Chapter 2

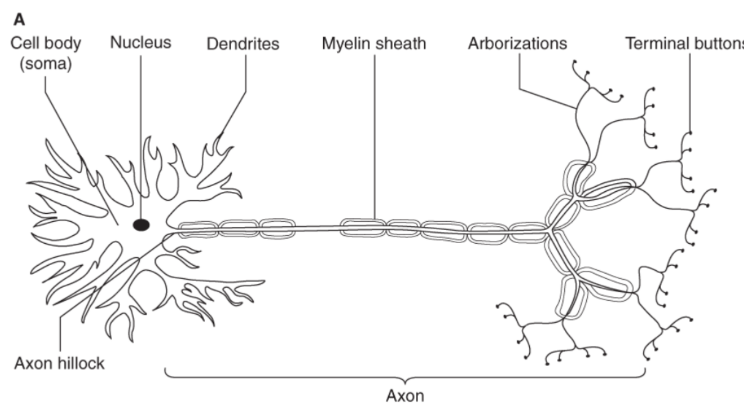
Cognitive Neuroscience

Cognitive Neuroscience

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

Neurons

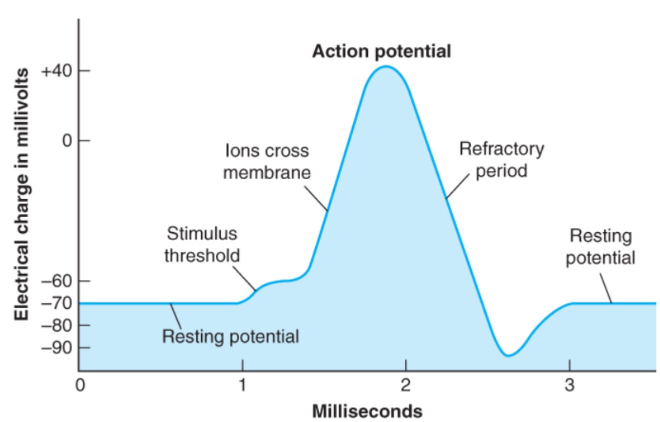
Neurons



How many neurons?

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

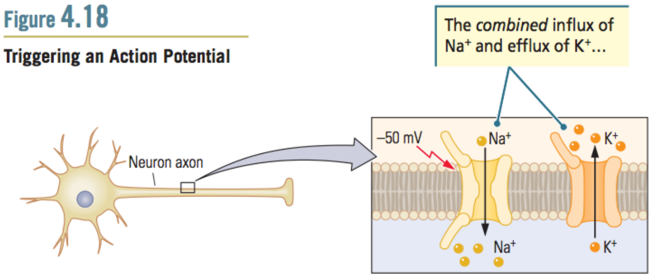
Action Potential



The Action Potential

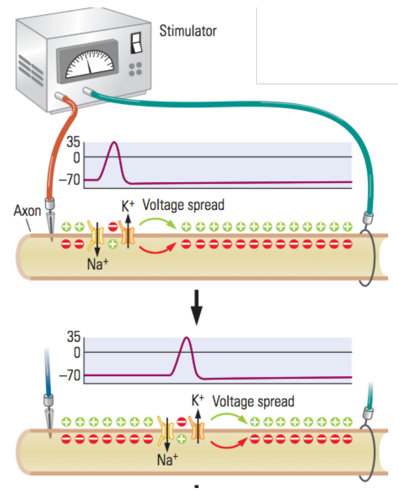
- Sodium (Na) ions enter cell, Potassium (K) ions exit
- Cell voltage changes

Figure 4.18
Triggering an Action Potential



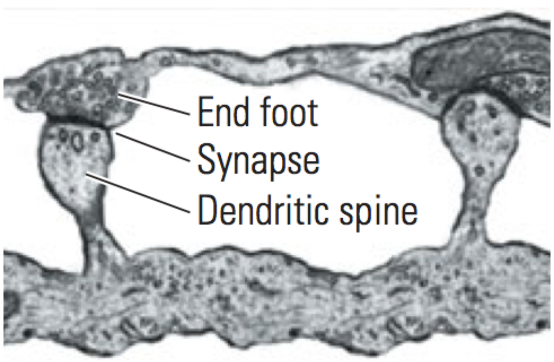
The Nerve Impulse

- Action Potentials travel along the axon
- aka "propagation"
- Domino Analogy



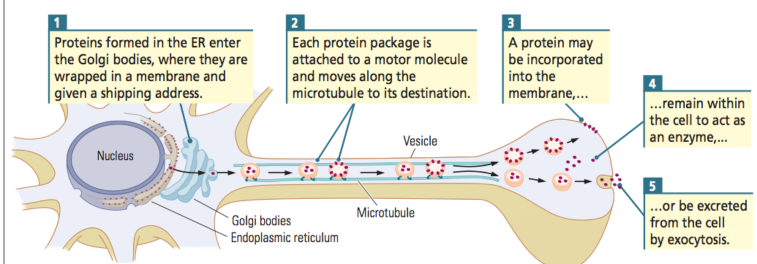
Synapse

- Gap between dendrite and axon



Vesicles and Neurotransmitters

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



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%

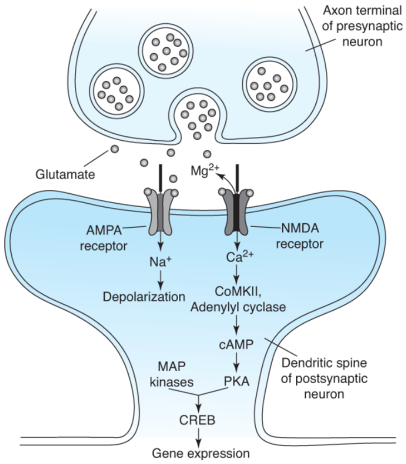
- 1%
  - Neuropeptides
    - short amino acid chains
  - Transmitter gasses
    - tiny water-soluble gas molecules such as NO and CO

Neurons as Calculators

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

Long Term Potentiation (LTP)

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



Neurobiology of Memory

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

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.

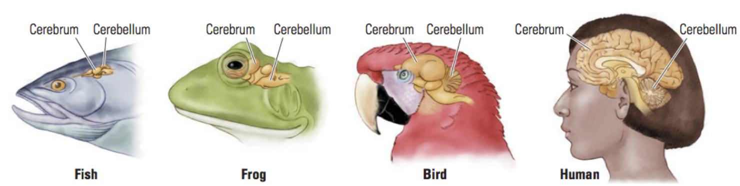
K.C. (Kent Cochrane)

- 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

Neuroanatomy

Brain Evolution

- General increase in brain size & complexity across species



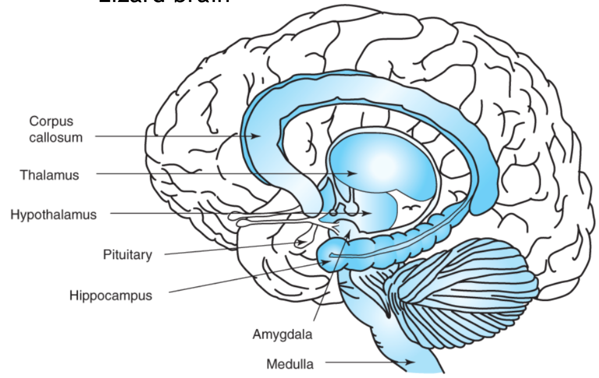
Encephalization Quotient (EQ)

- 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

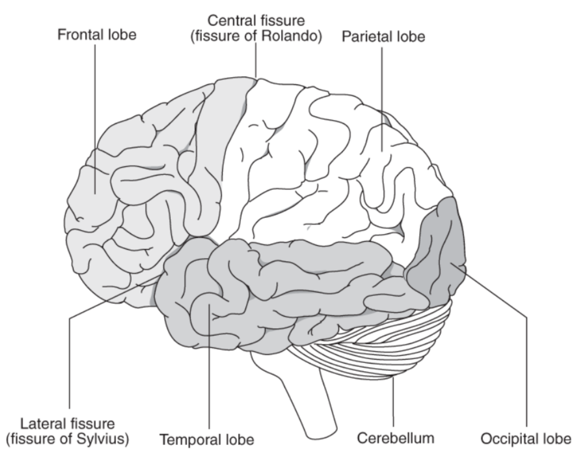
Old Brain

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



New Brain

- Forebrain or Neocortex
- 4 lobes

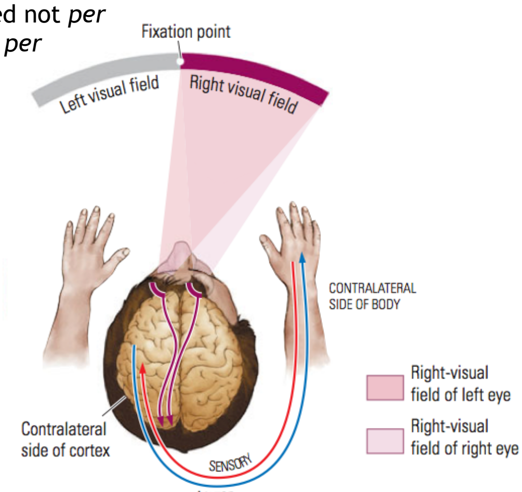


Principles of Organization

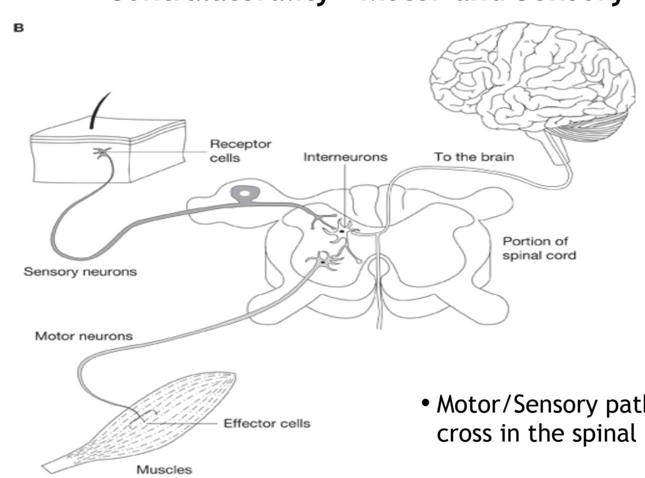
- Contralaterality…
- Hemispheric Specialization…
  - Lateralization
- Cortical Specialization…
  - different areas perform different functions

Contralaterality - the Crossed Brain - Vision

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



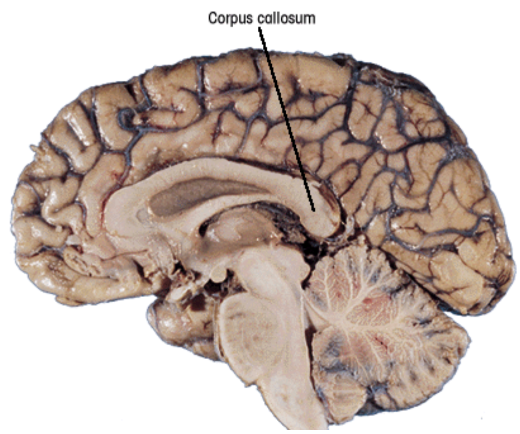
Contralaterality - Motor and Sensory



- Motor/Sensory pathways cross in the spinal cord

Lateralization

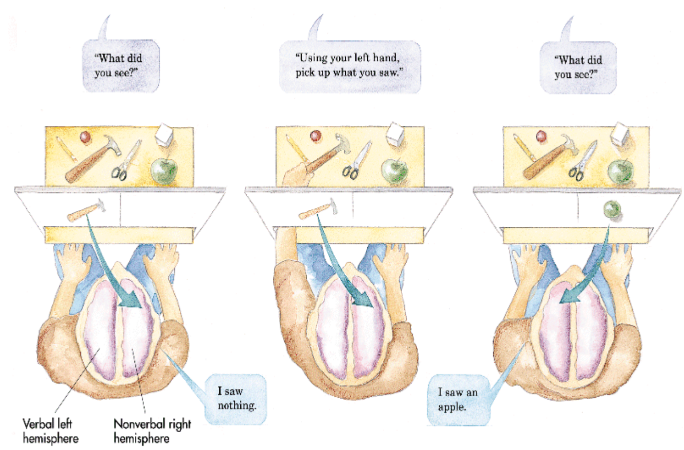
The two hemispheres of the brain are connected by a band of fibers called the corpus callosum



Split-Brain Patients

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

Split brain experiments

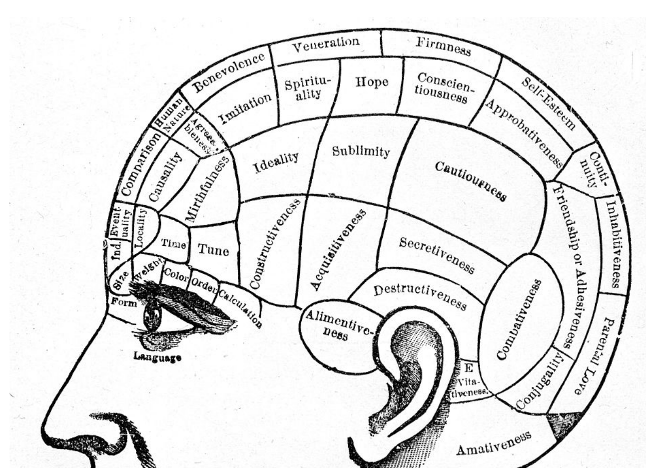


Lateralization

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

Cortical Specialization

- Different areas control different functions



Cortical Specialization

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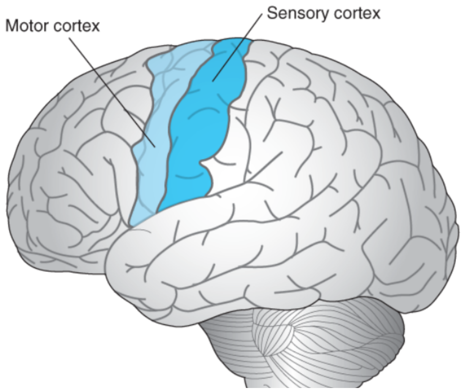
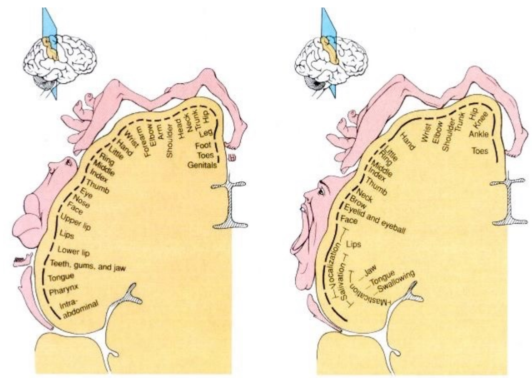


Projection Maps

- Functions are mapped in space



(a) Somatosensory cortex in right cerebral hemisphere

(b) Motor cortex in right cerebral hemisphere

More Principles of Organization

- Bottom to Top
- Back to Front

Neuroimaging

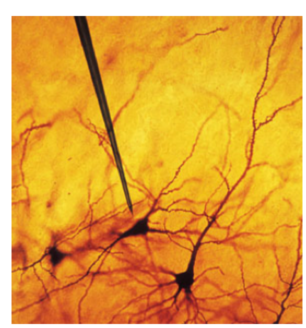
- Problem:
  - brain is well-protected inside skull
- Solution:
  - methods of neuroimaging

Neuroimaging Methods

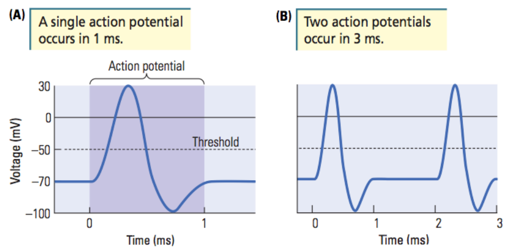
- Electrical
  - single cell
  - ERP
- Structural
  - CAT
  - MRI
- Metabolic / Functional
  - PET
  - fMRI
  - MEG

Single-Cell recording

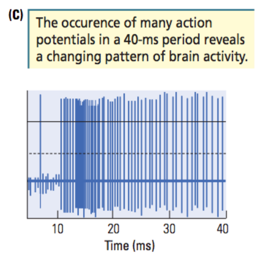
- Typically done in non-human animals
- Single electrode recording
- Arrays of electrodes
  - record from multiple cells



Action potential trains

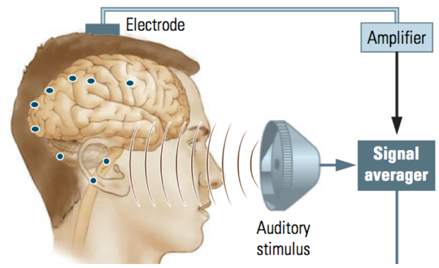


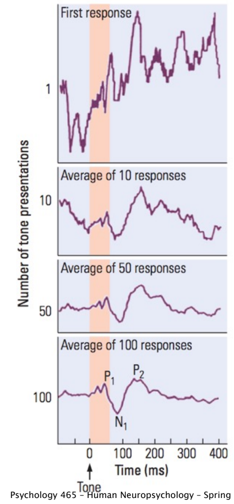
- Major question: How does the pattern of spikes encode information?



ERP - Event-Related-Potentials

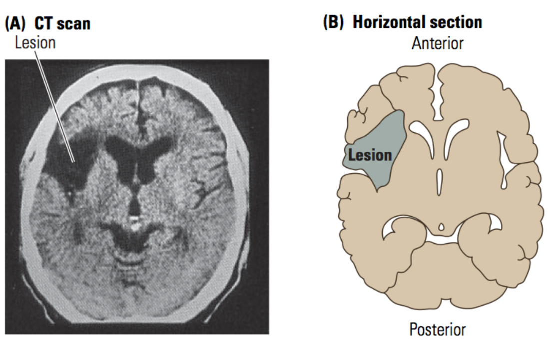
- Can you see "thinking" by watching EEG?
- In a single recording: No, it's too noisy
- By statistically averaging multiple events, a pattern emerges





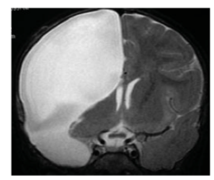
CT : Computed Tomography

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

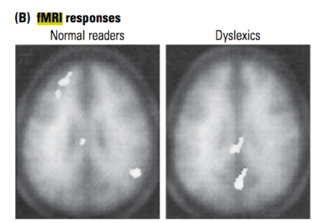


MRI

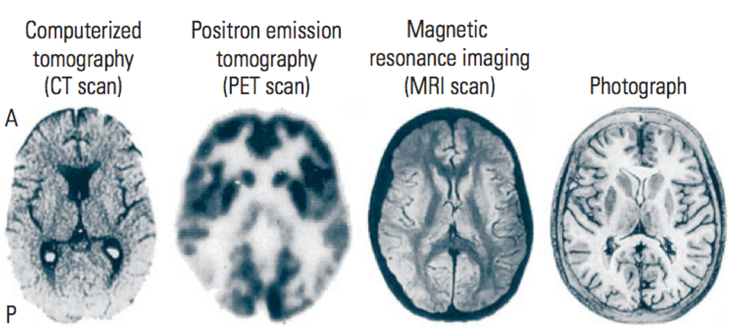
- MRI : Magnetic Resonance Imaging
  - magnetic fields
  - detailed
  - expensive



- fMRI : Functional MRI
  - metabolism in real time



Comparison of Neuroimaging images



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

Review: Neuroimaging

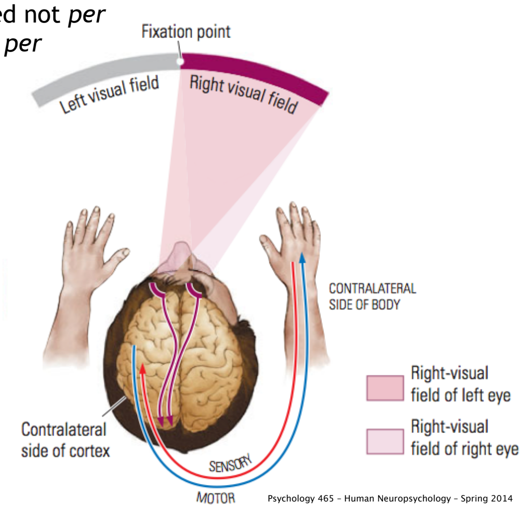
- Electrical
  - single cell
  - ERP
- Structural
  - CAT
  - MRI
- Metabolic / Functional
  - PET
  - fMRI
  - MEG

CogLab: Brain Asymmetry

- Visual Fields…
- Laterality…
- Specialization…

Contralaterality - the Crossed Brain - Vision

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



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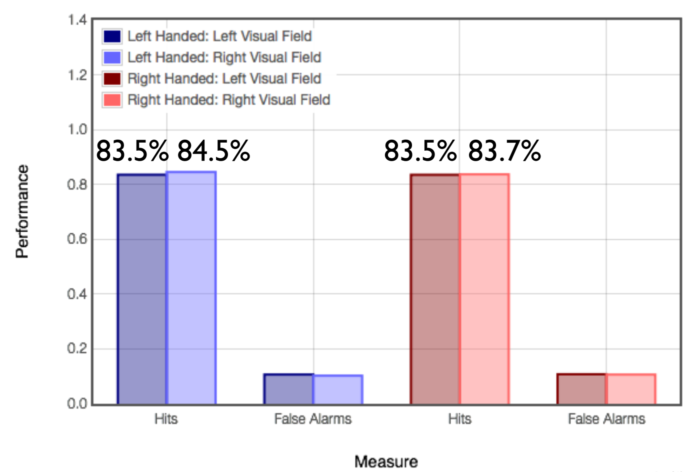
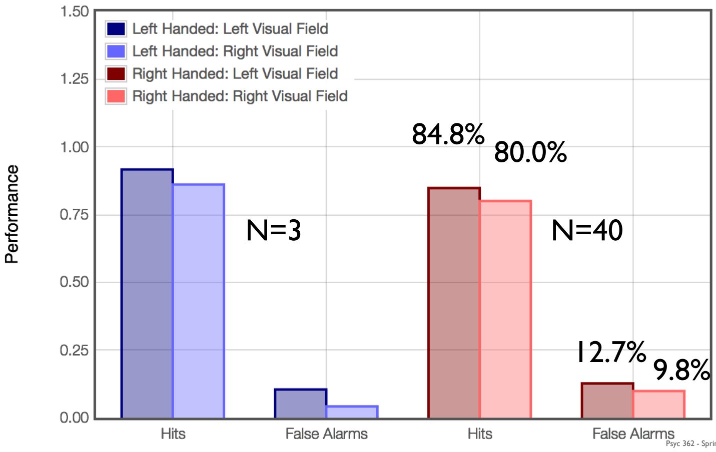
Individual Differences in Lateralization

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

Brain Asymmetry



Brain Asymmetry : Our Data



Brain Asymmetry

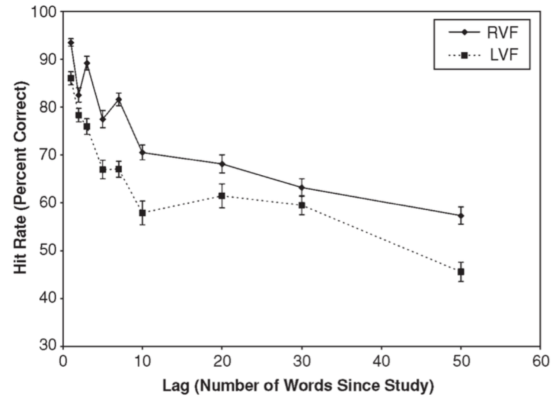


Figure 1. Hit rates (percent correct) for stimuli studied in the right visual field (RVF; diamonds) and the left visual field (LVF; squares) across the nine study–test lags. Error bars give the standard error. Trials in which saccades were detected during study were excluded. The false alarm rate was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

Brain Asymmetry

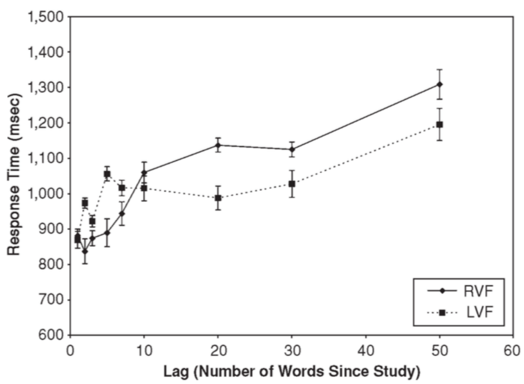


Figure 2. Response times (in milliseconds) for hits to stimuli studied in the right visual field (RVF; diamonds) and the left visual field (LVF; squares) across the nine study–test lags. Error bars give the standard error. Trials in which saccades were detected during study were excluded.

Brain Asymmetry

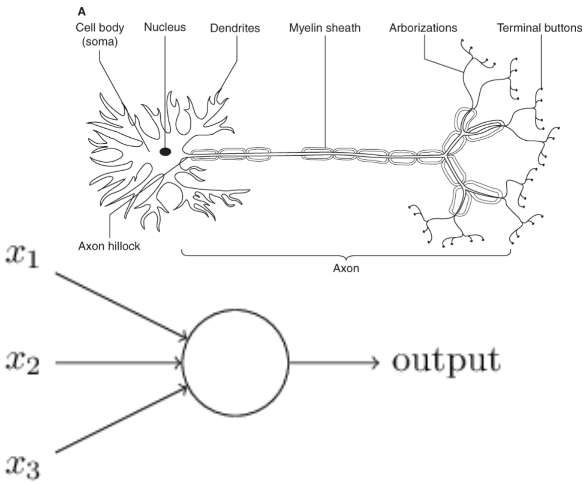
- Debriefing
  - Methods?
  - Predictions?
  - Robust? Limitations?

Neural Network Models

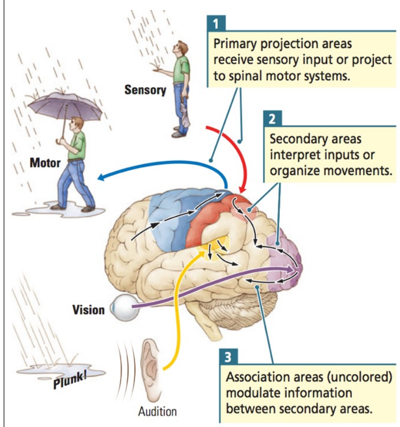
Parallel Distributed Processing

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

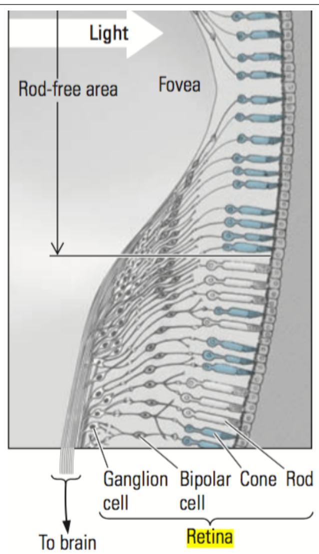
Neurons & Perceptrons



Layers in the Brain: Primary, Secondary, Association

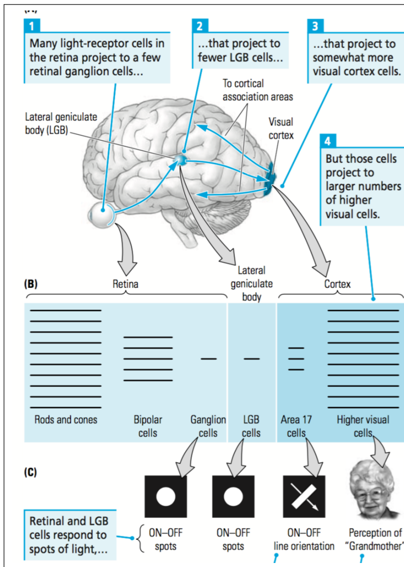


- Primary - first area to receive sensory input or final area to send motor commands
- Secondary - interpret sensory inputs or organize movement
- Association
  - everything else



Retinal organization

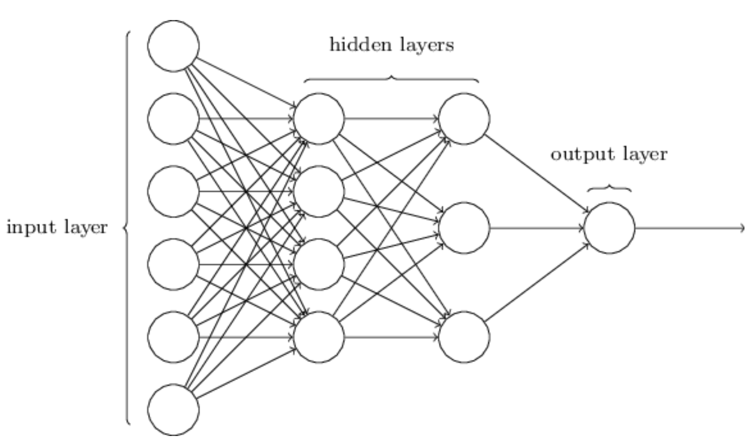
- Rods & Cones
- Bipolar cells
- Ganglion cells



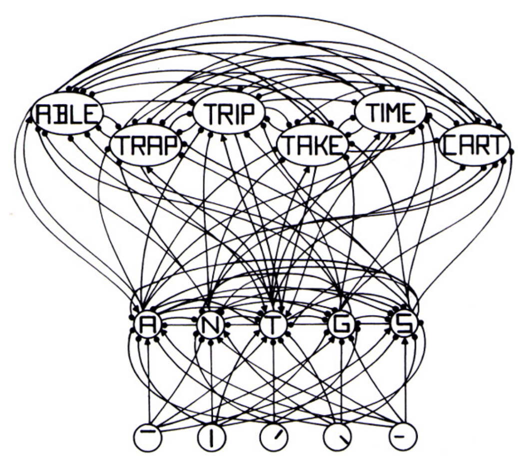
"Grandmother" Cells

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

Layers



Connectionist Model



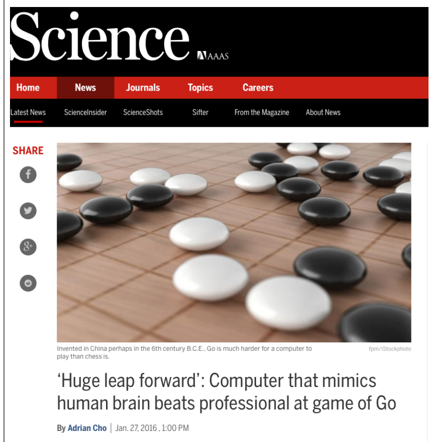
Brain vs. Computer

- 100 billion neurons (10^{12})
- "Clock speed" 1KHz (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…)

Computers vs Humans



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