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

Quick recap
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

Felleman and Van Essen. Cε
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**

**soma**

**axon**

*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

Neurophysiological recordings from primary visual cortex

Hubel & Wiesel
J. Physiol. 1959

Orientation selectivity

Direction selectivity

Hubel – Nobel Lecture

Hubel and Wiesel 1968
Simple Cells Video (Hubel and Wiesel)

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

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

Interlude 1: Multiplying a cosine and a Gaussian function
Receptive fields for simple cells in V1

Spatial receptive field  Gabor fit

Gabor function

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

Cell 1

Cell 2

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 \( \frac{1}{2} \times 2\frac{1}{2} \)". Receptive field was in the area centralis and was about \( 2 \times 3 \)" in size. A–D, \( \frac{1}{2} \)" 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.

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)

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

Cavanaugh et al. J. Neurophys. 2002


\[ R_{\text{ROG}}(x) = R_0 + \frac{k_D \left[w_D \operatorname{erf}(x/2w_D)\right]^2}{\sigma + k_N \left[w_N \operatorname{erf}(x/2w_N)\right]^2} \]
“Canonical” microcircuits in neocortex

Felleman and Van Essen 1991
Douglas and Martin 2004
Edges can take us a long way towards object recognition

MATLAB:
\[
I: \text{image} \\
I_{\text{edges}} = \text{edge}(I);
\]

Different methods:
Sobel, Prewitt, Roberts, Laplacian of Gaussian, Canny
(determining how the gradients of I are computed)

1.9% of pixels > 0

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

- Olshausen, B. A., & Field, D. J. (2005). How close are we to understanding V1?. Neural computation, 17(8), 1665-1699.