IV. Neural Networks and Learning

B. Biological Neural Networks

A Very Brief Tour of Real Neurons

(and Real Brains)
Part 4B: Real Neurons

The Lobes of the Cerebral Hemispheres

- Precentral gyrus
- Central fissure
- Postcentral gyrus
- Superior temporal gyrus
- Lateral fissure

Left Hemisphere

(fig. from internet)
Part 4B: Real Neurons

Typical Neuron

Overview of Brain to Neurons

<http://www.youtube.com/watch?v=DF04XPBj5uc>

(Play flash video)
Animation of Neuron

- An animated film about nicotine addiction
- A good visualization of a single neuron
- ©2006, Hurd Studios
- Winner of NSF/AAAS Visualization Challenge
- [View flash video](#)

Grey Matter vs. White Matter

(fig. from Carter 1998)
Neural Density in Cortex

- 148 000 neurons / sq. mm
- Hence, about 15 million / sq. cm

Cortical Areas

- human
  - (2200 sq. cm)
- ape
- cat or monkey
- rat
Intercortical Connections

- (1) Short arcuate bundles,
- (2) Superior longitudinal fasciculus,
- (3) External capsule,
- (4) Inferior occipitofrontal fasciculus,
- (5) Uncinate fasciculus,
- (6) Sagittal stratum,
- (7) Inferior longitudinal fasciculus

Intercortical Connections
(diffusion spectrum imaging)

Neural Representations

Brodmann’s Areas
Macaque Visual System

(fig. from Clark, *Being There*, 1997)

Hierarchy of Macaque Visual Areas

(fig. from Van Essen & al. 1992)
Bat Auditory Cortex

Neurons
Dendritic Trees of Some Neurons

A. inferior olivary nucleus
B. granule cell of cerebellar cortex
C. small cell of reticular formation
D. small gelatinosa cell of spinal trigeminal nucleus
E. ovoid cell, nucleus of tractus solitarius
F. large cell of reticular formation
G. spindle-shaped cell, substantia gelatinosa of spinal chord
H. large cell of spinal trigeminal nucleus
I. putamen of lenticular nucleus
J. double pyramidal cell, Ammon’s horn of hippocampal cortex
K. thalamic nucleus
L. globus pallidus of lenticular nucleus

(fig. from Trues & Carpenter, 1964)
Axonal Terminations
(Tectum of Turtle)

Axonal Net

(fig. from Sereno & Ulinski 1987)

(fig. from Arbib 1995)
Minicolumn

- Up to \(~100\) neurons
  - 75–80\% pyramidal
  - 20–25\% interneurons
- 20–50\,\mu m diameter
- Length: 0.8 (mouse) to 3 mm (human)
- \(~6\times10^5\) synapses
- 75–90\% synapses outside minicolumn
- Interacts with \(1.2\times10^5\) other minicolumns
- Mutually excitable
- Also called microcolumn
Layers and Minicolumns

- ~70 inhibitorally-coupled minicolumns in humans
- 70% of minicol. connections are within macrocol.
- Basket neurons provide shunting inhibition between minicolumns
- Winner-takes-all networks
- Represent microfeatures

Macrocolumns
Intracortical Connections

- Dendrites extend 2–4 minicol. diameters
- Axons extend $5 \times$ (or even $30–40 \times$) minicol. diameter
- Periodic spacing of axon terminal clusters causes entrainment
- $\sim 2 \times 10^7$ connections to macrocolumn
Neural Networks in Visual System of Frog

Reorganization of Cortex

- Median nerve sectioned to show fluidity of cortical organization
- (C) before
- (D) immediately after
- (E) several months later

(fig. from Arbib 1995, p. 1039)

(fig. < McClelland & al, Par. Distr. Proc. II)
Orientation Columns

(fig. < Nicholls & al., *Neur. to Brain*)

Orientation Columns

(fig. < Nicholls & al., *Neur. to Brain*)
Cell Responses in V4

(fig. < Clark, *Being There*, 1997)

Slow Potential Neuron

Frequency Coding

Variations in Spiking Behavior
Synapses

video by Hybrid Medical Animation

Chemical Synapse

1. Action potential arrives at synapse
2. Ca ions enter cell
3. Vesicles move to membrane, release neurotransmitter
4. Transmitter crosses cleft, causes postsynaptic voltage change

(fig. from Anderson, Intr. Neur. Nets)
Typical Receptor

Axon Hillock

(fig. from Anderson, *Intr. Neur. Nets*)

(fig. from Peters, Palay & Webster)
Part 4B: Real Neurons

Dendrite & Dendritic Branches
(fig. from Peters, Palay & Webster)

Dendrite & Dendritic Spine
(fig. from Peters, Palay & Webster)
Neuropil

Myelinated Axon Making Synapse on Dendrite
Various Synapses

Excitatory Synapse Between Axon Terminal and Dendritic Thorn
Dendro-dendritic Synapses

Type I (asymmetric)

Type II (symmetric)

Electrotonic Synapse

(fig. from Peters, Palay & Webster)
Nonsynaptic Communication ("twitching neurons")

- When neurons fire, the axons swell slightly
- This opens channels, releasing neurotransmitters (e.g., ATP)
- A form of nonsynaptic communication between neurons and glia
- May control formation of myelin and other processes
Neuronal Group Selection
(“Neural Darwinism”)

- Theory developed in ’70s and ‘80s by Gerald Edelman (Nobel Prize, 1972)
- Diversity
  - of neural responses to stimuli
  - disjunctive representations of categories
- Competitive Amplification
  - winner-take-all adaptation to stimuli
- Reentry
  - spatiotemporal continuity and coherence

Read Flake, ch. 20