IV. Neural Network Learning
A Very Brief Tour of Real Neurons

(and Real Brains)
The Lobes of the Cerebral Hemispheres

- Longitudinal fissure
- Precentral gyrus
- Central fissure
- Postcentral gyrus
- Parietal lobe
- Temporal lobe
- Occipital lobe

(fig. from internet)
Left Hemisphere
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 (figs. from Suga, 1985)
Neurons
Typical Neuron
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 Arbib 1995)
Neural Connections

(array tomography by O’Shea at SmithLab, Stanford)
Minicolumn

- Up to ~100 neurons
  - 75–80% pyramidal
  - 20–25% interneurons
- 20–50µ diameter
- Length: 0.8 (mouse) to 3mm (human)
- ~ 6×10⁵ synapses
- 75–90% synapses outside minicolumn
- Interacts with 1.2×10⁵ other minicolumns
- Mutually excitable
- Also called microcolumn
Layers and Minicolumns

(fig. from Arbib 1995, p. 270)
Macrocolumns

- ~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
Projection Macrocolumns 0.5-1.0mm wide

Interdigitating Columns in Anterior Cingulate Gyrus

Interleaving Input Columns in Superior Temporal Sulcus

(fig. from Arbib 1995, p. 270)
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

(fig. from Arbib 1995, p. 1039)
Reorganization of Cortex

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

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

(fig. < Nicholl & 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

(fig. from Anderson, Intr. Neur. Nets)
Variations in Spiking Behavior

[Diagram showing different types of neuronal structures and their corresponding spike patterns]
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

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

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

(fig. from Peters, Palay & Webster)
Neuropil

(fig. from Peters, Palay & Webster)
Myelinated Axon Making Synapse on Dendrite

(fig. from Peters, Palay & Webster)
Various Synapses

(fig. from Peters, Palay & Webster)
Excitatory Synapse Between Axon Terminal and Dendritic Thorn

(fig. from Peters, Palay & Webster)
Dendro-dendritic Synapses

Type I (asymmetric)

Type II (symmetric)

(fig. from Peters, Palay & Webster)
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
• See Fields & Ni, Science Signaling, 5 Oct. 2010
Release of ATP from Axons Firing Action Potentials

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