



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

General info:

EE 239AS.2, Neural signal processing and machine learning
Spring quarter, UCLA AY 2016-17.

Instructor:

Prof. Jonathan Kao
E-mail: kao@seas.ucla.edu
Office: 56-147H (Temp: Boelter 6730G)
Office hours: Tues, 2pm - 3pm

Special reader:

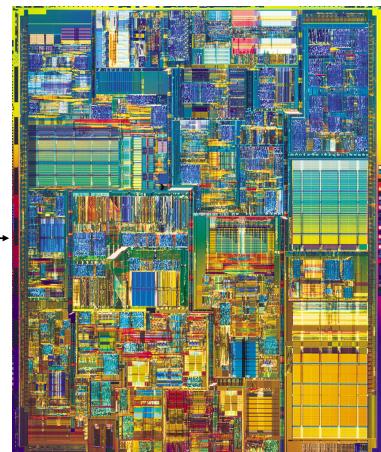
Manikandan Srinivasan
E-mail: mani93@ucla.edu
Office: 67-112 Engineering IV
Office hours: Tues + Thurs 3:30-4:30pm

Some high-level thoughts about this class:

- Brain meets engineering.
- While learning neuroscience + machine learning related topics is a goal of this class, it is my sincere hope that this class is also fun — you will be doing some pretty cool things with neural data!
- Interactive.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning



Prof. Jonathan Kao
Department of Electrical Engineering
University of California, Los Angeles
Spring 2016-17



What is neural signal processing?

For centuries, people have sought to understand what gives rise to our ability to **perceive** the world around us, to **reason** about it, and then to **act**.



Aristotle
(4th century BC)

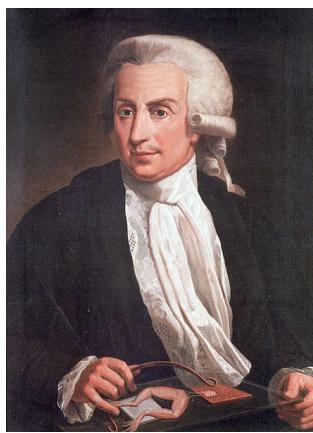


Galen
(2nd century AD)

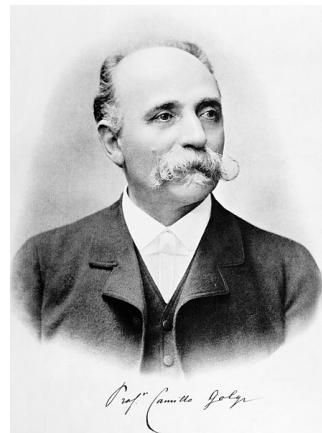


What is neural signal processing?

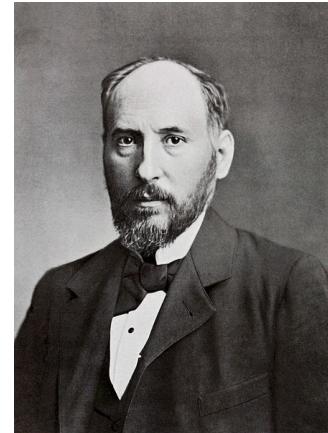
We've come a long way since then.



Galvani
(18th century)



Golgi
(19th century)

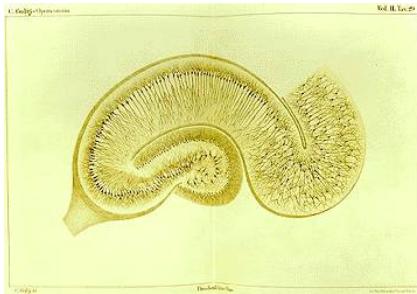


Ramón y Cajal
(19th century)

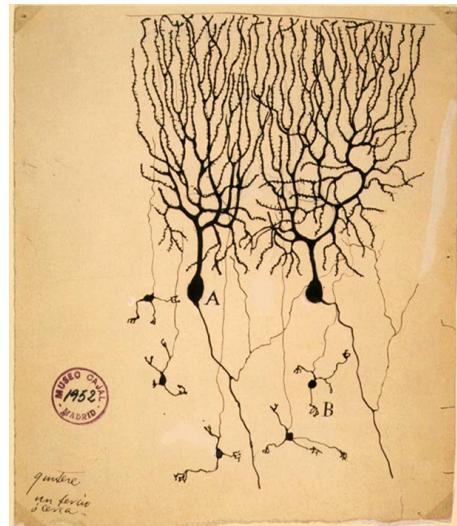


What is neural signal processing?

We've come a long way since then.



Golgi
(drawing of hippocampus)

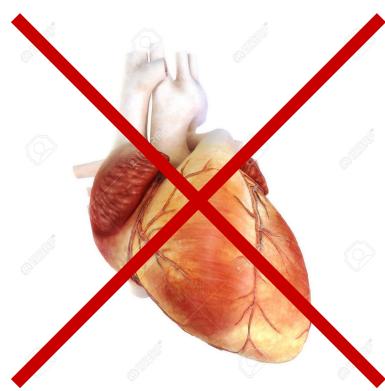


Ramón y Cajal
(drawing of Purkinje cells)



What is neural signal processing?

The “seat of consciousness”?



The heart

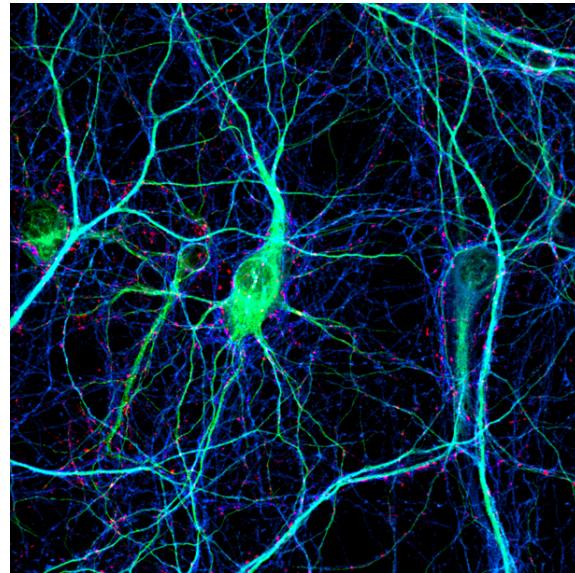


The brain



What is neural signal processing?

The Brain



What is neural signal processing?

Ultimately, the goal is to understand how information is processed in the brain, and then build / design / engineer therapeutic devices or treatments for neural disorders.

To do this, we need to know signal processing, but we also need to know basic neuroscience.

Regarding the brain, we're still only scratching the surface today. There's way more that we don't know about the brain than we do know.

Big question: How are we to further our understanding of the brain?

⇒ We must monitor the activity of its constituent elements: neurons.

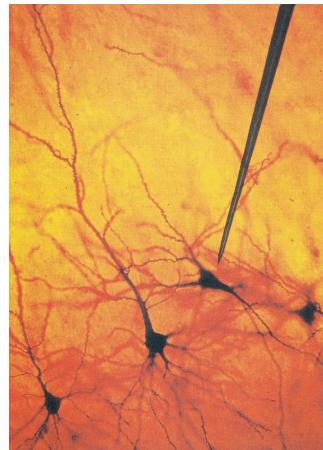
Holy grail: Monitor the activity of every neuron in the brain.

What is the best that we can do today?



On one end of the spectrum...

Single-electrode recordings



Pro: single-neuron resolution

Con: can only monitor one (or a small number of) neurons at a time



... the other end of the spectrum

Electroencephalography (EEG)



<http://people.brandeis.edu/~sekuler>

Functional magnetic resonance imaging (fMRI)



<http://neurophilosophy.files.wordpress.com/>

Pro: can monitor entire brain

Con: no single-neuron resolution

Different neural recording technologies:
it's all about tradeoffs



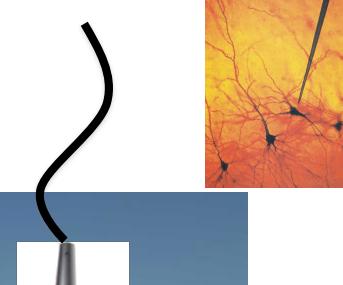
A stadium analogy

Imagine that the stadium is the brain...
... and each person is a neuron.



A stadium analogy

Single electrode recording is like
listening in to what one person is saying.





A stadium analogy

EEG and fMRI are like listening to the **collective** roar of the crowd.



A stadium analogy





A stadium analogy

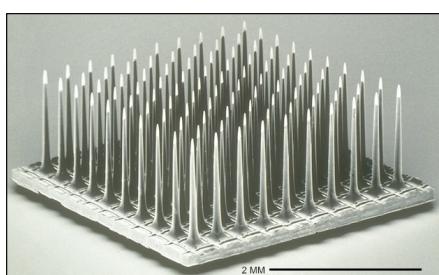
Ideally, we'd like to monitor what each individual person is saying.



Recent neurotechnology

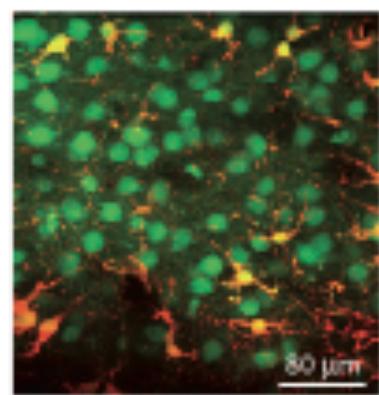
Only in last 20 years or so, we've been able to monitor **many neurons** at **single-neuron** resolution.

Multi-electrode arrays



Cyberkinetics, Inc

Optical imaging

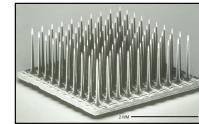


Kerr and Denk, 2008.

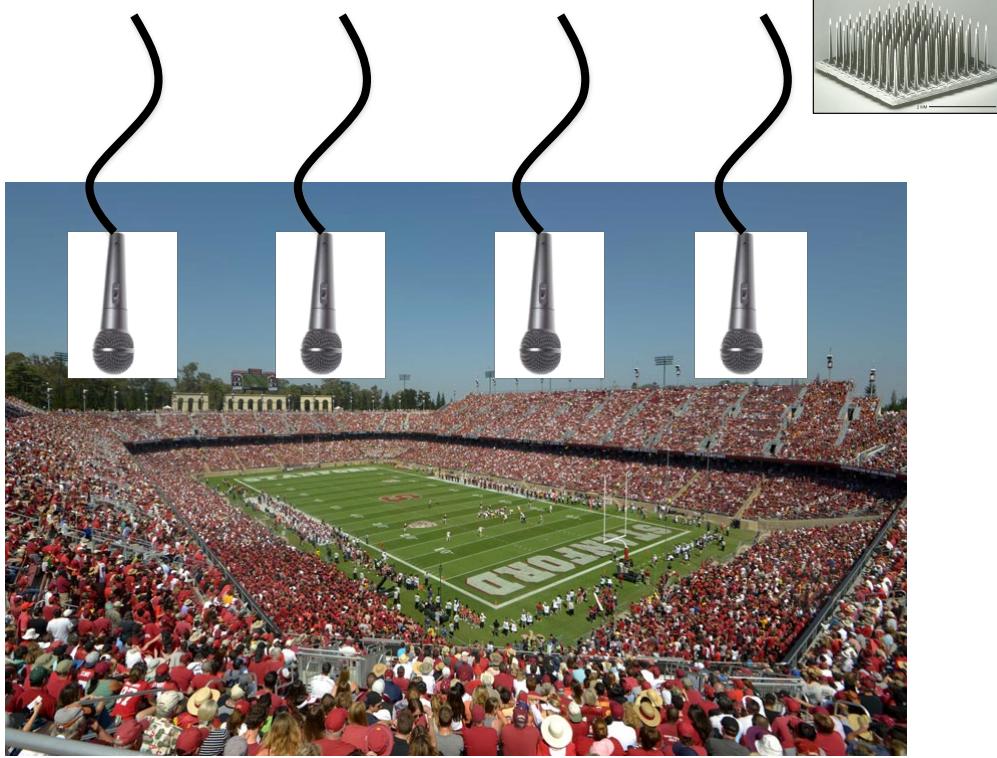


A stadium analogy

Multi-electrode array recording is like listening in on multiple individual conversations.



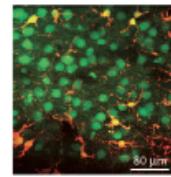
A stadium analogy



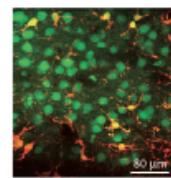


A stadium analogy

Optical imaging is like watching multiple individual mouths moving, from which we can deduce what each person is saying.



A stadium analogy





What is neural signal processing?

Technologies like multi-electrode arrays and optical imaging are providing unprecedented views of the brain's activity.

Even though we're far from monitoring every neuron in the brain, we now have more data than we know what to do with it.

Bottom line: **We need powerful statistical methods to make inferences about what the brain is doing from sparse sampling.**



What is neural signal processing?

What we have

- Novel experimental paradigms
- New neural recording technologies
- Huge and rich data sets

Goals

- Further our basic understanding of brain function
- Develop biomedical devices that interface with the brain



Missing link

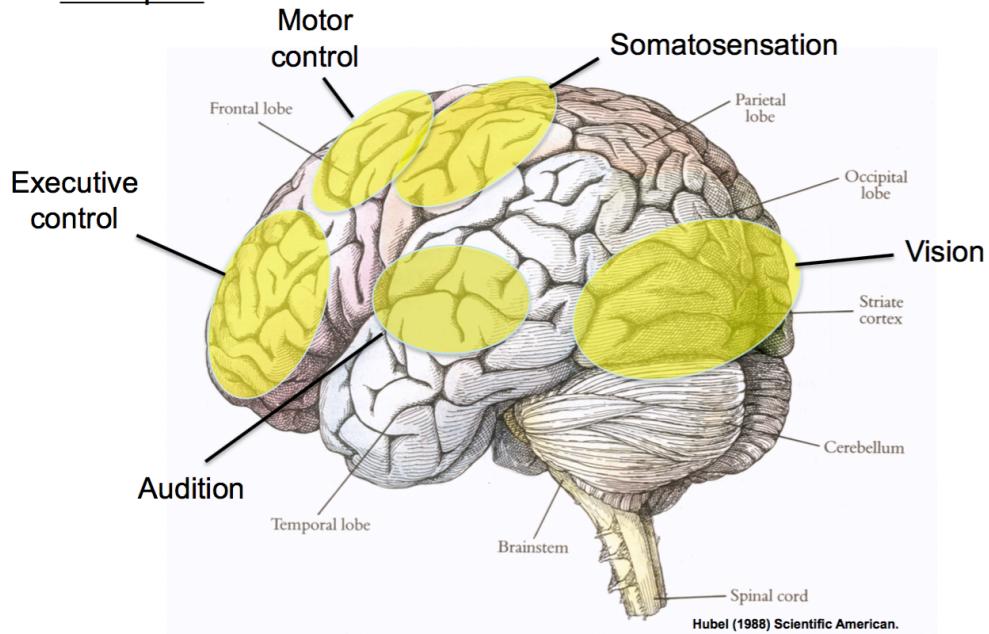
- Signal processing methods appropriate for neural data
- Creative ways of extracting meaningful features from huge data sets

Emphasis of this course!

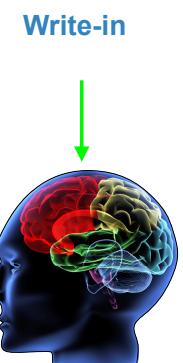


Furthering our basic understanding of brain function

Examples:



Developing biomedical devices that interface with the brain

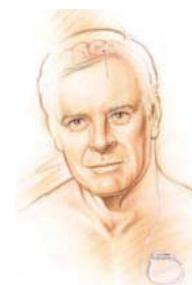


Retinal implant

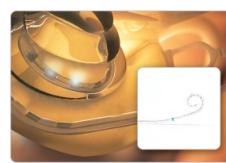


Second Sight

Parkinsons implant



Cochlear implant



Advanced Bionics

Medtronic



Epilepsy implant

Neuropace



Developing biomedical devices that interface with the brain

Write-in



(Source: Prof. Jaimie Henderson, MD)



Developing biomedical devices that interface with the brain

Write-in



(Source: Prof. Jaimie Henderson, MD)



Developing biomedical devices that interface with the brain

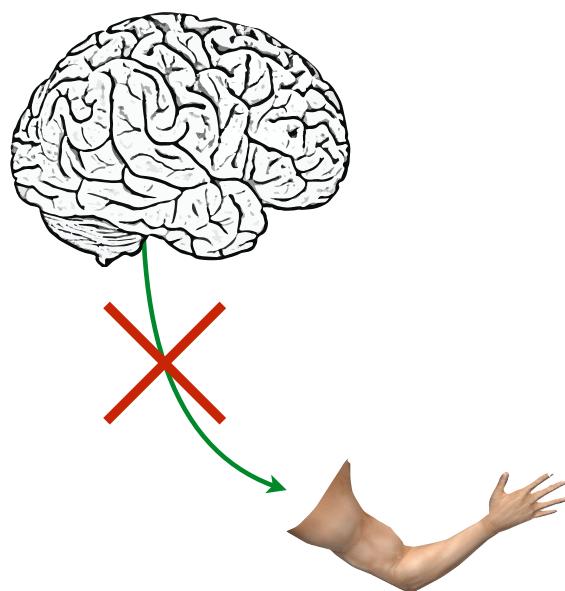
Read-out



Christopher Reeve

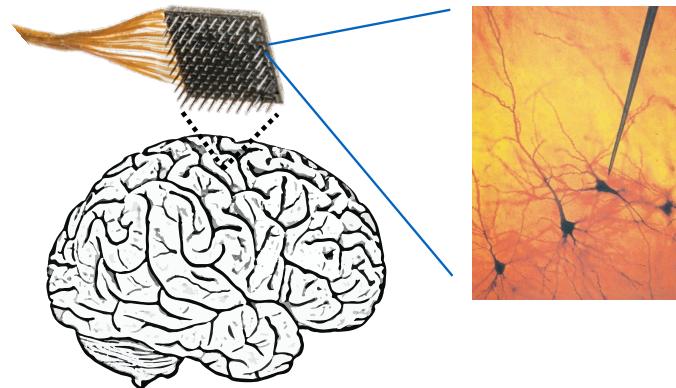


A brain-machine interface

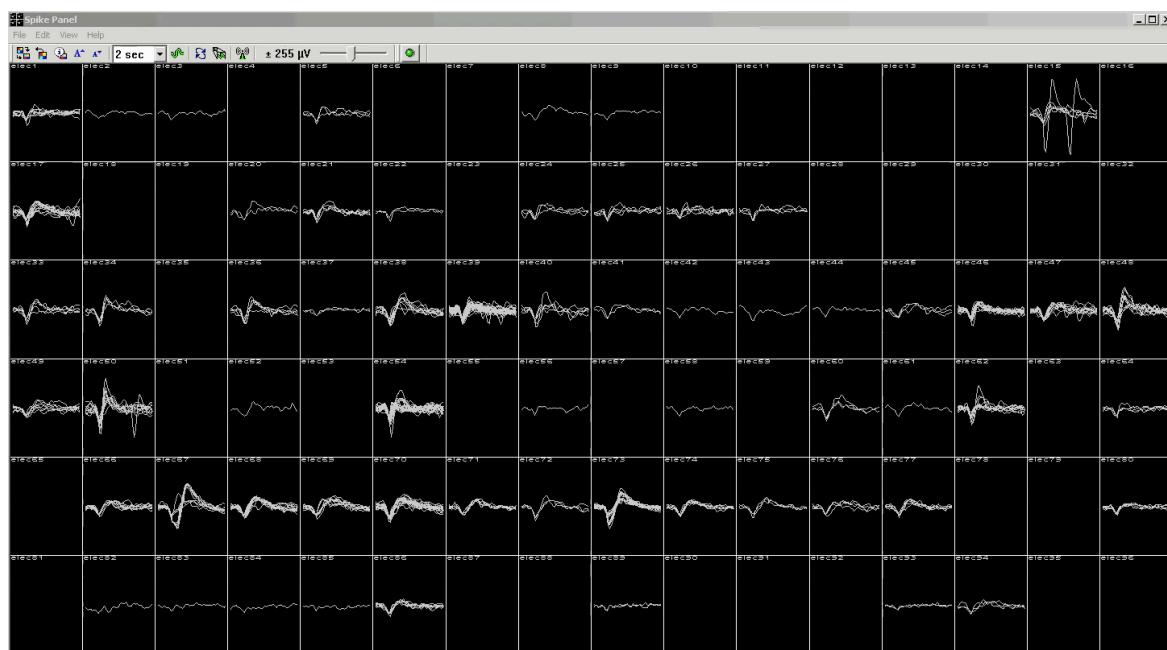




A brain-machine interface

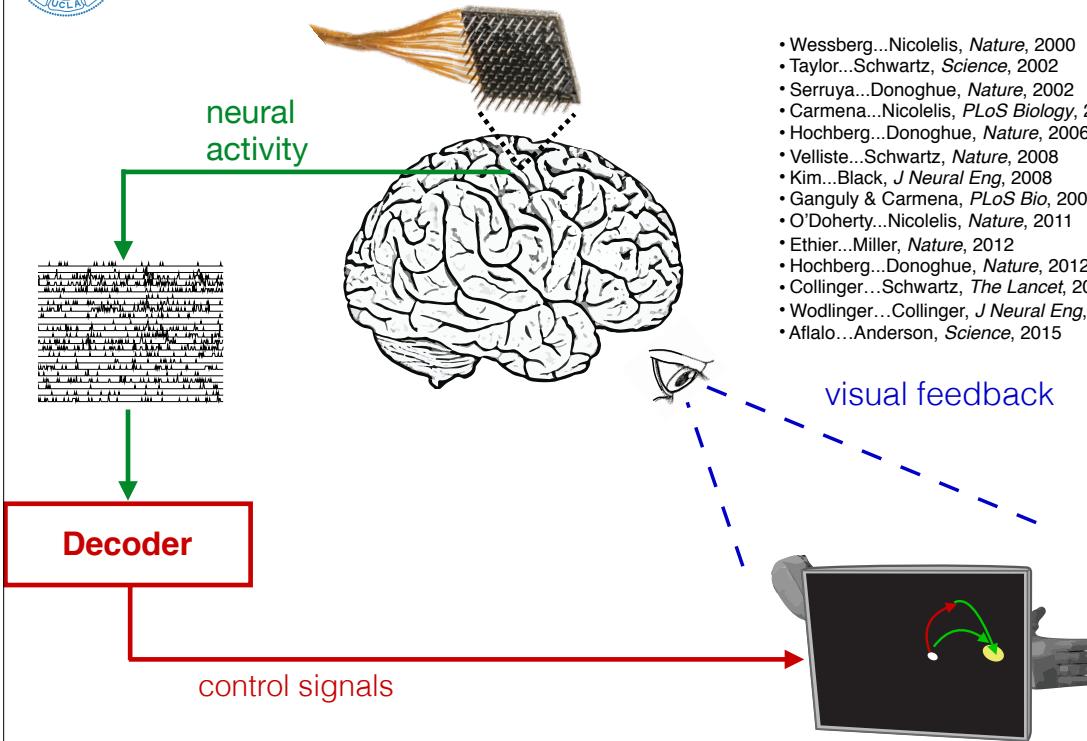


A brain-machine interface





A brain-machine interface



Clinical trial at Stanford University

Free-paced typing using the OPTI-II keyboard

“How did you encourage your sons
to practice music?”

Algorithm: ReFIT-KF + HMM
(**Kao***, *Nuyujukian**, et al., *IEEE TBME*, 2016)

Pandarinath*, *Nuyujukian**, et al., *eLife* 2017
BrainGate2 Pilot Clinical Trial at Stanford University
Caution: Investigational Device.
Limited by Federal Law to Investigational Use.



Clinical trial by BrainGate (Hochberg et al., 2012)



Brain Controlled Prosthetic Arm in Tetraplegic Participant
(spinocerebellar degeneration) using new DARPA prosthetic arm
FDA phase-I clinical trial



60
MINUTES



Collinger, ..., Schwartz (2012) *Lancet*

Brain Controlled Prosthetic Arm in Tetraplegic Participant
(spinocerebellar degeneration) using new DARPA prosthetic arm
FDA phase-I clinical trial



Collinger, ..., Schwartz (2012) *Lancet*



Clinical trial by University of Pittsburgh (Collinger et al., 2013)



Aired on December 30th, 2012

Source: 60 Minutes, CBS News Production

(Collinger et. al., *Lancet*, 2012)



Clinical trial by University of Pittsburgh (Collinger et al., 2013)



Aired on December 30th, 2012

(Collinger et al., Lancet, 2012)

Source: 60 Minutes, CBS News Production



The future of neural prostheses?

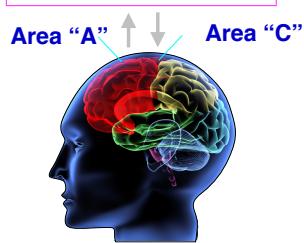
NEAR FUTURE

Brain Prosthesis

Read out: Area "A"

Move arm, sense object

Write in: Area "C"



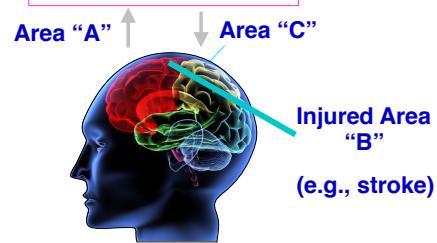
FARTHER FUTURE

Brain Prosthesis

Read out: Area "A"

Mimic: Area "B"

Write in: Area "C"





Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Why this course is timely:

Neuroscience used to be data-limited. Now, datasets are becoming large enough that we're becoming limited by techniques to analyze the data.

Clinical trials are demonstrating that intracortical neural interfaces can lead to devices with performance that may help those with motor disease and paralysis.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

General info:

EE 239AS.2, Neural signal processing and machine learning
Spring quarter, UCLA AY 2016-17.

Instructor:

Prof. Jonathan Kao
E-mail: kao@seas.ucla.edu
Office: 56-147H (Temp: Boelter 6730G)
Office hours: Tues, 2pm - 3pm

Special reader:

Manikandan Srinivasan
E-mail: mani93@ucla.edu
Office: 67-112 Engineering IV
Office hours: Tues + Thurs 3:30-4:30pm

Some high-level thoughts about this class:

- Brain meets engineering.
- While learning neuroscience + machine learning related topics is a goal of this class, it is my sincere hope that this class is also fun — you will be doing some pretty cool things with neural data!
- Interactive.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Rough Schedule:

Date (2017)	Lecture	Content
04 Apr	1	Introduction to neural signal processing and neurons
06 Apr	2	Neuroscience: ion channels & membrane potential
11 Apr	3	Neuroscience: membrane potential (cont.) & action potential
13 Apr	4	Neuroscience: action potential & synaptic transmission Homework 1 due Monday, 17 Apr
18 Apr	5	Neuroscience: spike trains and histograms
20 Apr	6	Poisson Processes I Homework 2 due Monday, 24 Apr
25 Apr	7	Poisson Processes II
27 Apr	8	Poisson Processes III Homework 3 due Monday, 01 May
02 May	9	Discrete Classification I
04 May	10	Discrete Classification II
09 May	M	Midterm, in class
11 May	11	Graphical models Homework 4 due Monday, 15 May
16 May	12	Continuous Decoding
18 May	13	Kalman Filter I Homework 5 due Monday, 22 May
23 May	14	Kalman Filter II
25 May	15	Principal components analysis Homework 6 due Monday, 29 May
30 May	16	Mixture models and Expectation Maximization
01 Jun	17	Probabilistic dimensionality reduction I
06 Jun	18	Probabilistic dimensionality reduction II
08 Jun	19	Overview and Q&A Homework 7 due Friday, 09 Jun
15 Jun	F	Final Examination, 8:00 - 11:00am



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Schedule:

Note, first 2.5 weeks are neuroscience heavy without math.

The rest of the class will have more math.

To give you some indication of the math, I've uploaded a draft of our first mathematical topic, Poisson processes, as well as in-progress rough notes on discrete classification to CCLE.

Pre-requisites:

- (1) Probability — independence, conditional probability, Bayes rule, multivariate Gaussian distribution, Poisson distribution, marginalization, expectation, variance
- (2) Linear algebra — basic matrix operations, eigenvalue decomposition, singular value decomposition, rank, matrix inversion
- (3) MATLAB. (If using Python, all good, but you'll need to convert the data.)



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Grading:

30% Homework (7 planned assignments)

30% Midterm

40% Final

Late assignments will not be accepted. They are due at 11:59pm on the Monday they are due (to Gradescope). If you do not get the assignment in, it won't let you submit. You can repeatedly submit, and so you should keep submitting early and often as you work on the homework.

To accommodate unforeseen circumstances, we will *drop* the lowest homework score.

A word about Gradescope, which we are trying for the first time.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Textbooks:

Neuroscience: *Principles of Neural Science*, by Kandel, Jessell, Schwartz, et al.

Machine learning: *Pattern Recognition and Machine Learning*, by Christopher Bishop

Available [here](http://users.isr.ist.utl.pt/~wurmd/Livros/school/Bishop%20-%20Pattern%20Recognition%20And%20Machine%20Learning%20-%20Springer%20-%202006.pdf) (<http://users.isr.ist.utl.pt/~wurmd/Livros/school/Bishop%20-%20Pattern%20Recognition%20And%20Machine%20Learning%20-%20Springer%20-%202006.pdf>).

Theoretical Neuroscience, by Peter Dayan and Larry F Abbott (we will only need chapter 1, and so I will upload it to the course website).

Course materials on CCLE.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

About me:

- Did graduate work with Krishna V. Shenoy at Stanford University (research group including neuroscientists and engineers; regularly performed experiments and did neural recordings with monkeys)
- Postdoc at Stanford in the same lab (focus on deep learning and its applications to neuroscience)
- First quarter teaching here at UCLA. Your patience much appreciated.
- Taught a version of this class at Stanford.

E-mail: kao@seas.ucla.edu
Office: 56-147H (Temp: Boelter 6730G)
Office hours: Tues, 2pm - 3pm



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

About Mani:

- Second year PhD student in UCLA EE.
- His research interests include information theory, bioinformatics, and machine learning.

E-mail: mani93@ucla.edu
Office: 67-112 Engineering IV
Office hours: Tues + Thurs 3:30-4:30pm



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

The honor code:

Academic integrity

UCLA embraces the core values of integrity, excellence, accountability, respect, and service through the True Bruin program <http://www.truebruin.ucla.edu>.

I take honor code very seriously; students caught cheating or violating the honor code will face disciplinary action. Please refer to the UCLA student conduct code:

<http://www.deanofstudents.ucla.edu/portals/16/documents/UCLA%20Student%20Conduct%20Code%209-29-14%20final.pdf>

In this class, unacceptable behavior includes plagiarizing the work of others, plagiarizing code, or copying another person's exam. In accordance with UCLA policy, any instance of suspected academic dishonesty will be immediately reported to the Dean of Students Office and zero credit will be given for any work determined to be dishonest.



Lecture 1: EE 239AS.2 — Neural Signal Processing and Machine Learning

Questions?



Roadmap

Introduction to neuroscience

Chapter 1: The brain and behavior
Chapter 2: Nerve cells and behavior

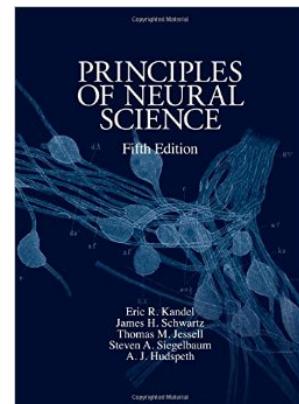


How are neural signals generated?

Chapter 5+6: Ion channels and membrane potential
Chapter 7: Propagated signaling: the action potential

How do neurons communicate with each other?

Chapter 8: Overview of synaptic transmission
Chapter 10: Synaptic integration



Introduction to neuroscience

- Reading assignment from Kandell, Schwartz & Jessell:
 - Chapter 1 – The brain and behavior
 - Chapter 2 – Nerve cells, neural circuitry, and behavior
- Neural science (neuroscience) – understand mental processes underlying perception, action, learning and memory.
- Are mental processes localized in the brain, or distributed?
- What is the relationship between anatomy, physiology & function?
- Should we study regions as a whole, or individual cells?
- Are mental processes hard wired?
- Role of genetics in nerve growth? Regulated by learning?
- How does experience alter brain processing of subsequent events?



Introduction to neuroscience

- Neuroscience studies all of this and attempts to link molecules to mind.
- Human brain: highly-interconnected network of ~100 billion individual nerve cells.
 - Must learn how neurons are organized into signaling pathways and how they communicate.
- So, let's get started...



A Brief History

- Galvani (1700s) – muscle and nerve cells produce electricity.
- Golgi and Ramon y Cajal (1800s) – saw a network of discrete cells, not a continuous mass/web, with compound microscope.
- DuBouis-Reymond, Muller & Helmholtz (1800s) – electrical activity of one nerve cell affects activity of adjacent cell in predictable ways.
- Ramon y Cajal's *neuron doctrine* (1800s) – individual neurons are the elementary signaling elements of the nervous system.
- Harrison (1920s) – two processes that grow out of cell body: dendrites and the axon.
- Bernard, Erlich & Langley (1800s) – drugs bind specifically to receptors in the cell surface (membrane) → chemical basis of communication between nerve cells.



Cellular Connectionism

- Wernicke, Sherrington & Camon y Cajal (~1850) put forth a view of the brain termed *cellular connectionism*:
 - Individual neurons are the signaling units of the brain
 - They are generally arranged in functional groups
 - They connect to one another in a precise fashion
- This is in opposition to a previous view termed *aggregate field*.



Brain has Distinct Functional Regions

- CNS is bilateral and symmetrical.
- Modern imaging techniques confirm that different regions are specialized for different functions.
- However, parallel distributed processing (functions served by more than one neural pathway) in operation.
- CNS has 7 major parts:
 - 1) skin, joints, muscle
 - 2) breathing, heart rate
 - 3) movement: $4 \leftrightarrow 7$
 - 4) learning motor skills
 - 5) eye movements
 - 6) info gate keeper $7 \leftarrow \rightarrow$ rest
 - 7) higher brain funtions: sensory, motor, memory, emotion

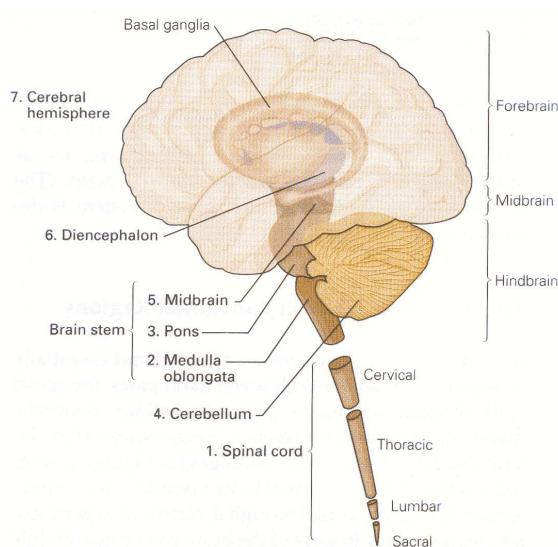


Figure 1-2A The central nervous system can be divided into seven main parts.



Major Divisions of the Brain

- Easy to see the major divisions anatomically (left) or with modern non-invasive imaging such as MRI.

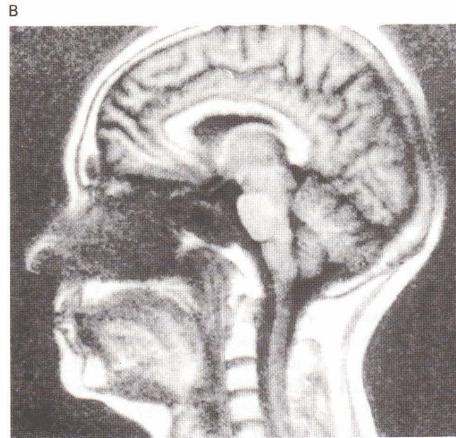
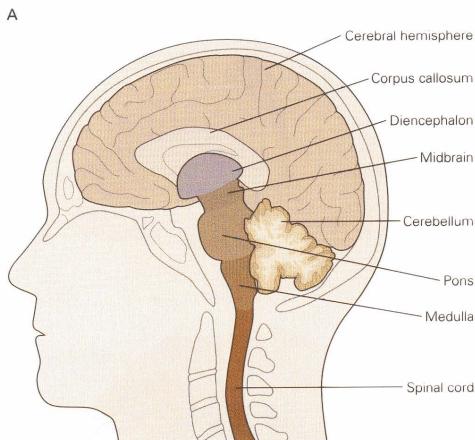


Figure 1-3 The main divisions are clearly visible when the brain is cut down the midline between the two hemispheres.

A. This schematic drawing shows the position of major structures of the brain in relation to external landmarks. Students of

brain anatomy quickly learn to distinguish the major internal landmarks, such as the corpus callosum, a large bundle of nerve fibers that connects the left and right hemispheres.

B. The major brain divisions drawn in A are also evident here in a magnetic resonance image of a living human brain.



Cerebral Cortex

- Brain operations responsible for our cognitive abilities occur in the cerebral cortex.
- Cerebral cortex – “furrowed gray matter” covering the two cerebral hemispheres.
- Folds increase surface area: gyri (crests) and sulci (grooves)
- Four anatomically distinct lobes:
 - Frontal – planning future action and the control of movement.
 - Parietal – relating position of body to extra-personal space.
 - Temporal – hearing, learning, memory and emotion.
 - Occipital – vision.

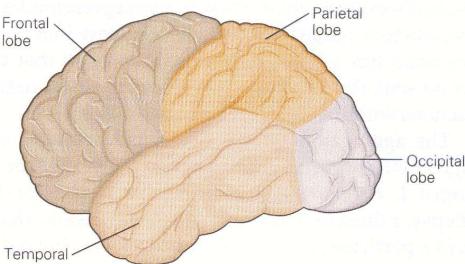


Figure 1-2B The four lobes of the cerebral cortex.

← anterior posterior →
(front) (back)



Two Important Features of Cerebral Cortex

- Each hemisphere is concerned primarily with sensory and motor processing of the contralateral (opposite) side of the body.

- E.g., electrically stimulate right motor cortex → left arm movement (Fritsch & Hitzig, 1870s).

- The hemispheres are similar in appearance, but are not completely symmetrical in structure or in function.

- E.g., language centers in left hemisphere (aphasia patients, Broca, 1860s).

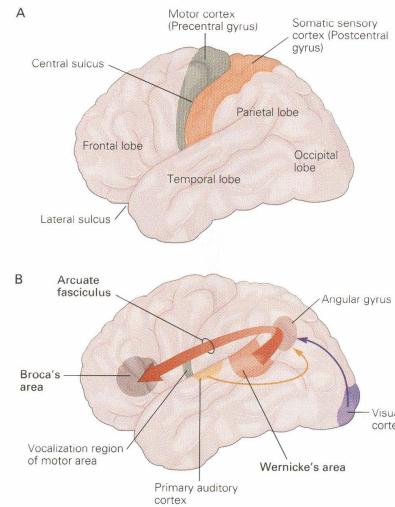


Figure 1-4 The major areas of the cerebral cortex are shown in this lateral view of the left hemisphere.

A. Outline of the left hemisphere.

B. Areas involved in language. Wernicke's area processes the auditory input for language and is important to the understanding of speech. It lies near the primary auditory cortex and the angular gyrus, which combines auditory input with information from other senses. Broca's area controls the production of intelligible speech. It lies near the region of the motor area that controls the mouth and tongue movements that form words. Wernicke's area communicates with Broca's area by a bidirectional pathway, part of which is made up of the arcuate fasciculus. (Adapted from Geschwind 1979.)



Brodmann's Areas

- Brodmann (~1900) distinguished *functional areas* of the cortex based on variations in the *structure of cells* and in the *arrangement of these cells* into layers.
- Termed *cytoarchitectonic* method.
- 52 anatomically and functionally distinct areas in human cerebral cortex.
- Still widely used today (e.g., motor cortex is area 4).
- We will return to this central concept of **functional localization** in various neuroengineering applications.

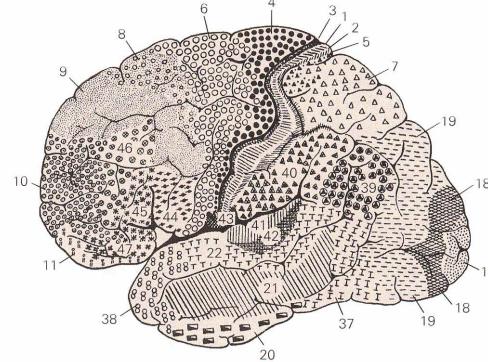


Figure 1-5 In the early part of the twentieth century Korbinian Brodmann divided the human cerebral cortex into 52 discrete areas on the basis of distinctive nerve cell structures and characteristic arrangements of cell layers. Brodmann's scheme of the cortex is still widely used today and is continually updated. In this drawing each area is represented by its own symbol and is assigned a unique number. Several areas defined by Brodmann have been found to control specific brain functions. For instance, area 4, the motor cortex, is responsible for voluntary movement. Areas 1, 2, and 3 comprise the primary somatosensory cortex, which receives information on bodily sensation. Area 17 is the primary visual cortex, which receives signals from the eyes and relays them to other areas for further deciphering. Areas 41 and 42 comprise the primary auditory cortex. Areas not visible from the outer surface of the cortex are not shown in this drawing.



Functional Localization in Language

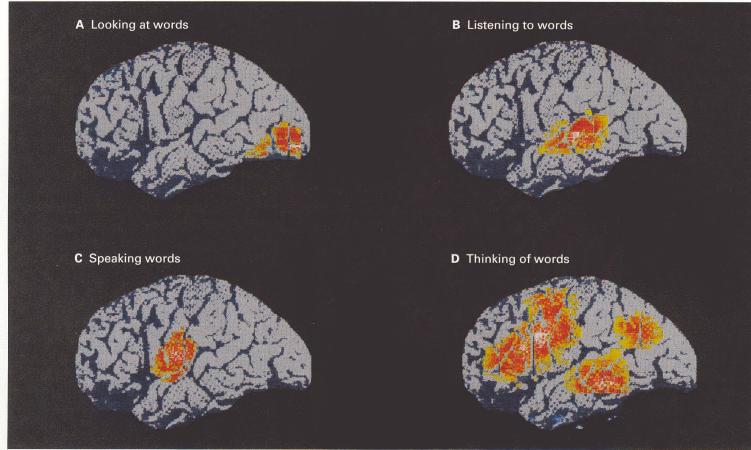


Figure 1-6 Specific regions of the cortex involved in the recognition of a spoken or written word can be identified with PET scanning. Each of the four images of the human brain shown here (from the left side of the cortex) actually represents the averaged brain activity of several normal subjects. (In these PET images white represents the areas of highest activity, red and yellow quite high activity, and blue and gray the areas of minimal activity.) The "input" component of language (reading or hearing a word) activates the regions of the brain shown in A and B. The motor "output" component of language (speech or thought) activates the regions shown in C and D. (Courtesy of Cathy Price.)

A. The reading of a single word produces a response both in the primary visual cortex and in the visual association cortex (see Figure 1-5).

B. Hearing a word activates an entirely different set of areas in the temporal cortex and at the junction of the temporal-

parietal cortex. (To control for irrelevant differences, the same list of words was used in both the reading and listening tests.) A and B show that the brain uses several discrete pathways for processing language and does not transform visual signals for processing in the auditory pathway.

C. Subjects were asked to repeat a word presented either through earphones or on a screen. Speaking a word activates the supplementary motor area of the medial frontal cortex. Broca's area is activated whether the word is presented orally or visually. Thus both visual and auditory pathways converge on Broca's area, the common site for the motor articulation of speech.

D. Subjects were asked to respond to the word "brain" with an appropriate verb (for example, "to think"). This type of thinking activates the frontal cortex as well as Broca's and Wernicke's areas. These areas play a role in all cognition and abstract representation.



Neurons

- Nerve cells (neurons) are the basic unit of the brain.
- Neurons are relatively simple in their morphology.
- Approximately 10^{11} neurons in the human brain.
- About 1000 different types, but all have same basic architecture.
- Thus "complexity" arises primarily from precise anatomical circuits, not neuron specialization.
- Neurons with basically similar properties produce quite different actions because of their connections with each other.
- Rather like any single transistor in a VLSI digital circuit.



Neurons Continued

- There are four basic features of the nervous system we are primarily interested in:
 - 1) Mechanisms by which neurons produce signals.
 - 2) Patterns of connections between neurons.
 - 3) Relationship of different patterns of interconnection to different type of behavior.
 - 4) Means by which neurons and their connections are modified by experience.



Nervous System has two Cell Classes

- Nerve cells (neurons) and glial cells (glia).
- Glia are support cells, and outnumber neurons 10-50:1.
- Glia are not directly involved in information processing.
- Glia do:
 - 1) Support neurons by providing structure.
 - 2) Produce myelin used to electrically insulate neural axons (*oligodendrocytes & Schwann cells*).
 - 3) Scavenge to remove debris after injury or cell death.
 - 4) So up previously-released chemical transmitters.
 - 5) Help guide axon growth during development.
 - 6) Help regulate properties of presynaptic terminal.
 - 7) Help form blood-brain barrier (*astrocytes*).
 - 8) Release growth factors and nourish neurons.

An interesting read: <https://www.technologyreview.com/s/601137/the-rogue-immune-cells-that-wreck-the-brain/>



Glia

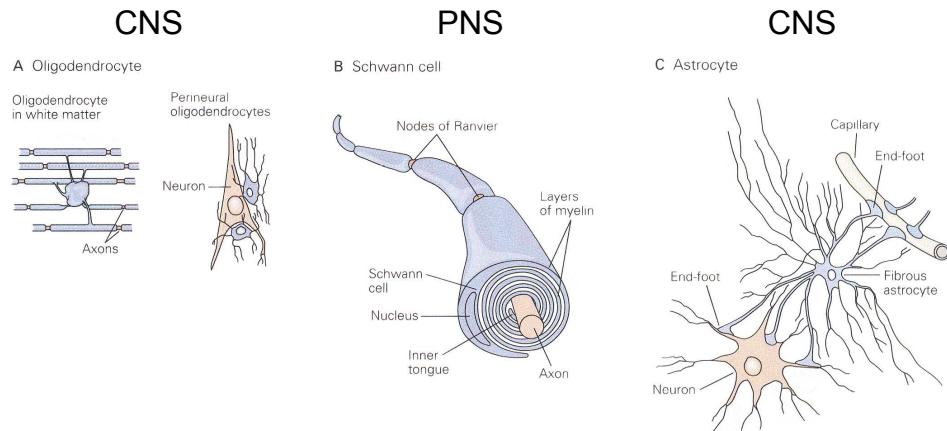


Figure 2-1 The principal types of glial cells in the central nervous system are astrocytes and oligodendrocytes and in the peripheral nervous system, Schwann cells.

A. Oligodendrocytes are small cells with relatively few processes. In white matter (left) they provide the myelin, and in gray matter (right) perineurial oligodendrocytes surround and support the cell bodies of neurons. A single oligodendrocyte can wrap its membranous processes around many axons, insulating them with a myelin sheath.

B. Schwann cells furnish the myelin sheaths that insulate axons in the peripheral nervous system. Each of several Schwann cells, positioned along the length of a single axon, forms a segment of myelin sheath about 1 mm long. The

sheath assumes its form as the inner tongue of the Schwann cell turns around the axon several times, wrapping it in concentric layers of membrane. The intervals between segments of myelin are known as the nodes of Ranvier. In living cells the layers of myelin are more compact than what is shown here. (Adapted from Alberts et al. 1994.)

C. Astrocytes, the most numerous of glial cells in the central nervous system, are characterized by their star-like shape and the broad end-feet on their processes. Because these end-feet put the astrocyte into contact with both capillaries and neurons, astrocytes are thought to have a nutritive function. Astrocytes also play an important role in forming the blood-brain barrier.



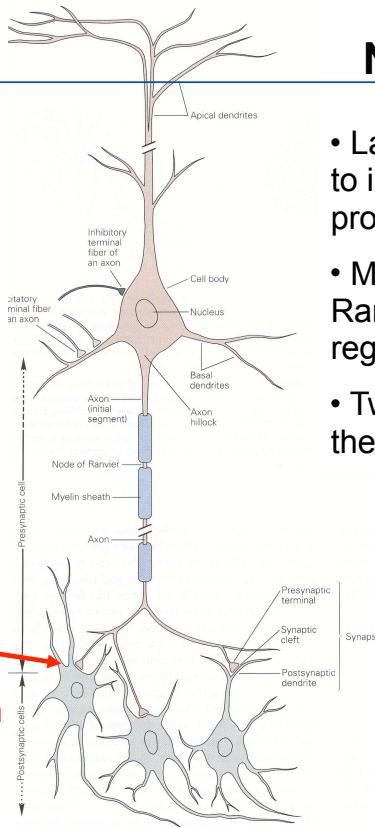
Neurons

- Neurons are the main signaling units of the nervous system.
- Neurons have four regions:
 - 1) Cell body (soma) – metabolic center, with nucleus, etc.
 - 2) Dendrites – tree like structure for receiving incoming signals.
 - 3) Axon – single, long, tubular structure for sending outgoing signals.
 - 4) Presynaptic terminals – sites of communication to next neurons.
- Axons convey signals to other neurons:
 - Conveys electrical signals long distances (0.1mm – 3 m).
 - Conveys **action potentials** (~100 mV, ~1 ms pulses).
 - Action potentials initiate at the axon hillock.
 - Propagate w/o distortion or failure at 1-100 m/s.
 - Actively regenerated while propagating; shape preserved.



Information flow

Not random connection (synapse)



Neurons

- Large axons are wrapped in fatty myelin to increase the speed of action potential propagation.
- Myelin sheath interrupted at Nodes of Ranvier; it is here that action potentials are regenerated.
- Two neurons communicate, chemically, at the **synapse**.

Figure 2-2 Structure of a neuron. Most neurons in the vertebrate nervous system have several main features in common. The cell body contains the nucleus, the storehouse of genetic information, and gives rise to two types of cell processes, axons and dendrites. Axons, the transmitting element of neurons, can vary greatly in length: some can extend more than 3 m within the body. Most axons in the central nervous system are very thin (between 0.2 and 20 μm in diameter) compared with the diameter of the cell body (50 μm or more). Many axons are insulated by a fatty sheath of myelin that is interrupted at regular intervals by the nodes of Ranvier. The action potential, the cell's conducting signal, is initiated either at the axon hillock, the initial segment of the axon, or in some cases slightly farther down the axon at the first node of Ranvier. Branches of the axon of one neuron (the presynaptic neuron) transmit signals to another neuron (the postsynaptic cell) at a site called the synapse. The branches of a single axon may form synapses with as many as 1000 other neurons. Whereas the axon is the output element of the neuron, the dendrites (apical and basal) are input elements of the neuron. Together with the cell body, they receive synaptic contacts from other neurons.



Action Potentials

- Signals by which brain receives, analyzes and conveys information.
- Action potentials are highly stereotyped throughout nervous system.
- Action potentials convey all information about vision, audition, odors, etc...
- Information not conveyed by shape.
- Information conveyed by the path the signal travels and pattern of action potentials.

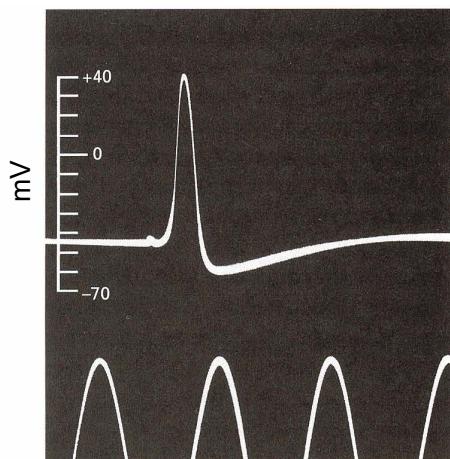


Figure 2-3 This historic tracing is the first published intracellular recording of an action potential. It was obtained in 1939 by Hodgkin and Huxley from the squid giant axon, using glass capillary electrodes filled with sea water. Time marker is 500 Hz. The vertical scale indicates the potential of the internal electrode in millivolts, the sea water outside being taken as zero potential. (From Hodgkin and Huxley 1939.)



Two principles advanced by Ramon y Cajal

- Principle of dynamic polarization:

Electrical signals within a nerve cell flow only in one direction.

- Principle of connectional specificity:

Neurons do not connect indiscriminately to form random networks. Instead, neurons make specific connections with certain target neurons but not others.



Neuron Shape Varies Considerably

Figure 2-4 Neurons can be classified as unipolar, bipolar, or multipolar according to the number of processes that originate from the cell body.

A. Unipolar cells have a single process, with different segments serving as receptive surfaces or releasing terminals. Unipolar cells are characteristic of the invertebrate nervous system.

B. Bipolar cells have two processes that are functionally specialized: the dendrite carries information to the cell, and the axon transmits information to other cells.

C. Certain neurons that carry sensory information, such as information about touch or stretch, to the spinal cord belong to a subclass of bipolar cells designated as pseudo-unipolar. As such cells develop, the two processes of the embryonic bipolar cell become fused and emerge from the cell body as a single process. This outgrowth then splits into two processes, both of which function as axons, one going to peripheral skin or muscle, the other going to the central spinal cord.

D. Multipolar cells have an axon and many dendrites. They are the most common type of neuron in the mammalian nervous system. Three examples illustrate the large diversity of these cells. Spinal motor neurons (left) innervate skeletal muscle fibers. Pyramidal cells (middle) have a roughly triangular cell body; dendrites emerge from both the apex (the apical dendrite) and the base (the basal dendrites). Pyramidal cells are found in the hippocampus and throughout the cerebral cortex. Purkinje cells of the cerebellum (right) are characterized by the rich and extensive dendritic tree in one plane. Such a structure permits enormous synaptic input. (Adapted from Ramón y Cajal 1933.)

