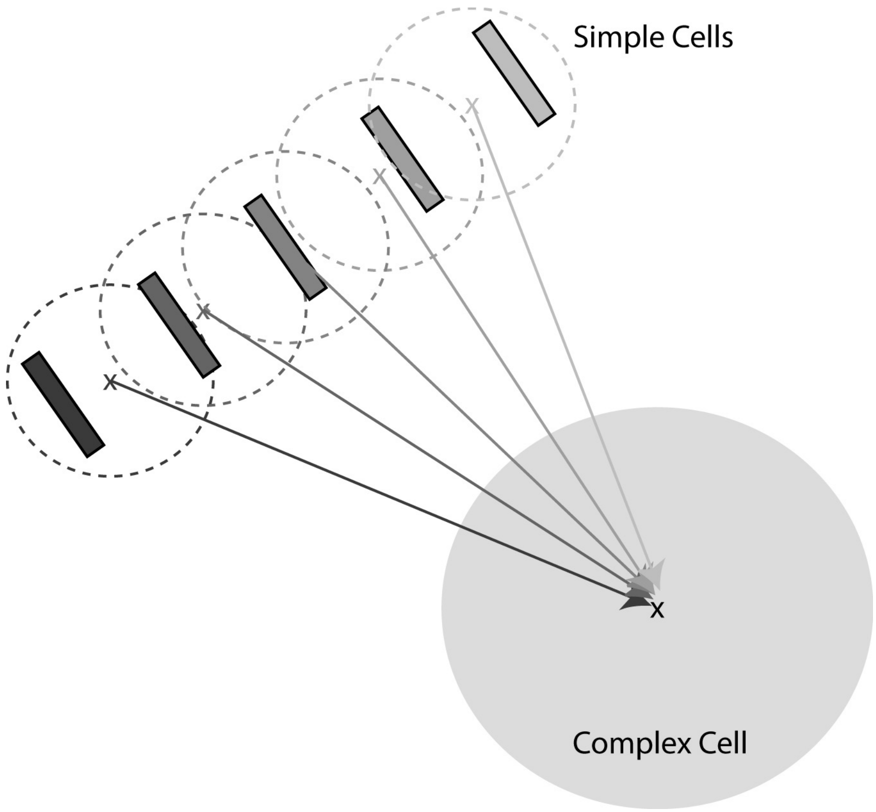
Stimulus presentation time



Receptive field

Hubel and Wiesel, J. Physiol. 1962

# A model to describe tolerance in complex cells

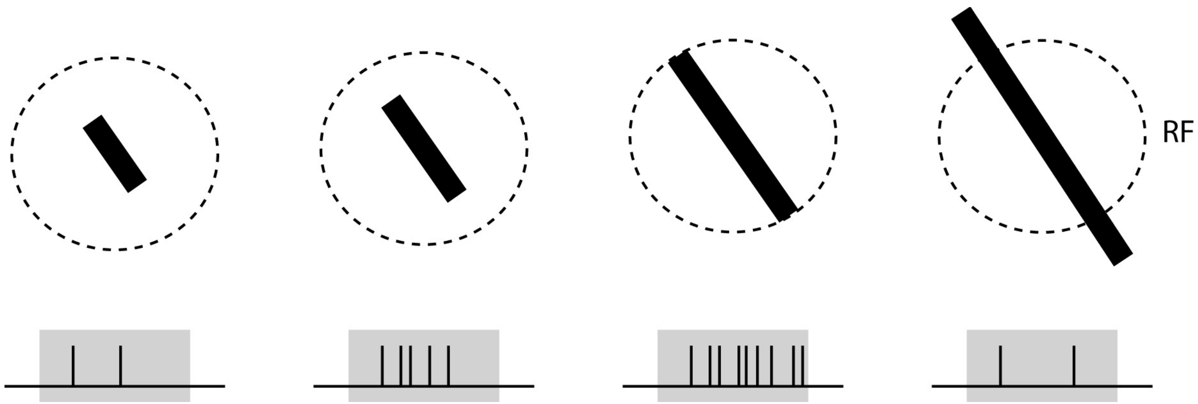



A feed-forward model describing the responses of complex cells arising from non-linear (e.g. OR) adding of inputs from multiple simple cells

(by no means the only model)

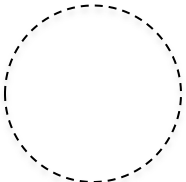
Wandell (1995), Foundations of Vision. Sinauer Books
Dayan and Abbott. (2001) Theoretical Neuroscience. The MIT Press

# End stopping



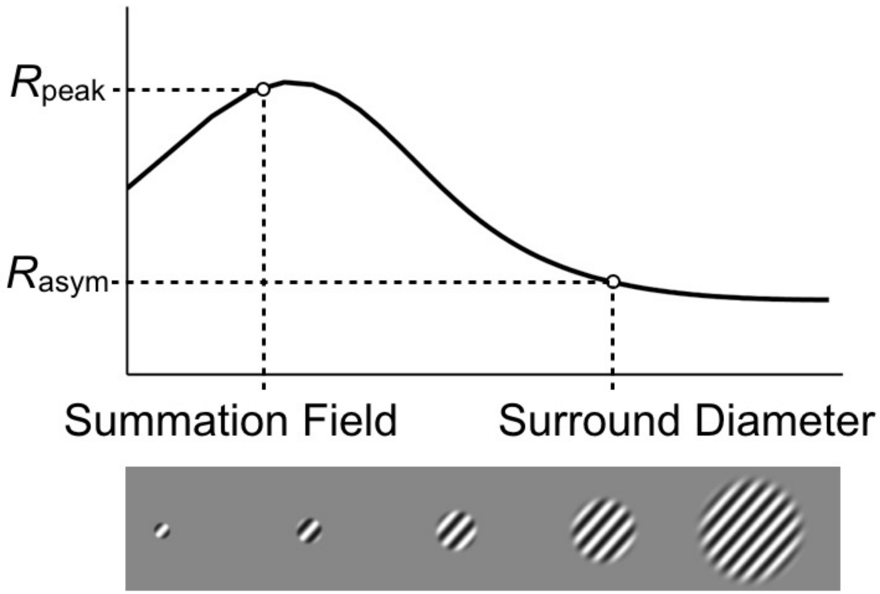

Stimulus: bar with preferred orientation

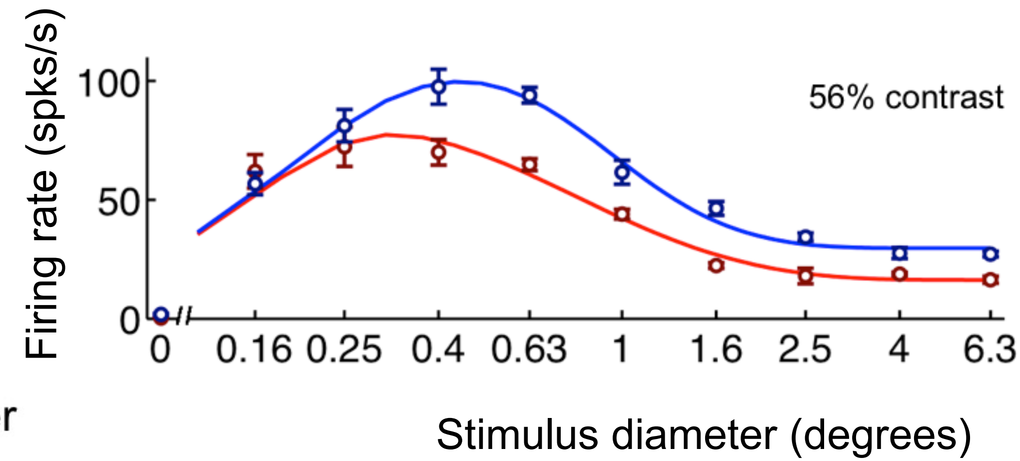
Stimulus presentation time



Receptive field

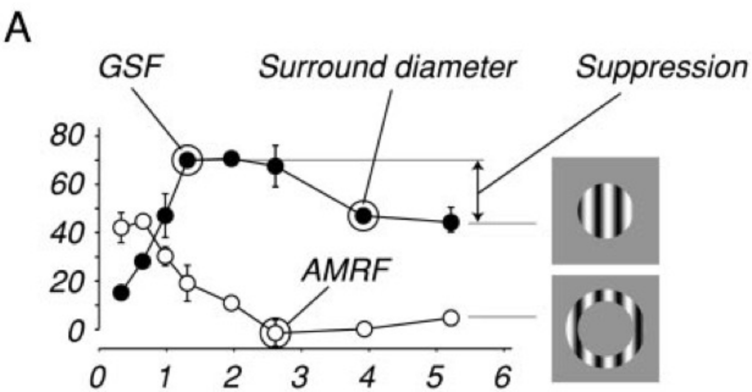
# More is not necessarily better: the surround can inhibit the responses of neurons in V1



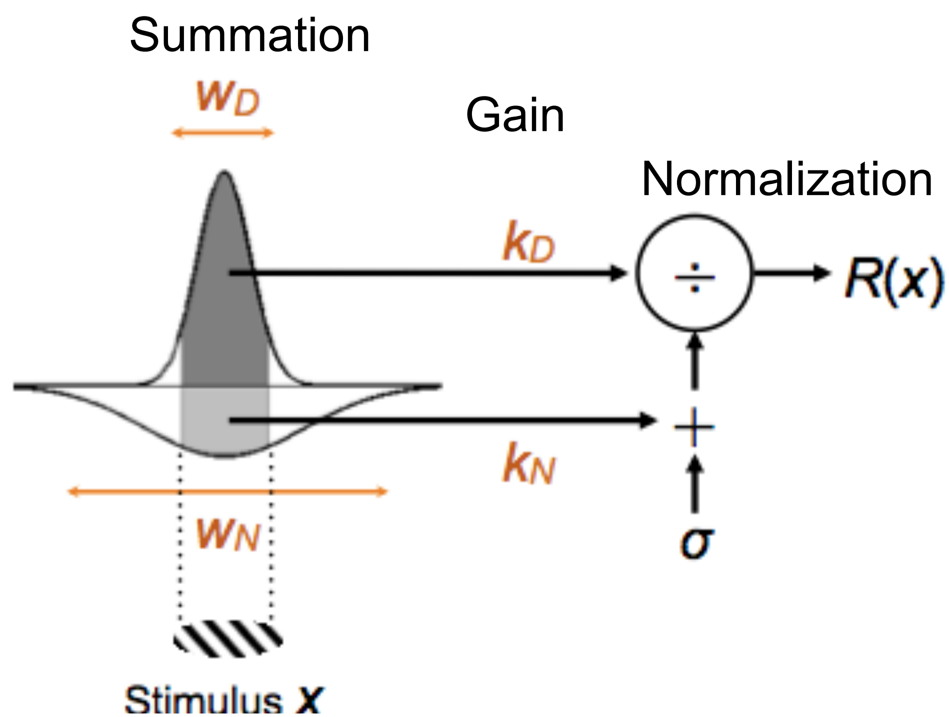




Nassi, Gomez-Laberge, Born

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



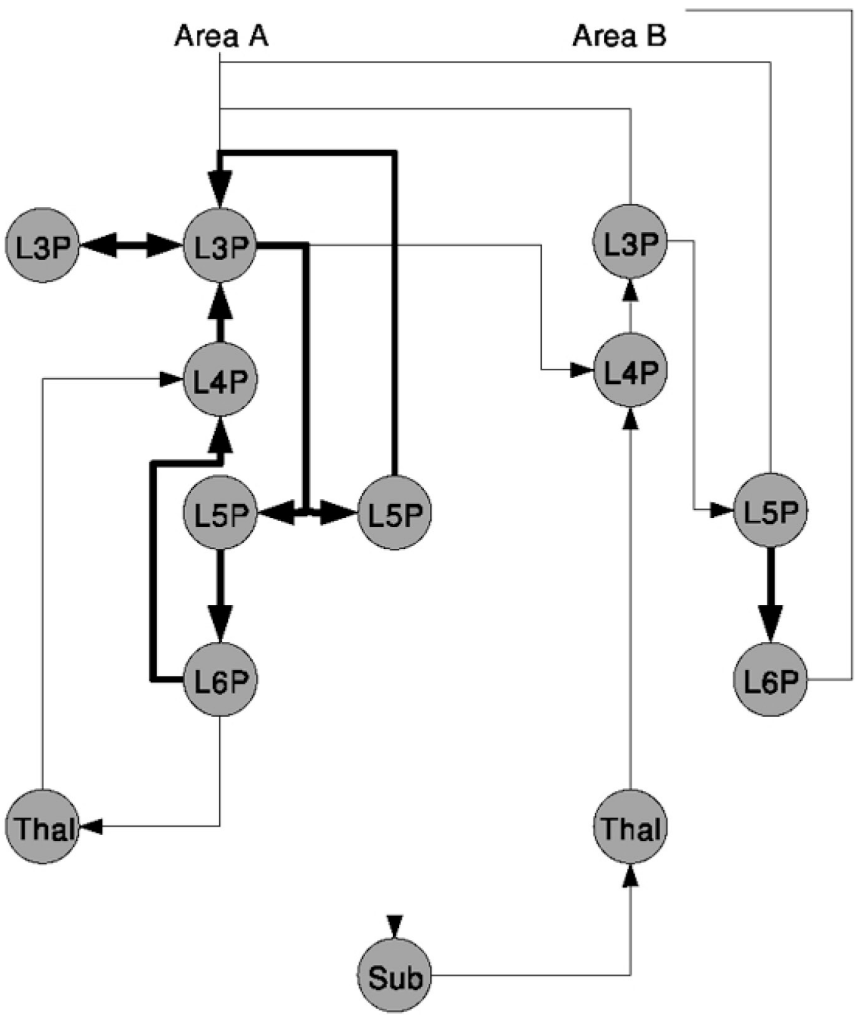

Cavanaugh et al J. Neurophys 2002




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

Nassi et al Front. Syst. Neurosci. 2014

# “Canonical” microcircuits in neocortex




Felleman and Van Essen 1991
Douglas and Martin 2004

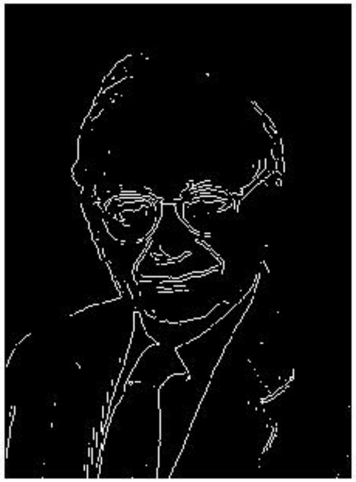
# Edges can take us a long way towards object recognition

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?

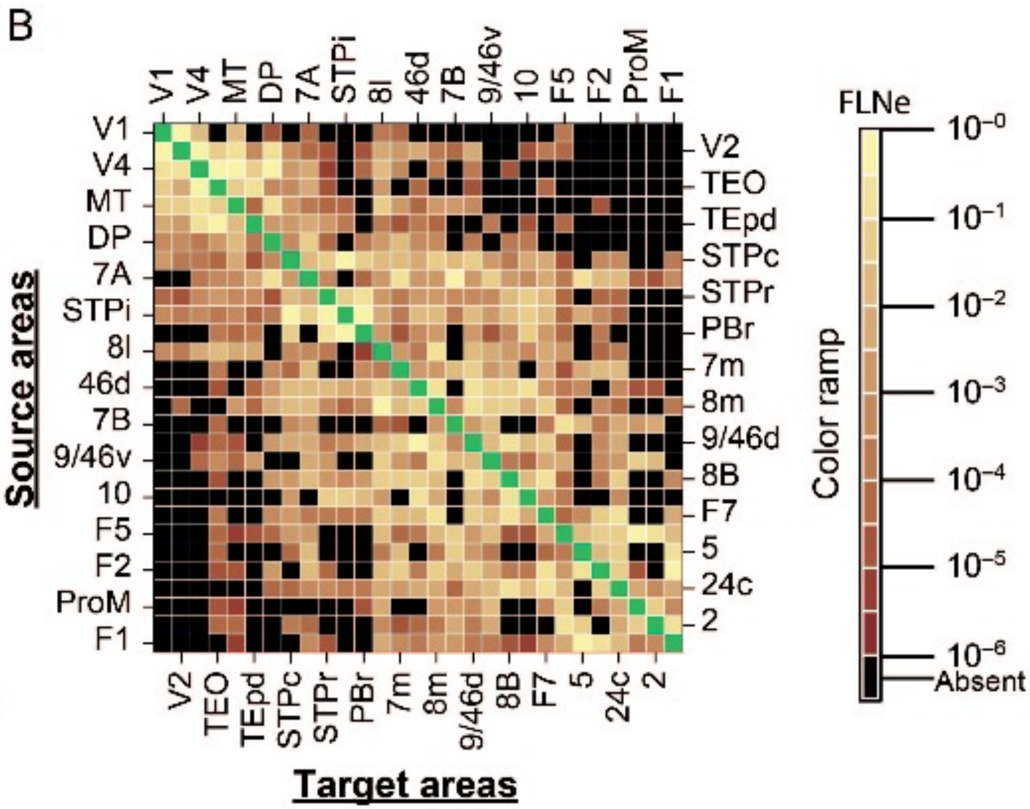
Up to 85% of “V1 function” has yet to be accounted for (Olshausen and Field 2005)

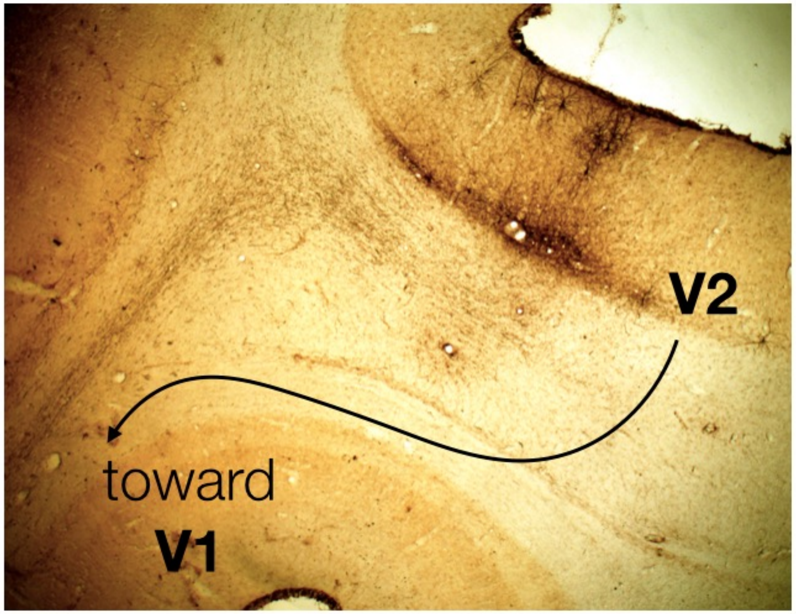
- Biased sampling of neurons
- Biased stimuli
- Biased theories
- Contextual effects
- Internal connections and feedback
- Joint activity

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

Carandini et al J. Neurosci. 2005

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

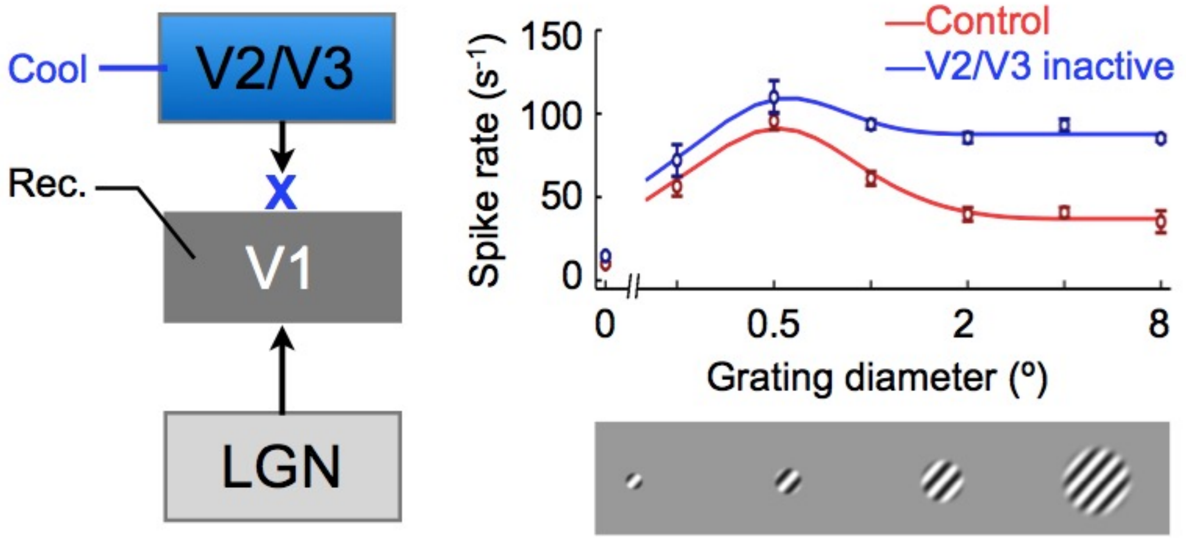



Markov et al.

Cerebral Cortex 2014

# Inactivating feedback to V1 leads to less surround suppression




Nassi et al Front. Syst. Neurosci. 2014

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