

Chapter 2

Cognitive Neuroscience

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Cognitive Neuroscience

- Neurons
- Dissociations...
 - KC example
- Neurotransmission
- Neuroanatomy
- Neuroimaging
- PDP: Neural Network Models

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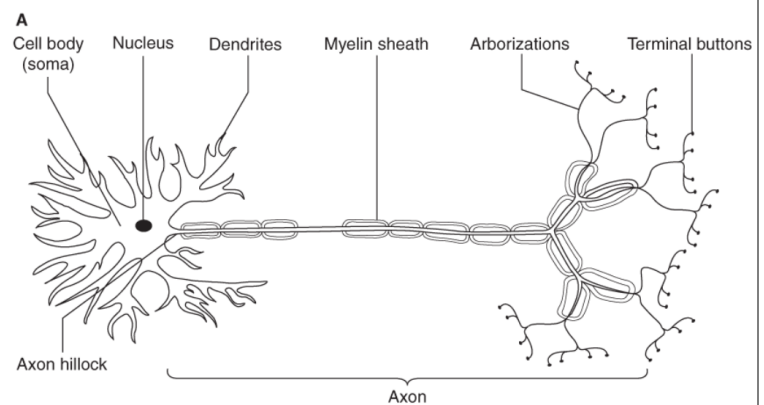
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Neurons

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Neurons



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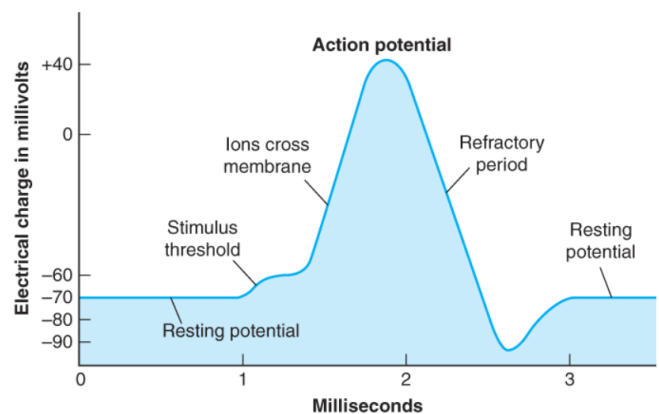
How many neurons?

- Your brain
 - 100 billion neurons
 - 100,000,000,000
 - 1.0×10^{11}
- Average domestic cat has 50 million hairs
 - 50,000,000
 - 5.0×10^7
- Two thousand cats have about same number of hairs as neurons in your brain
- Each neuron has 1-1000 connections

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Action Potential



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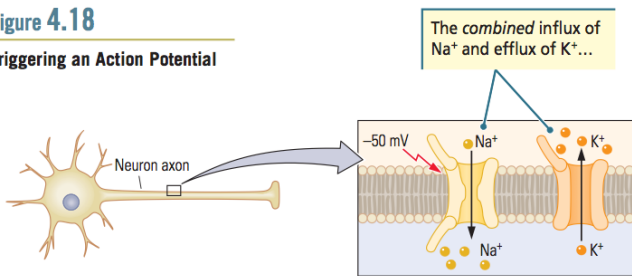
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The Action Potential

- Sodium (Na) ions enter cell, Potassium (K) ions exit
- Cell voltage changes

Figure 4.18

Triggering an Action Potential



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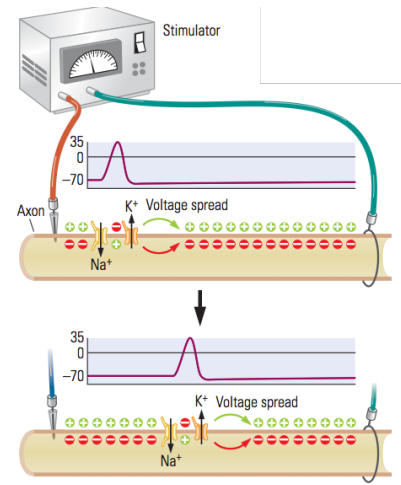
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The Nerve Impulse

- Action Potentials travel along the axon

- aka "propagation"

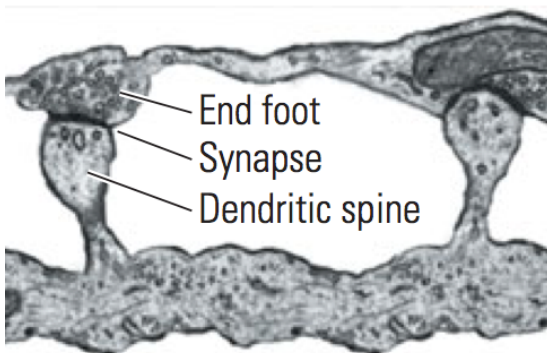
- Domino Analogy



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Synapse

- Gap between dendrite and axon

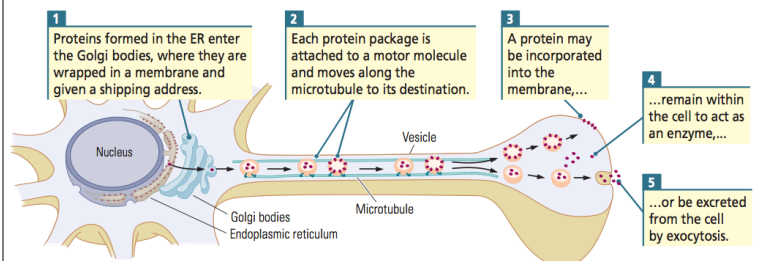


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Vesicles and Neurotransmitters

- Neurotransmitters bridge the synapse between axon and dendrite
- Vesicles are created in cell body and hold neurotransmitters



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Neurotransmitters

- More than 100
- More than one NT may be in single vesicle
- 99%
 - Small-molecules
 - organic chemicals
 - **Glutamate** (Glu) : Major Excitatory NT, more than 90%
 - Gama-aminobutyric acid (**GABA**) : Major Inhibitory NT, more than 9%
- 1%
 - Neuropeptides
 - short amino acid chains
 - Transmitter gasses
 - tiny water-soluble gas molecules such as NO and CO

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Neurons as Calculators

- Input Connections
 - Excitatory
 - Inhibitory
- Function
 - Summation
- Output
 - Action Potential

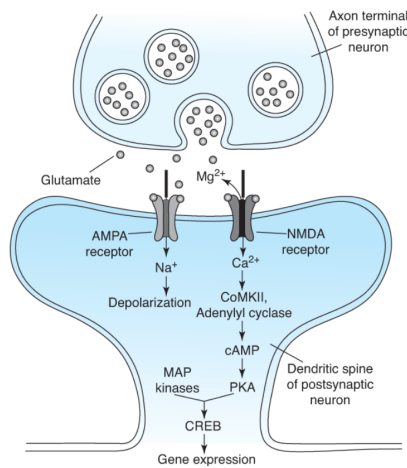
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Long Term Potentiation (LTP)

- Glutamate

- AMPA receptors (fast, cause action potential)
- NMDA receptors (slow, makes new NMDA receptors)



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Neurobiology of Memory

- LTP (Long Term Potentiation)
 - days or weeks
- Consolidation
 - Permanent
 - REM sleep?

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Dissociations

- Dissociation: A disruption in one cognitive process but no impairment of another.
- Double Dissociation: Finding reciprocal patterns of disruption
 - In one patient, A is disrupted by brain damage but B is not.
 - In a second patient, B is disrupted but A is not.

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K.C. (Kent Cochrane)

- Widespread brain injury, especially frontal regions, in a motorcycle accident in 1981.
- Complete loss of episodic memory "he cannot remember...a single thing he has ever done or experienced in the past...from either before or after his accident"
- Can not "time travel" - (can not imagine future or past events or plans) - loss of "autonoetic consciousness"
- Episodic: Amnesia -- Anterograde? Retrograde?
 - but shows Priming
- Semantic: normal.
- Confabulation? -- brother's funeral was "very sad"
- b. 1951, d. March 2014

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Review

- Neuroscience
 - Neurons & Neurotransmitters
 - Neuron as calculator
 - Neurobiology of Memory
 - LTP, Consolidation
- Clinical Neuropsychology
 - Patient KC
 - Memory test

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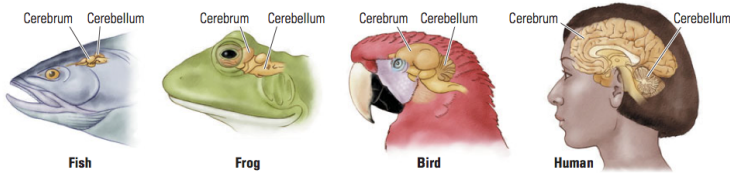
Neuroanatomy

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Brain Evolution

- General increase in brain size & complexity across species



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Encephalization Quotient (EQ)

- Humans are special

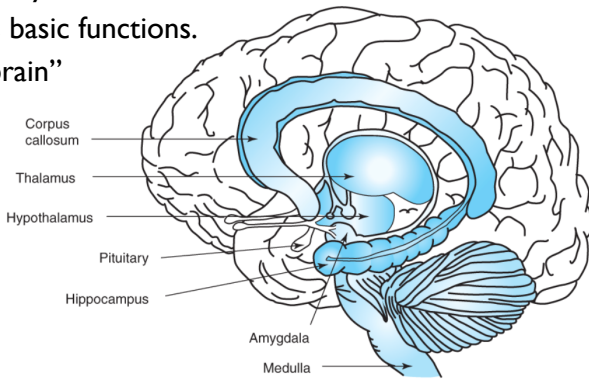
Species	Brain Volume (ml)	EQ
Rat	2	0.4
Cat	25	1.0
Rhesus monkey	106	2.1
Chimpanzee	440	2.5
Human	1350	7.3

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Old Brain

- Brain Stem and Subcortical areas
- Evolutionary more ancient
- Controls basic functions.
- “Lizard brain”

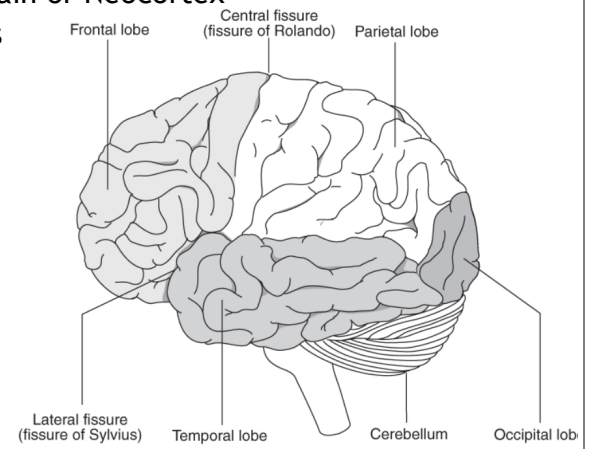


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New Brain

- Forebrain or Neocortex
- 4 lobes



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Principles of Organization

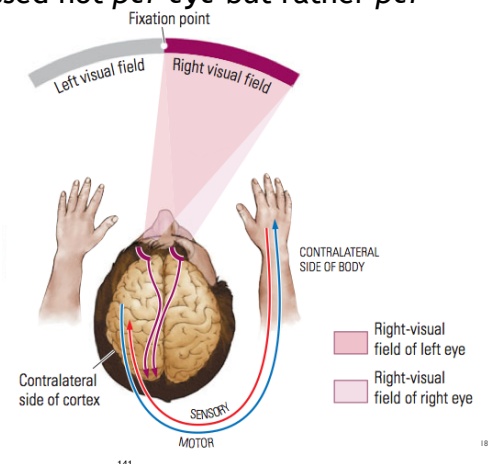
- Contralaterality...
- Hemispheric Specialization...
 - Lateralization
- Cortical Specialization...
 - different areas perform different functions

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Contralaterality - the Crossed Brain - Vision

- Vision is crossed not *per eye* but rather *per visual field*

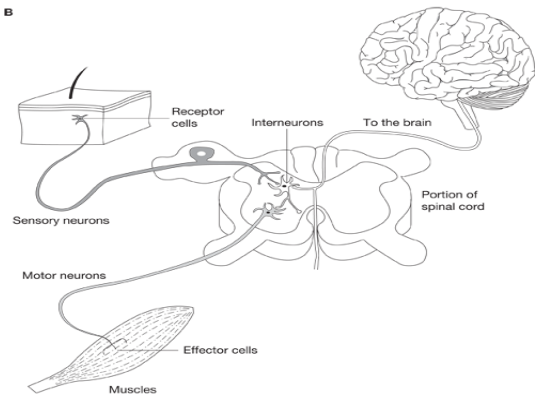


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Contralaterality - Motor and Sensory

- Motor/Sensory pathways cross in the spinal cord



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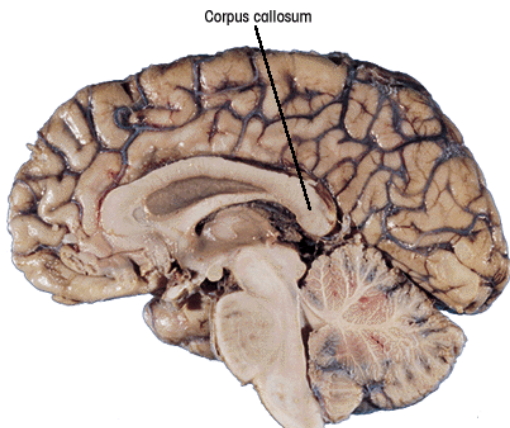
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Lateralization

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The two hemispheres of the brain are connected by a band of fibers called the corpus callosum



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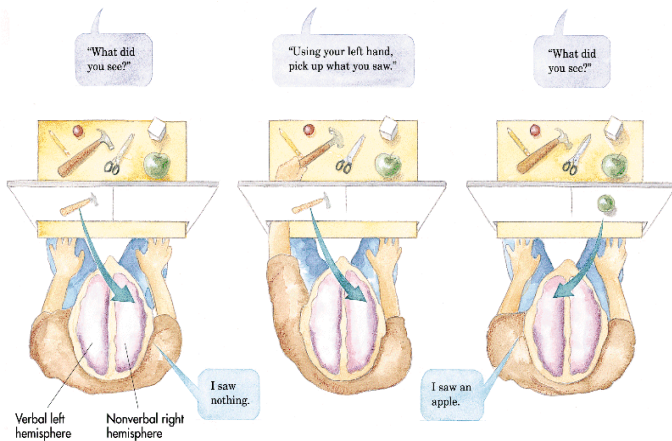
Split-Brain Patients

- Severed corpus callosum to stop epileptic seizures
- No obvious problems!
- Laboratory testing revealed unusual findings

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Split brain experiments



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Lateralization

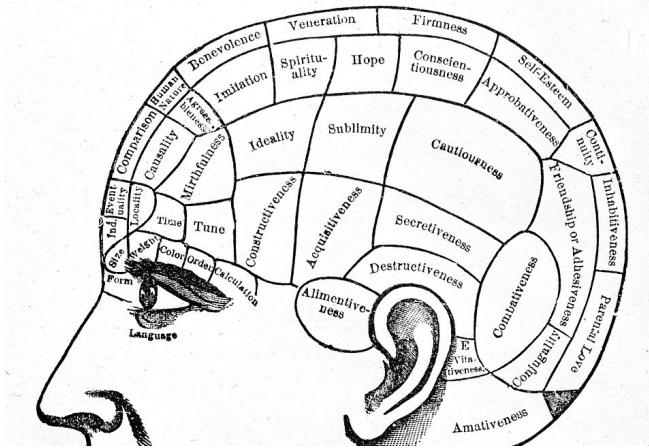
Function	Left Hemisphere	Right Hemisphere
Visual System	Letters, Words	Geometric patterns, faces
Auditory	Language-related sounds	non-language sounds, music
Memory	Verbal	Nonverbal
Language	speech	prosody
Spatial		geometry, map-reading, mental rotation

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Cortical Specialization

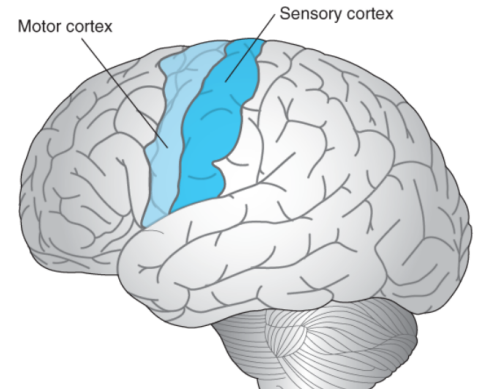
- Different areas control different functions



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Cortical Specialization

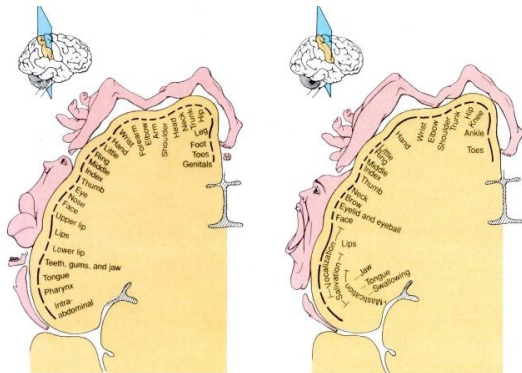
- Different areas control different functions



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Projection Maps

- Functions are mapped in space



(a) Somatosensory cortex in right cerebral hemisphere

(b) Motor cortex in right cerebral hemisphere

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More Principles of Organization

- Bottom to Top
- Back to Front

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Neuroimaging

- Problem:
 - brain is well-protected inside skull
- Solution:
 - methods of neuroimaging

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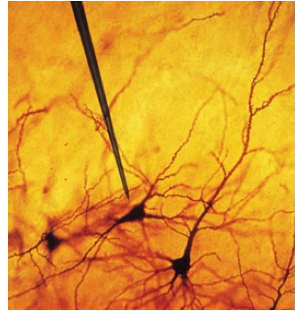
Neuroimaging Methods

- Electrical
 - single cell
 - ERP
- Structural
 - CAT
 - MRI
- Metabolic / Functional
 - PET
 - fMRI
 - MEG

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Single-Cell recording

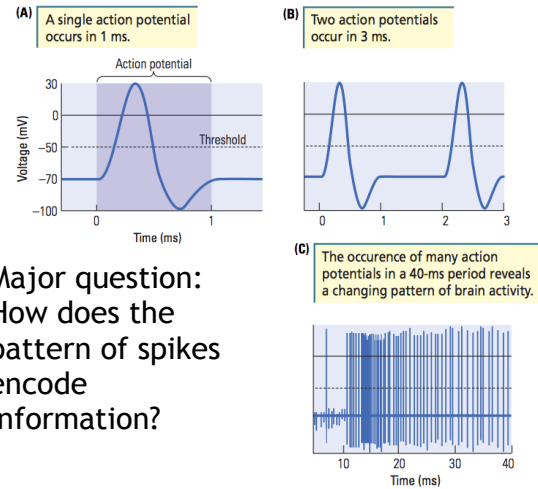
- Typically done in non-human animals
- Single electrode recording
- Arrays of electrodes
 - record from multiple cells



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Action potential trains

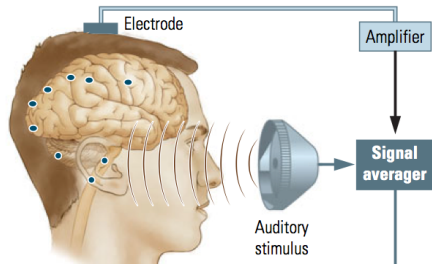
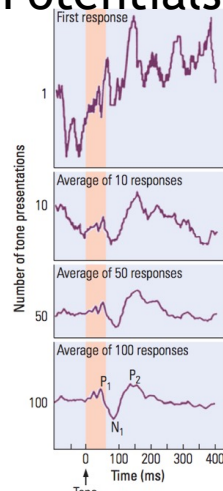


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ERP - Event-Related-Potentials

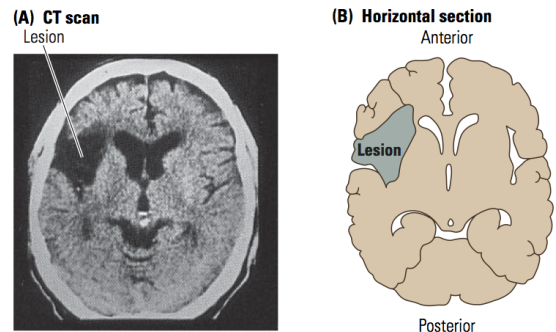
- Can you see “thinking” by watching EEG?
- In a single recording: No, it’s too noisy
- By statistically averaging multiple events, a pattern emerges



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CT : Computed Tomography

- Xrays are sent through head from all angles
- Computer reconstructs data into 3-D image
- Aka “Computed Axial Tomography” or CAT

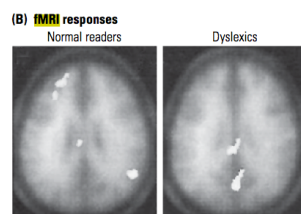
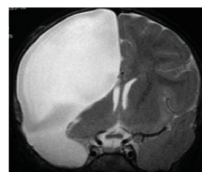


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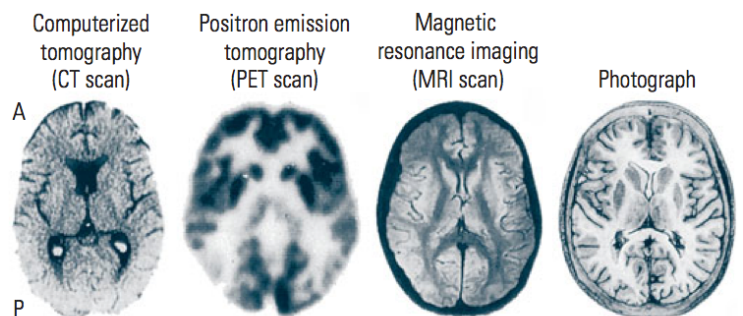
MRI

- MRI : Magnetic Resonance Imaging
 - magnetic fields
 - detailed
 - expensive
- fMRI : Functional MRI
 - metabolism in real time



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Comparison of Neuroimaging images



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MEG : magnetoencephalography

- Maxwell-Faraday equation - relates change in Electrical potential (voltage) “E-field” to change in magnetic field “B-field”

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

- Electrical voltages : can be measured with cheap equipment
- Magnetic fields : measured with fancy equipment
 - SQUIDs : Superconducting quantum interference device
 - Requires liquid helium
 - \$\$\$
- Pro: higher resolution



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Review: Neuroimaging

- Electrical
 - single cell
 - ERP
- Structural
 - CAT
 - MRI
- Metabolic / Functional
 - PET
 - fMRI
 - MEG

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CogLab: Brain Asymmetry

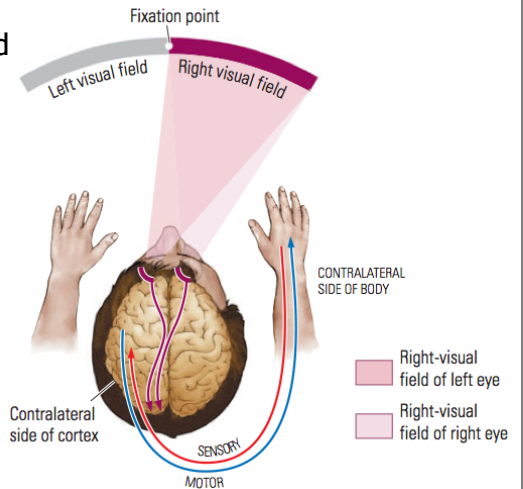
- Visual Fields...
- Laterality...
- Specialization...

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Contralaterality - the Crossed Brain - Vision

Vision is crossed not *per eye* but rather *per visual field*



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Lateralization

Function	Left Hemisphere	Right Hemisphere
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Memory	Verbal	Nonverbal
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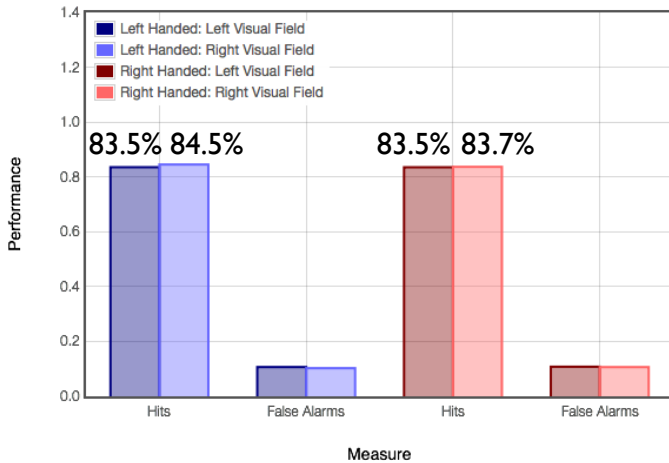
Individual Differences in Lateralization

- Left Hemisphere Language Advantage
 - Right Handed
 - 95% of Men
 - 90% of Women
 - Left Handed
 - 73% of Men
 - 63% of Women

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Brain Asymmetry



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Brain Asymmetry

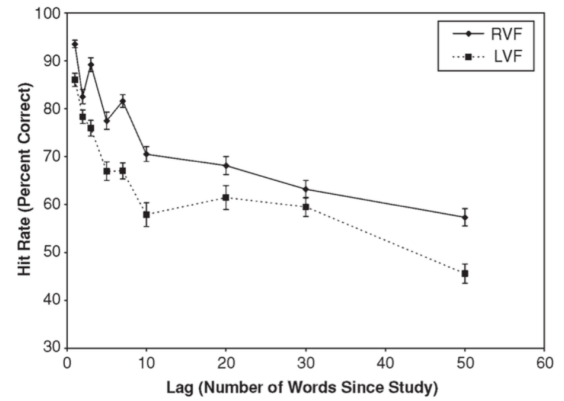


Figure 1. Hit rates (percent correct) for stimuli studied in the right visual field (RVF; diamonds) and the left visual field (LVF; squares) across the nine study-test lags. Error bars give the standard error. Trials in which saccades were detected during study were excluded. The false alarm rate was 9%.

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Brain Asymmetry

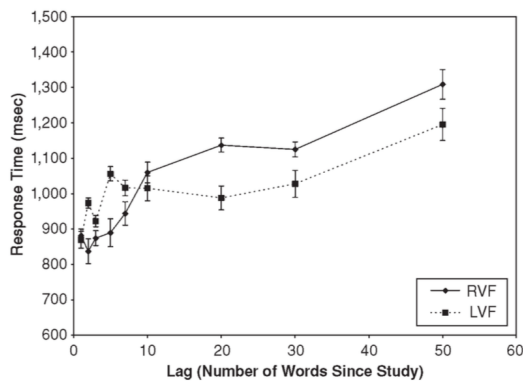


Figure 2. Response times (in milliseconds) for hits to stimuli studied in the right visual field (RVF; diamonds) and the left visual field (LVF; squares) across the nine study-test lags. Error bars give the standard error. Trials in which saccades were detected during study were excluded.

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Brain Asymmetry

- Debriefing
- Methods?
- Predictions?
- Robust? Limitations?

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Neural Network Models

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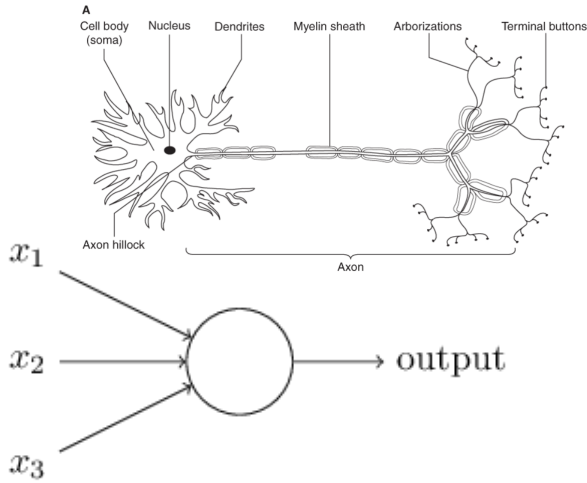
Parallel Distributed Processing

- Inspired by neuroanatomy
- small units
- multiple connections
- positive and negative weights

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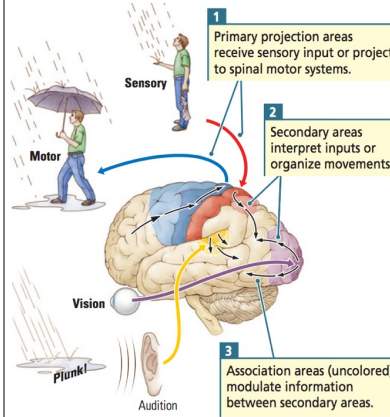
Neurons & Perceptrons



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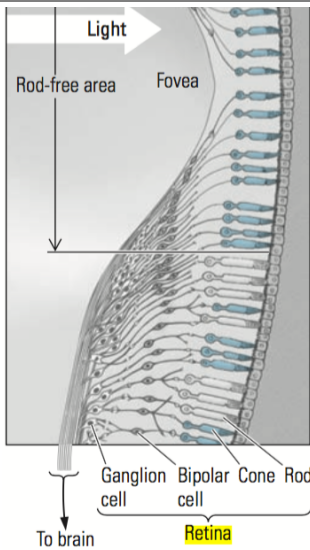
Layers in the Brain: Primary, Secondary, Association



- Primary - first area to receive sensory input or final area to send motor commands
- Secondary - interpret sensory inputs or organize movement
- Association
 - everything else

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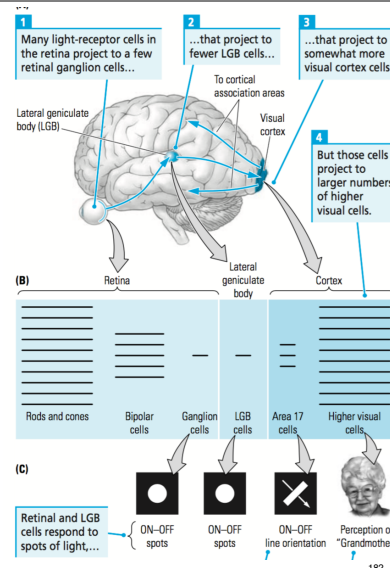
Retinal organization



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- Rods & Cones
- Bipolar cells
- Ganglion cells

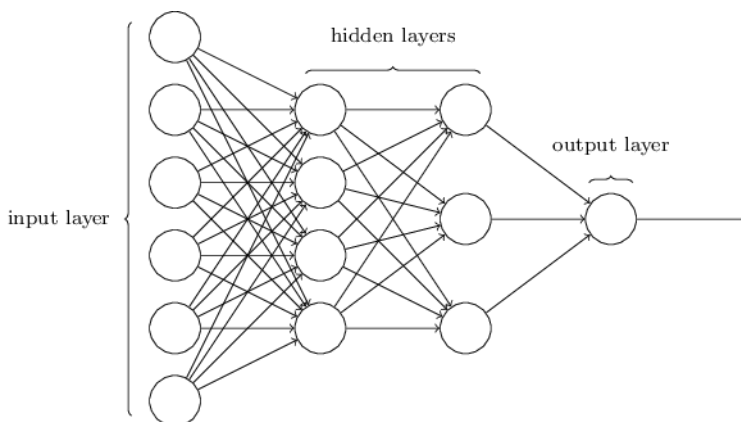
“Grandmother” Cells



- Brain has hierarchical organization in layers
- Each subsequent layer has fewer neurons
- And encodes “higher level” (more abstract) information

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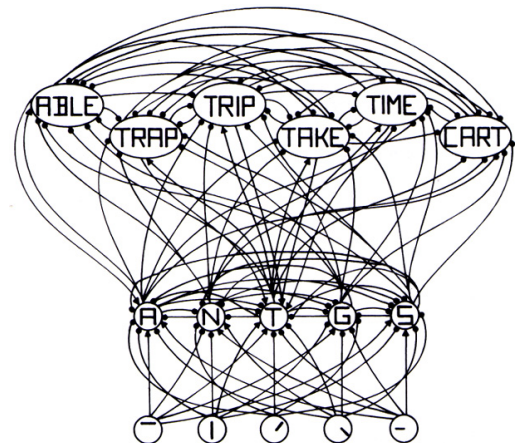
Layers



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Connectionist Model



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Brain vs. Computer

- 100 billion neurons (10^{12})
- “Clock speed” 1 KHz (10^3)
- # of processors : ?
- Equivalent MIPS: 100 million (10^8)
- 1 billion transistors (10^9)
- Clock speed: 1 GHz (10^{12})
- # of processors : 8
- Equivalent MIPS: 100,000 (10^5)

Brain 1000x faster (for now...)

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Computers vs Humans



- 1952: Tic-Tac-Toe
- 1994: Checkers
- 1997: Chess
- 2016: Go

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