IV. Neural Networks and Learning

B. Biological Neural Networks

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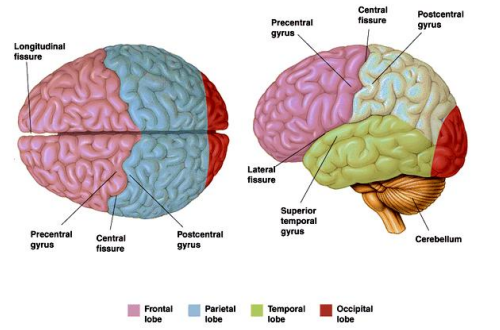
A Very Brief Tour of Real Neurons

(and Real Brains)

► The Lobes of the Cerebral Hemispheres



2013/3/11 (fig. from internet) 3

Left Hemisphere

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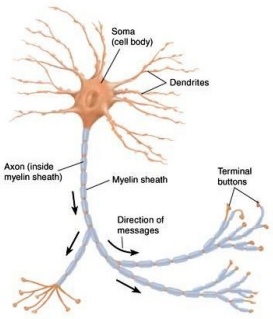
Typical Neuron



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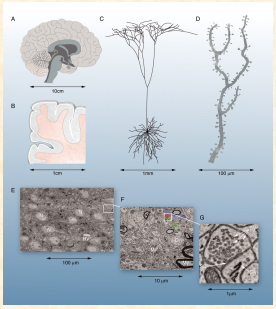
The brain is organized over sizes that span 6 orders of magnitude



J W Lichtman, W Denk Science 2011;334:618-623

Science AAAS

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Overview of Brain to Neurons

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

(play flash video)

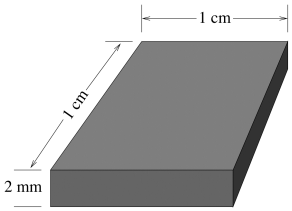
Animation of Neuron

- 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

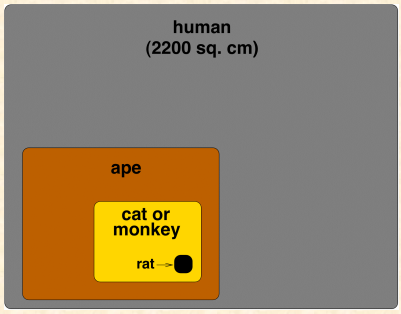
(fig. from Carter 1998)

Neural Density in Cortex

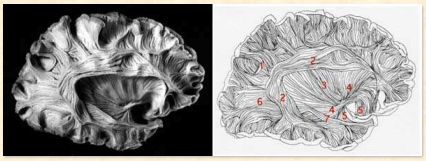


- 148 000 neurons / sq. mm
- Hence, about 15 million / sq. cm

Cortical Areas

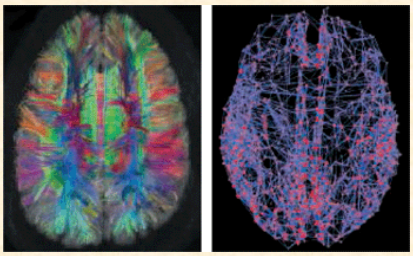


Intercortical Connections



- (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)



G. Miller Science 330, 164 (2010) (2010)

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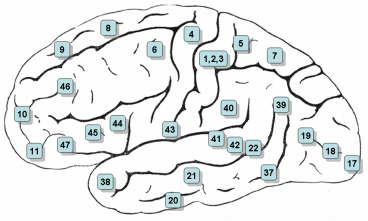
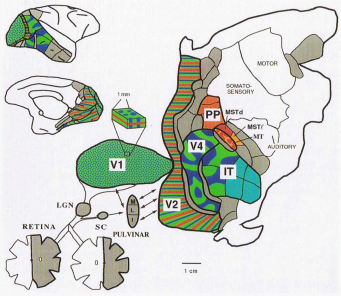
Neural Representations

Brodmann's Areas

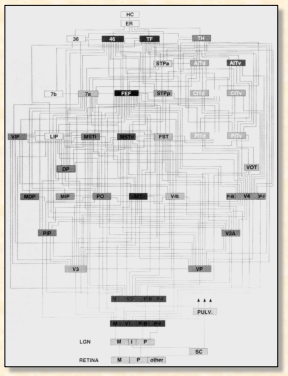


Macaque Visual System



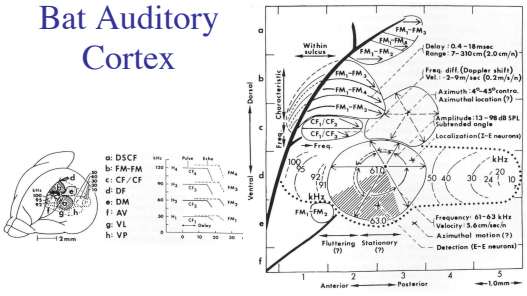
(fig. from Clark, *Being There*, 1997)

Hierarchy of Macaque Visual Areas



(fig. from Van Essen & al. 1992)

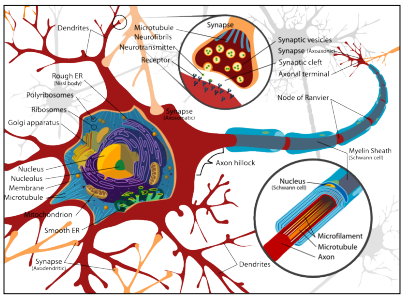
Bat Auditory Cortex



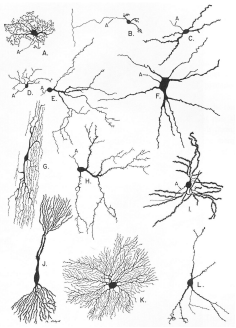
(figs. from Suga, 1985)

Neurons

Typical Neuron



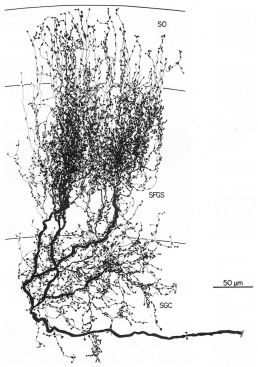
Dendritic Trees of Some Neurons



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

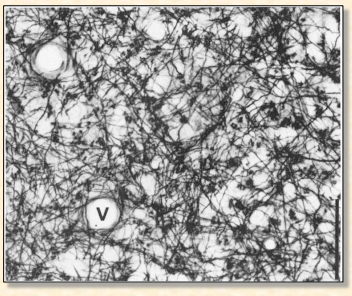
 (fig. from Trues & Carpenter, 1964)

Axonal Terminations (Tectum of Turtle)



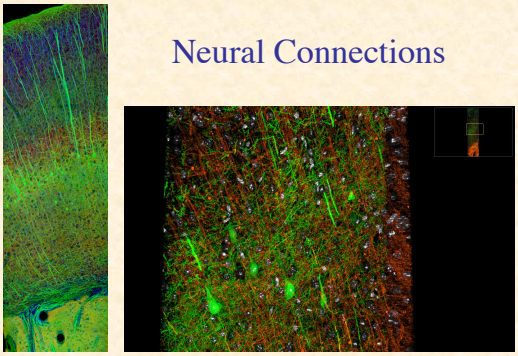
 (fig. from Sereno & Ulinski 1987)

Axonal Net



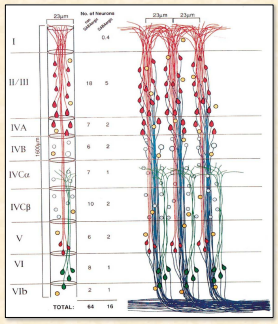
 (fig. from Arbib 1995)

Neural Connections



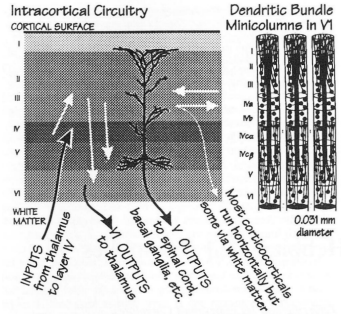
 (array tomography by O'Shea at SmithLab, Stanford)

Minicolumn



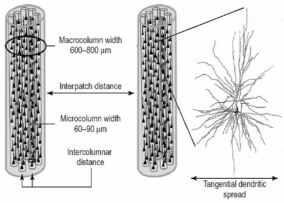
- Up to ~100 neurons
  - 75–80% pyramidal
  - 20–25% interneurons
- 20–50μ diameter
- Length: 0.8 (mouse) to 3mm (human)
- ~ 6×10^5 synapses
- 75–90% synapses outside minicolumn
- Interacts with 1.2×10^5 other minicolumns
- Mutually excitable
- Also called *microcolumn*

Layers and Minicolumns

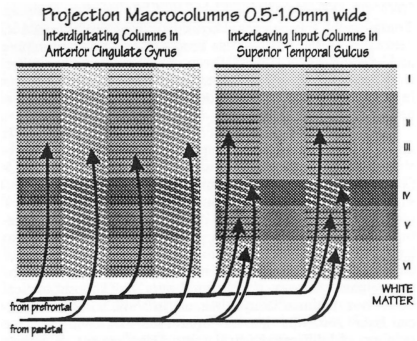


 (fig. from Arbib 1995, p. 270)

Macrocolumns



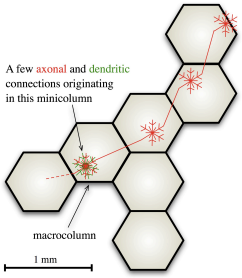
- ~70 inhibitorally-coupled minicolumns in humans
- 70% of minicol. connections are within macrocol.
- Basket neurons provide shunting inhibition between minicolumns
- Winner-takes-all networks
- Represent microfeatures



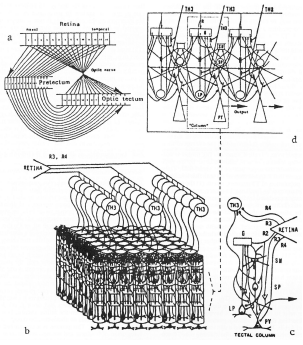
 (fig. from Arbib 1995, p. 270)

Intracortical Connections

- Dendrites extend 2–4 minicol. diameters
- Axons extend 5× (or even 30–40×) minicol. diameter
- Periodic spacing of axon terminal clusters causes entrainment
- ~2×10^7 connections to macrocolumn

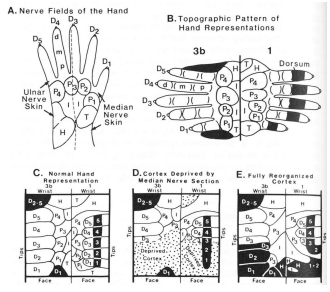


Neural Networks in Visual System of Frog



 (fig. from Arbib 1995, p. 1039)

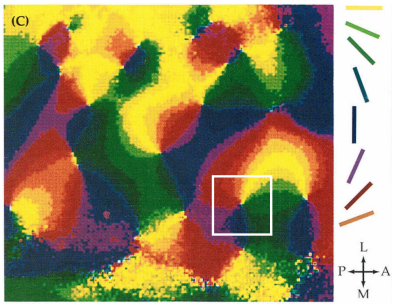
Reorganization of Cortex



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

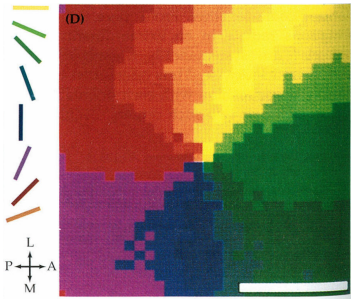
2013/3/11 (fig. < McClelland & al, *Par. Distr. Proc.* II) 31

Orientation Columns



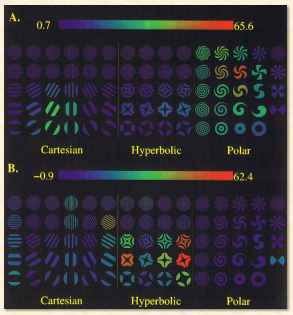
2013/3/11 (fig. < Nicholls & al., *Neur. to Brain*) 32

Orientation Columns



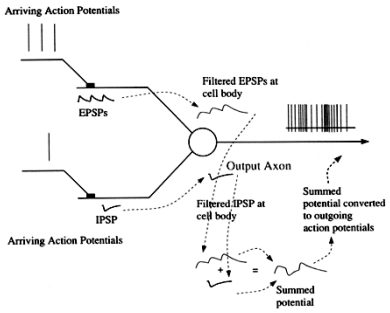
2013/3/11 (fig. < Nicholls & al., *Neur. to Brain*) 33

Cell Responses in V4



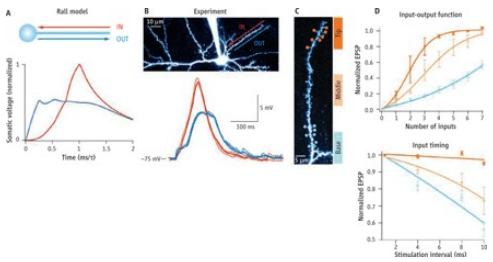
2013/3/11 (fig. < Clark, *Being There*, 1997) 34

Slow Potential Neuron



2013/3/11 (fig. < Anderson, *Intr. Neur. Nets*) 35

Dendritic computation in pyramidal cells.



T Branco Science 2011;334:615-616

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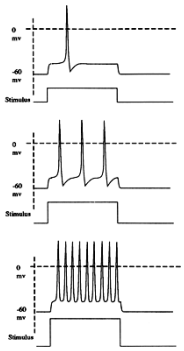
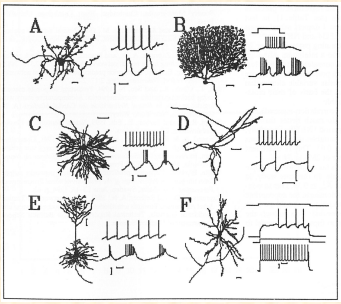
Frequency Coding



2013/3/11 (fig. from Anderson, *Intr. Neur. Nets*) 37

Variations in Spiking Behavior



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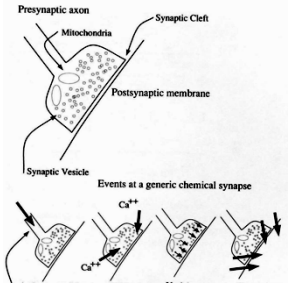
Synapses

2013/3/11 video by Hybrid Medical Animation 39

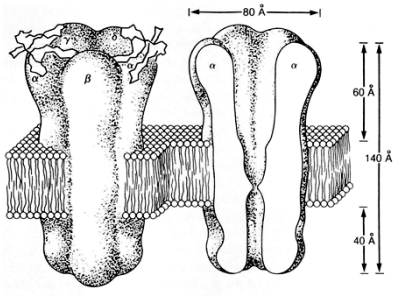
Chemical Synapse



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

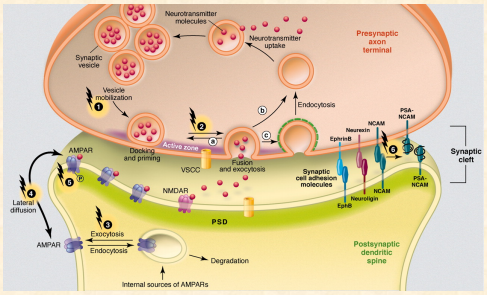
2013/3/11 (fig. from Anderson, *Intr. Neur. Nets*) 40

Typical Receptor



2013/3/11 (fig. from Anderson, *Intr. Neur. Nets*) 41

Fig. 3 Activity-dependent modulation of pre-, post-, and trans-synaptic components.



V M Ho et al. Science 2011;334:623-628

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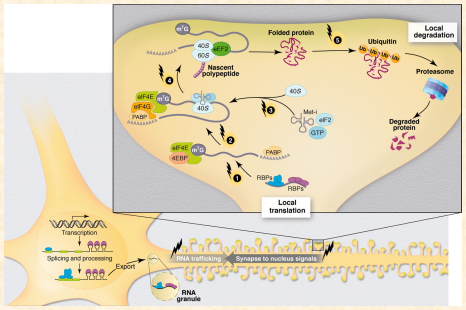
Fig. 4 Local regulation of the synaptic proteome.



V M Ho et al. Science 2011;334:623-628

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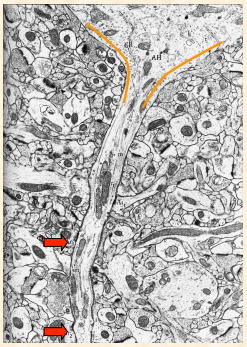
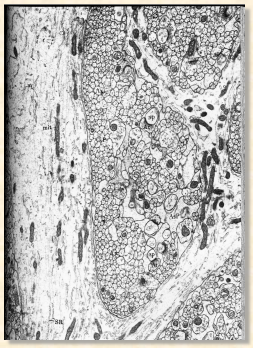
Axon Hillock

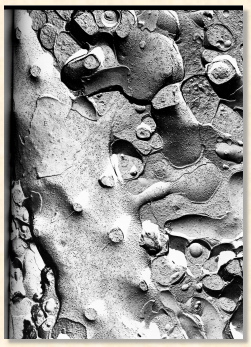


2013/3/11 (fig. from Peters, Palay & Webster) 44



Dendrite & Dendritic Branches

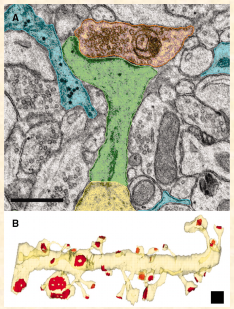
2013/3/11 (fig. from Peters, Palay & Webster) 45



Dendrite & Dendritic Spine

2013/3/11 (fig. from Peters, Palay & Webster) 46

Fig. 2 The ultrastructure of the synapse.



V M Ho et al. Science 2011;334:623-628

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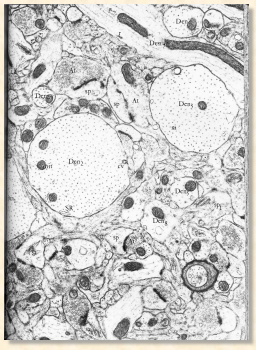
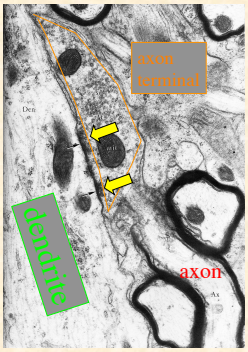
Neuropil



2013/3/11 (fig. from Peters, Palay & Webster) 48

Myelinated Axon Making Synapse on Dendrite

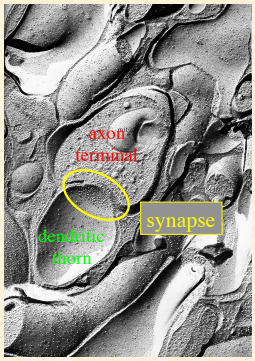


2013/3/11 (fig. from Peters, Palay & Webster) 49

Various Synapses

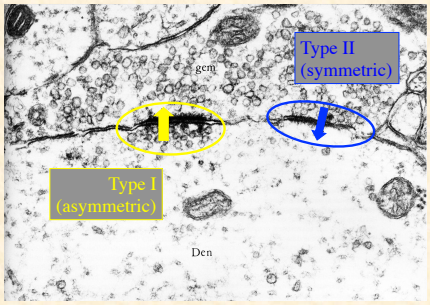
2013/3/11 (fig. from Peters, Palay & Webster) 50

Excitatory Synapse Between Axon Terminal and Dendritic Thorn



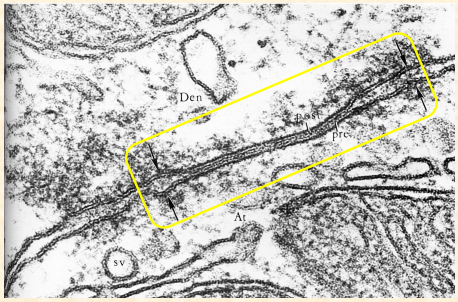
2013/3/11 (fig. from Peters, Palay & Webster) 51

Dendro-dendritic Synapses



2013/3/11 (fig. from Peters, Palay & Webster) 52

Electrotonic Synapse



2013/3/11 (fig. from Peters, Palay & Webster) 53 5B

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

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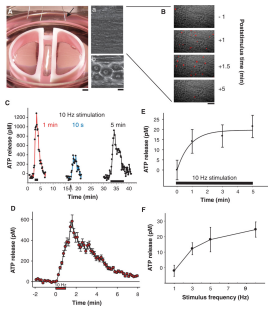
Release of ATP from Axons Firing Action Potentials



2013/3/11
Published by AAAS

R. D. Fields et al., Sci. Signal. 3, ra73 (2010)

Science Signaling

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

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Read Flake, ch. 20

V

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