
welcome
to 6998 6!


Computation
and the Brain

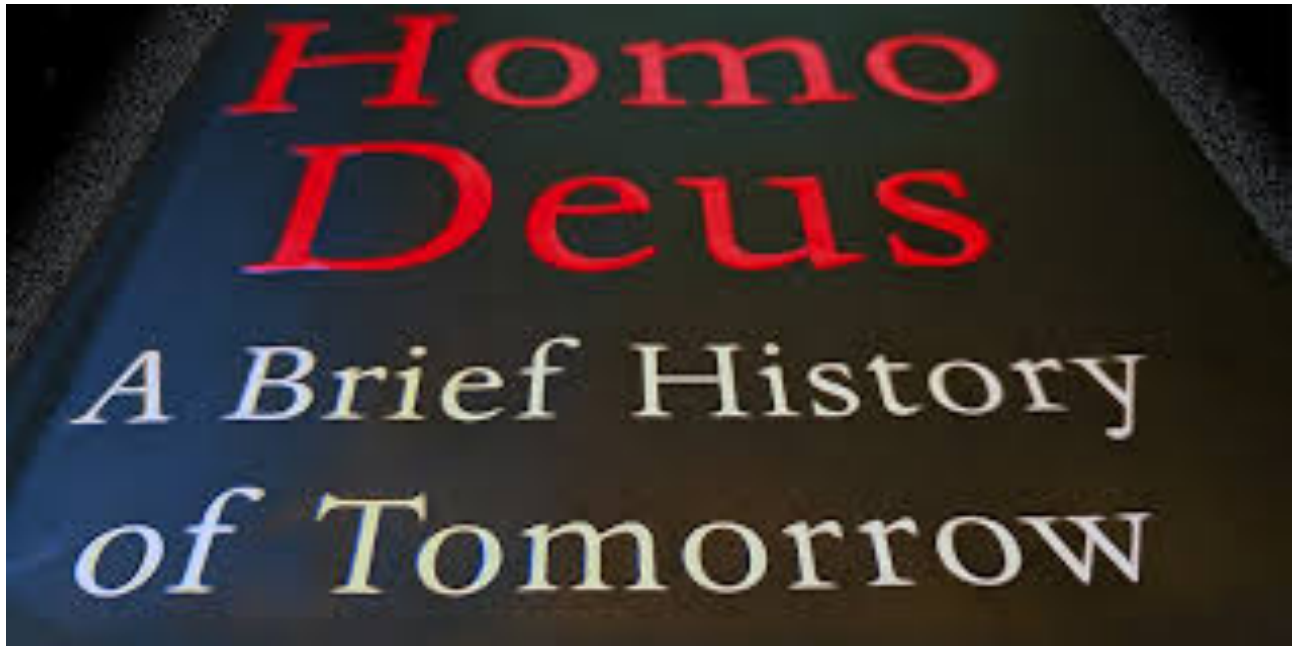
Q: Is the brain a computer?

A: “Face it, your brain is a computer”

Gary Marcus, cognitive scientist NYU, NYT April 2015

A: “Your Brain is an algorithm”

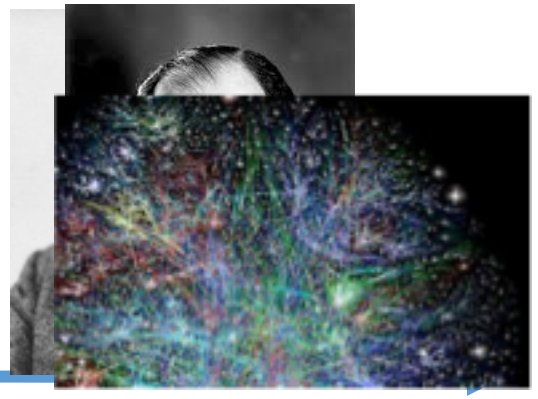
Yuval Harari, historian, ***Homo Deus*** 2017



COMPUTER	THE BRAIN
Inorganic	Alive
Exact	Error prone
70 – 7,000,000 Watts	20 Watts
Chess, Go, Jeopardy	Survival, creativity, dreams
$10^{10\text{ -- }18}$ operations/s 1 – 40,000 processors	50 operations/s, 10^{11} components
Connects to others	If in the mood
Was designed	Has evolved
Cool machine	Rather emotional
Behavior is deliberately programmed	Behavior is emergent

Let’s look at history.
Computation timeline first

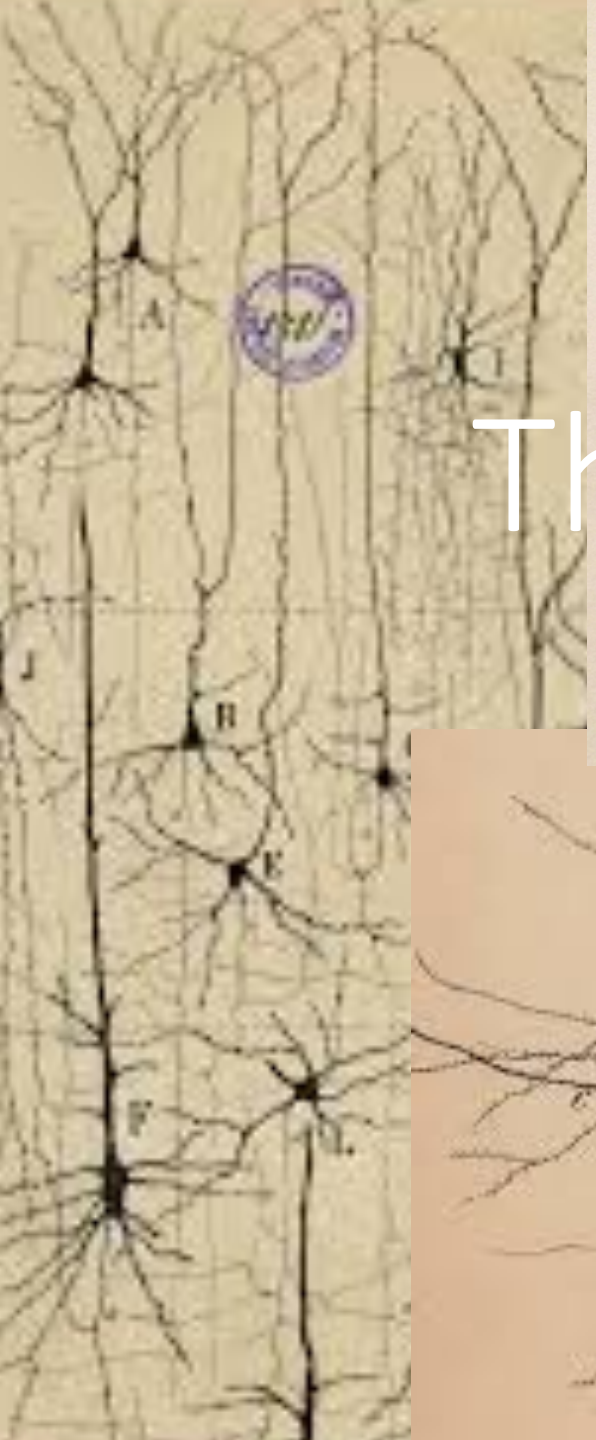


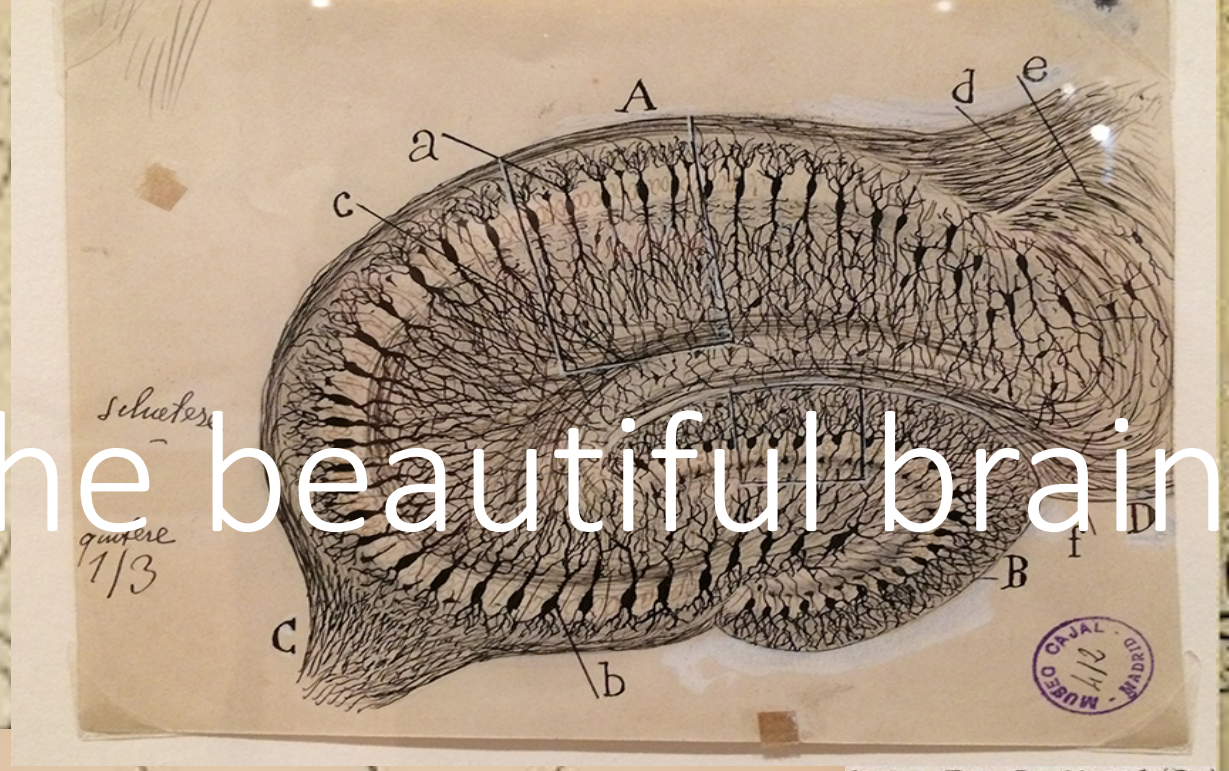



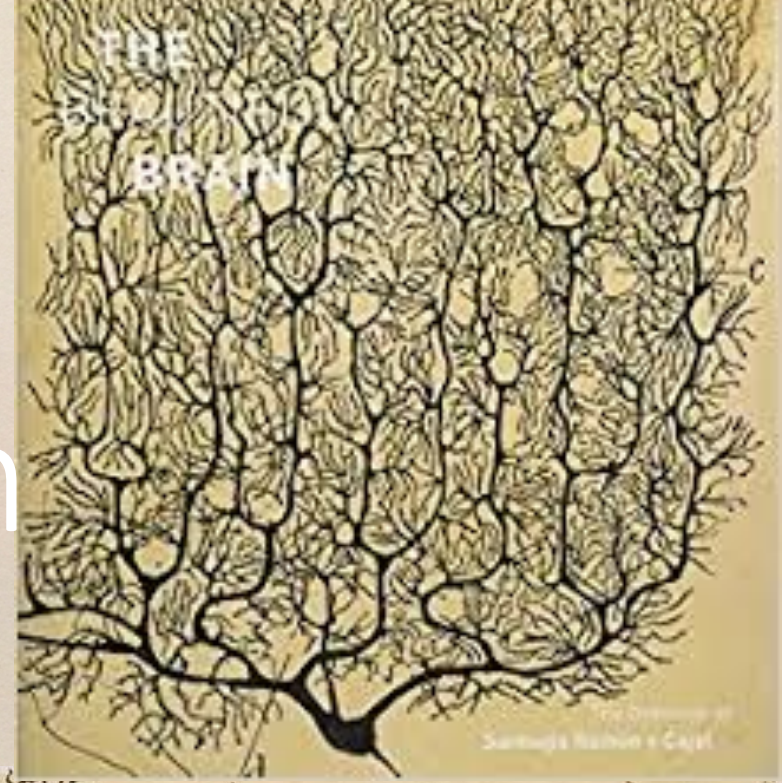
Neuroscience

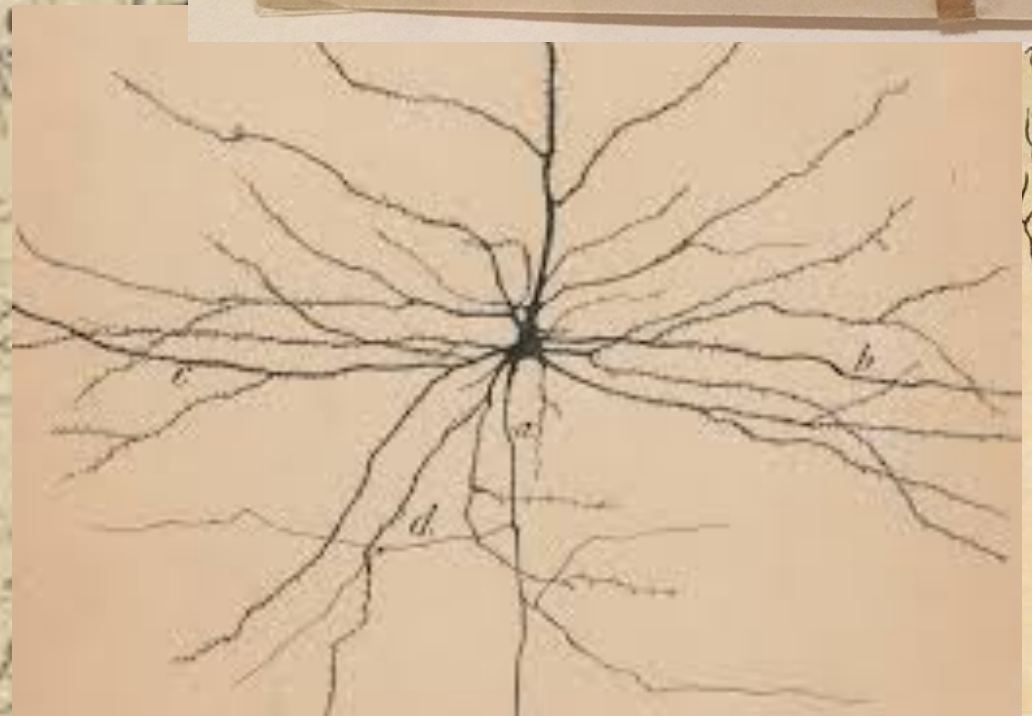
- Alcmaeon of Croton 520 BC
- Hippocrates 400 BC vs Aristotle 330 BC vs Galen 100AD
- …
- L. Galvani electrical activity 1760
- Broca and Wernicke: language in the brain 1870
- C. Golgi reazione nera (Golgi stain) 1872
- S. Ramon y Cajal neuron drawings, axonal cone 1880
- Reticulism vs the neuron hypothesis and the Nobel fight, 1906

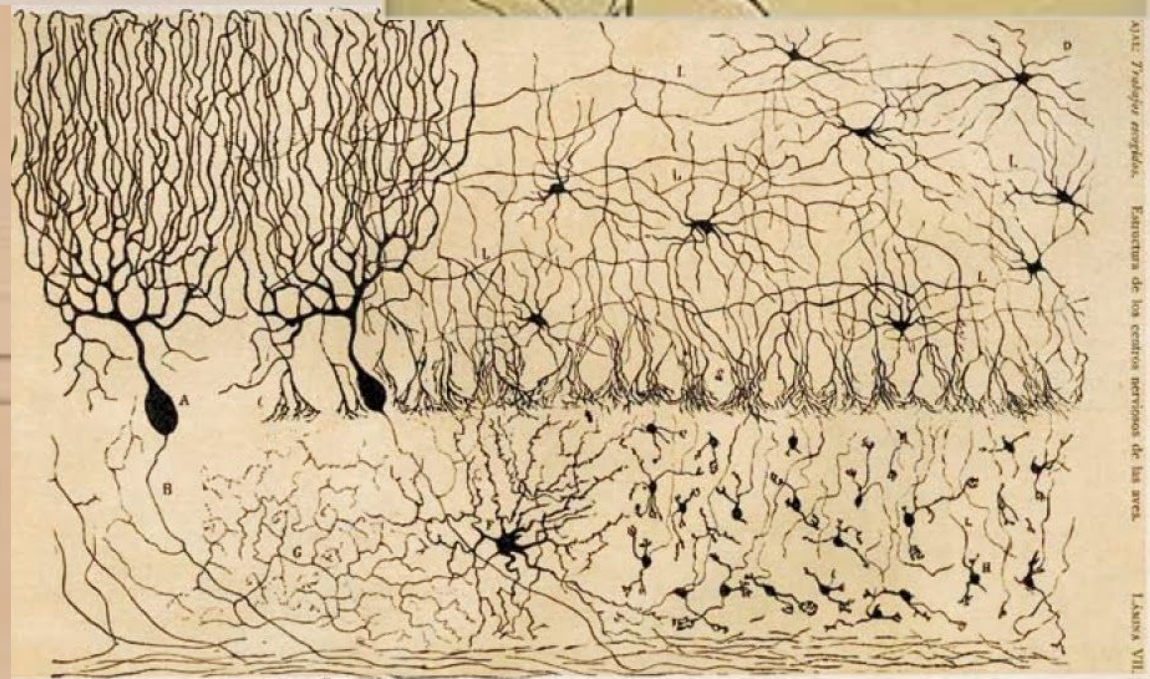
The beautiful brain











Next: The rise of Neuroscience, as seen from Karolinska

- 1906: Ramon y Cajal and Golgi: ***the neuron***
- 1932: C. Sherrington: ***the synapse***
- 1936: H. Dale and O. Loewi: ***neurotransmitters***
- 1963: Eccles, Hodgkin, Huxley: ***the spike***
- 1967 Granit, Hartline, and Wald; 1981 Sperry, Hubel, and Wiesel: ***vision***
- 1970: Katz, von Euler, Axelrod: ***synaptic vesicles***
- 1991: Neher – Sakmann; 2000: Carlsson, Greengard, Kandel: ***ion channels***
- 2006: R. Axel and L. Buck: ***olfaction***
- 2014: O'Keefe, M. Moser, and E. Moser: ***place cells and grid cells***

Next: brief discussions of the lauded topics

- *The neuron*
- *Synapses*
- *Neurotransmitters and vesicles*
- *Spikes and Ion channels*
- *Olfaction*
- *Place cells and grid cells*
- *Vision*
- Plus: the rise of the *computer-brain interface*, 1944 – 1990

But first: About the class

- TAs: Jacob Portes, Tim Randolph, Kiran Vodrahali (and Dan Mitropolski?)
- Weekly ***reading*** assignments, plus talks to watch, posted Wednesday night.
- Research papers researched
- Weekly ***responses*** to the readings/talks, due Wednesday at noon. Plus 1-2 ***discussion points***
- Resources
- Attendance and participation
- Final project: ideally in groups of 3-4

Also:

Deep Learning to Learn

Pieter Abbeel
University of California, Berkeley

Monday, Sep. 10, 11:30, Davis Auditorium

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- *Synapses*
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- *Vision*
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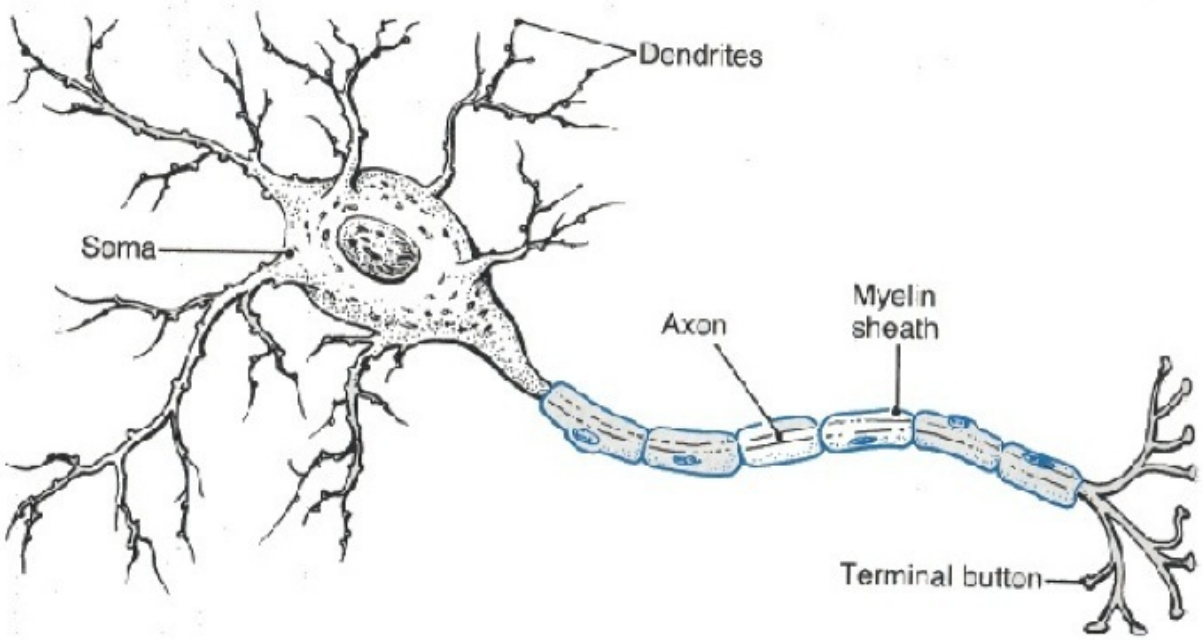
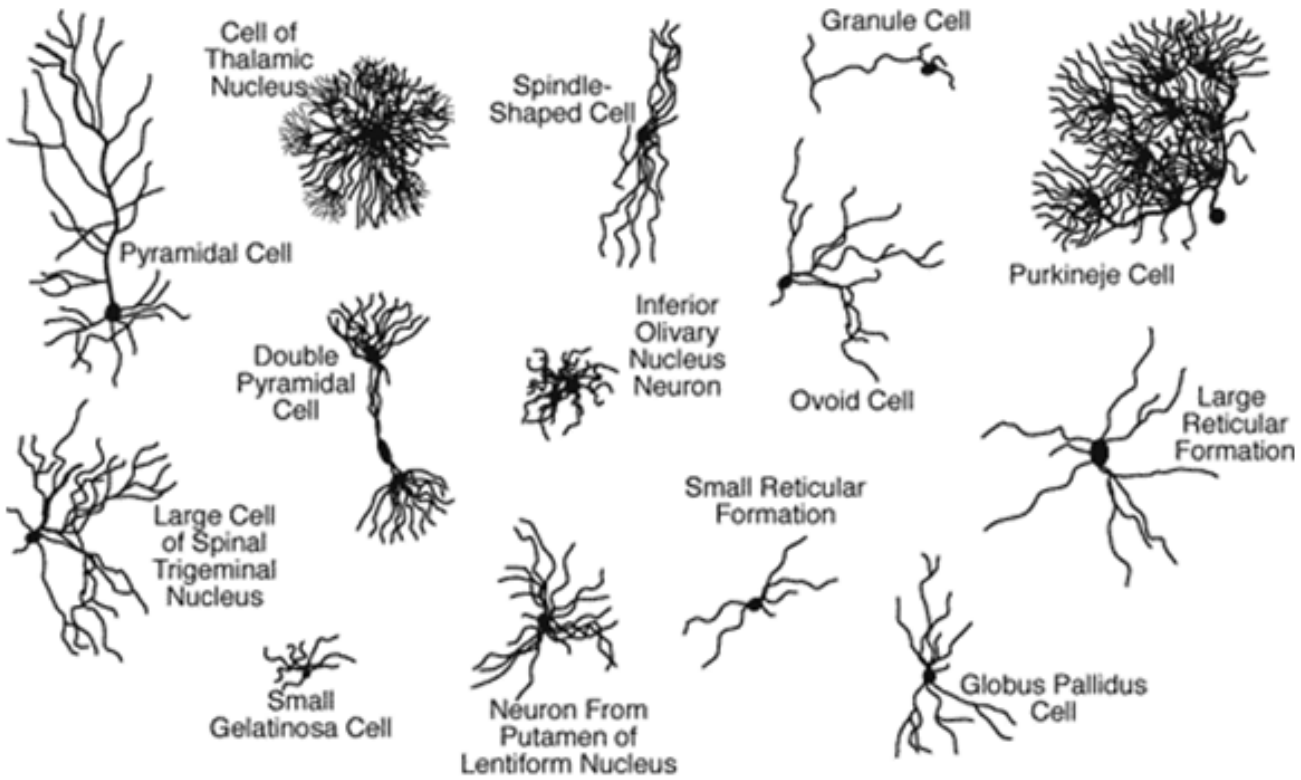
The Neuron

- soma
- dendrite
- axon
- cone
- myeline
- boutons and spines
- membrane and its potential (-70 mV in steady state)

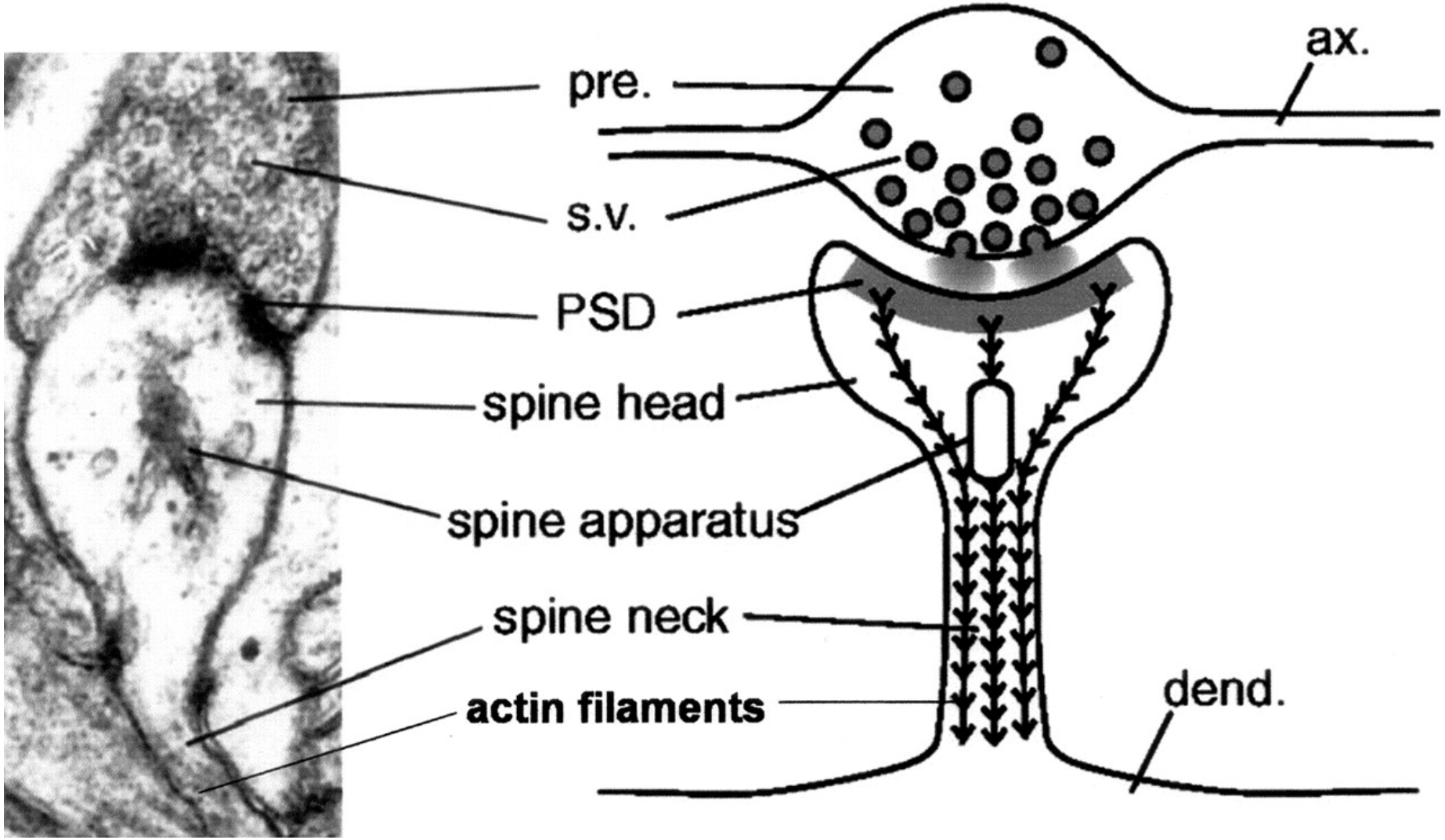


The Neuron

- soma
- dendrite
- axon
- myeline
- boutons and spines
- ***many*** kinds

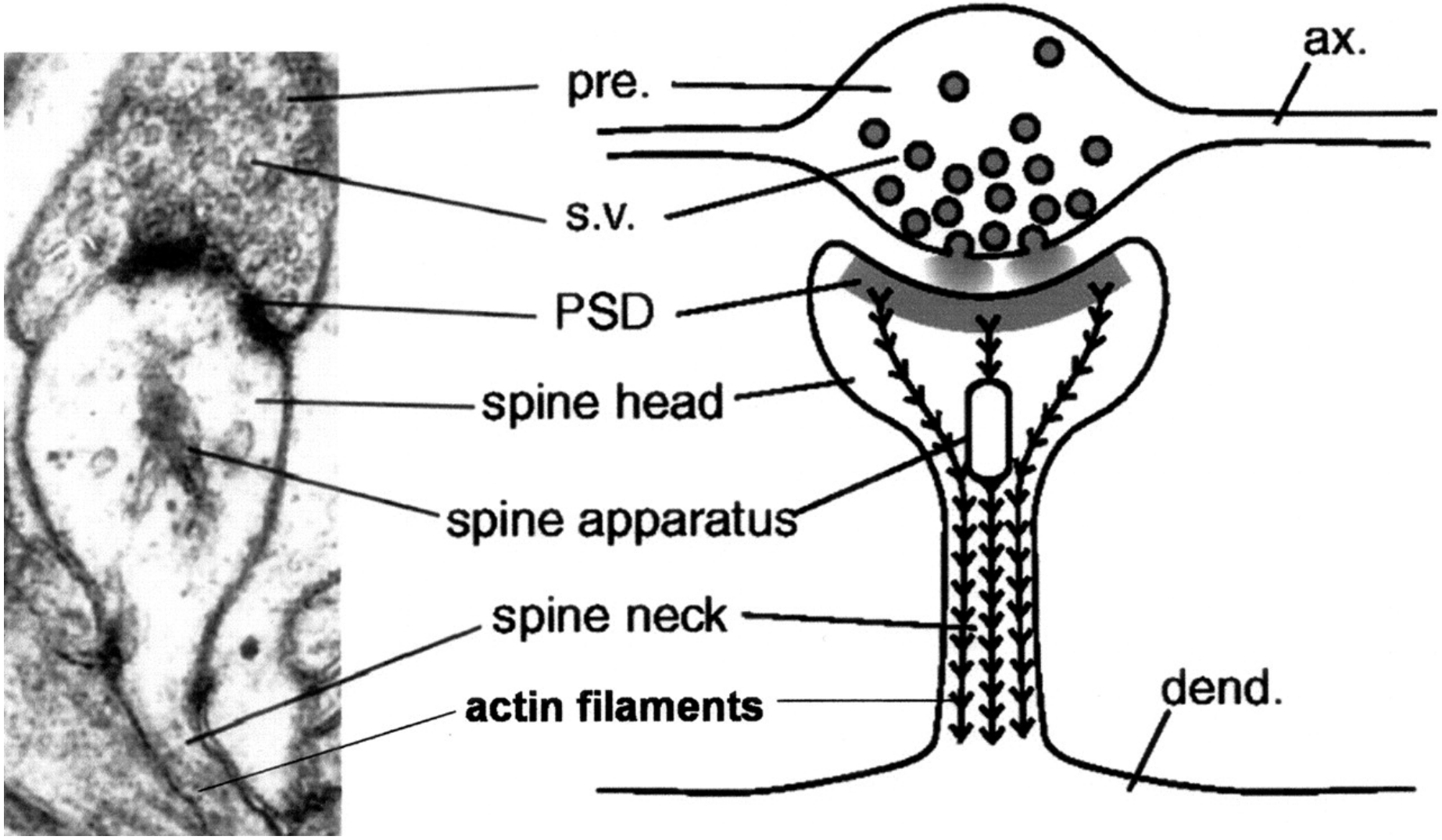


The synapse



- Bouton
- Spine
- Cleft

The synapse



- Bouton
- Spine
- Cleft
- ***Synaptic weight and its plasticity***

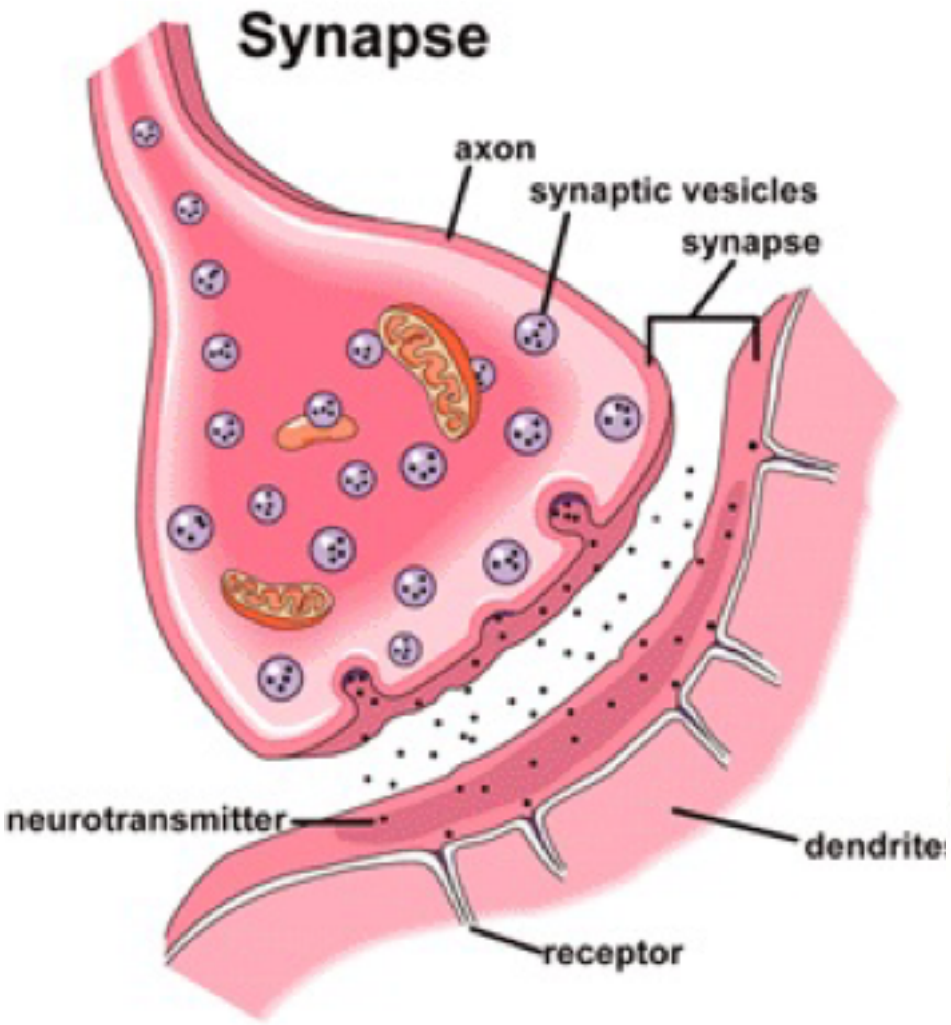
Neurotransmitters

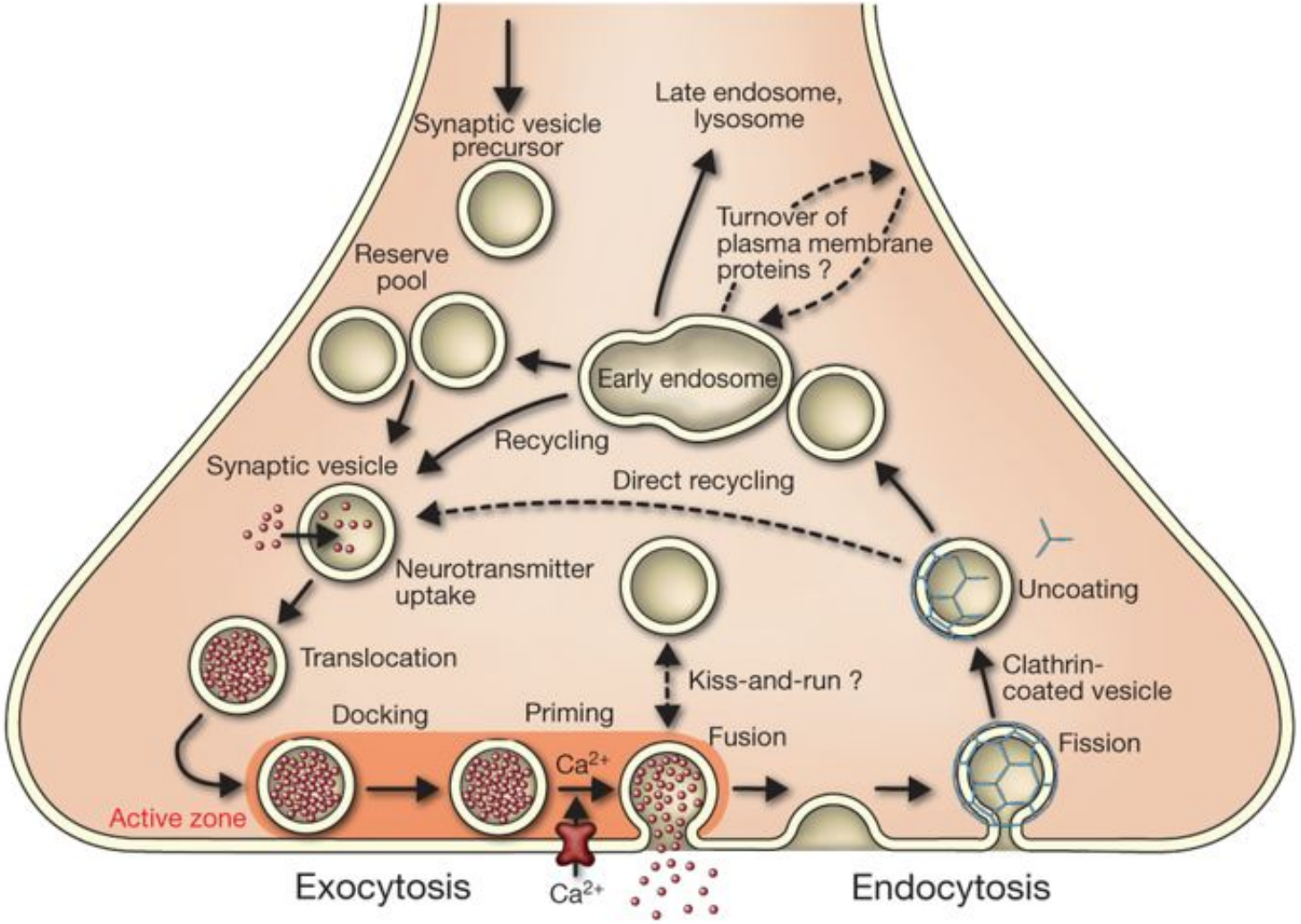
- The chemical language of neurons
- The main result of the firing of a neuron is the release of neurotransmitter molecules at the synaptic clefts, and their uptake by the post-synaptic neurons
- Some neurotransmitters (Glu, GABA) affect membrane potential and eventually the firing of postsynaptic neurons
- Others (dopamine, seratonin, oxytocin) act in more complex ways…

Neurotransmitters: many kinds

- **Amino acids**: glutamate, aspartate, D-serine, γ-aminobutyric acid (GABA), glycine
- **Gasotransmitters**: nitric oxide (NO), carbon monoxide (CO), hydrogen sulfide (H_2S)
- **Monoamines**: dopamine (DA), norepinephrine (noradrenaline; NE, NA), epinephrine (adrenaline), histamine, serotonin (SER, 5-HT)
- **Trace amines**: phenethylamine, *N*-methylphenethylamine, tyramine, 3-iodothyronamine, octopamine, tryptamine, etc.
- **Peptides**: somatostatin, substance P, cocaine and amphetamine regulated transcript, opioid peptides[11]
- **Purines**: adenosine triphosphate (ATP), adenosine
- Others: acetylcholine (ACh), anandamide, etc.

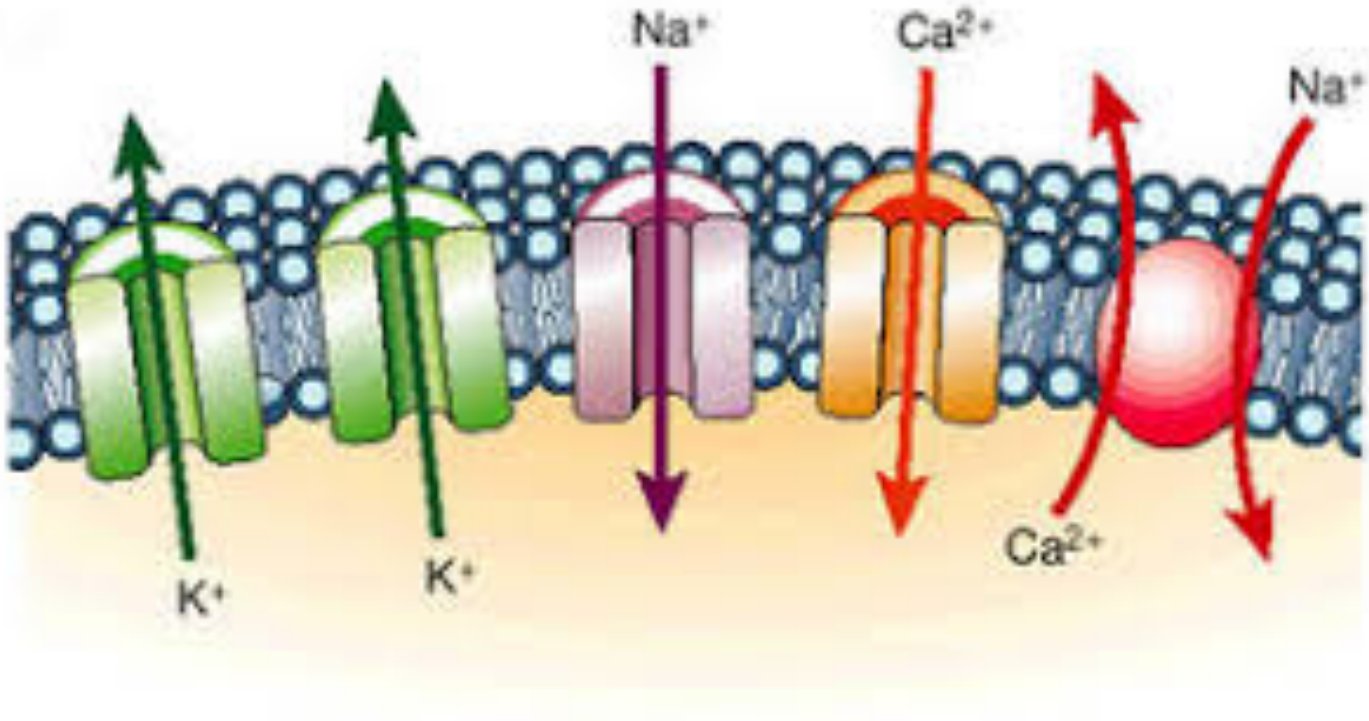
Vesicles release neurotransmitters



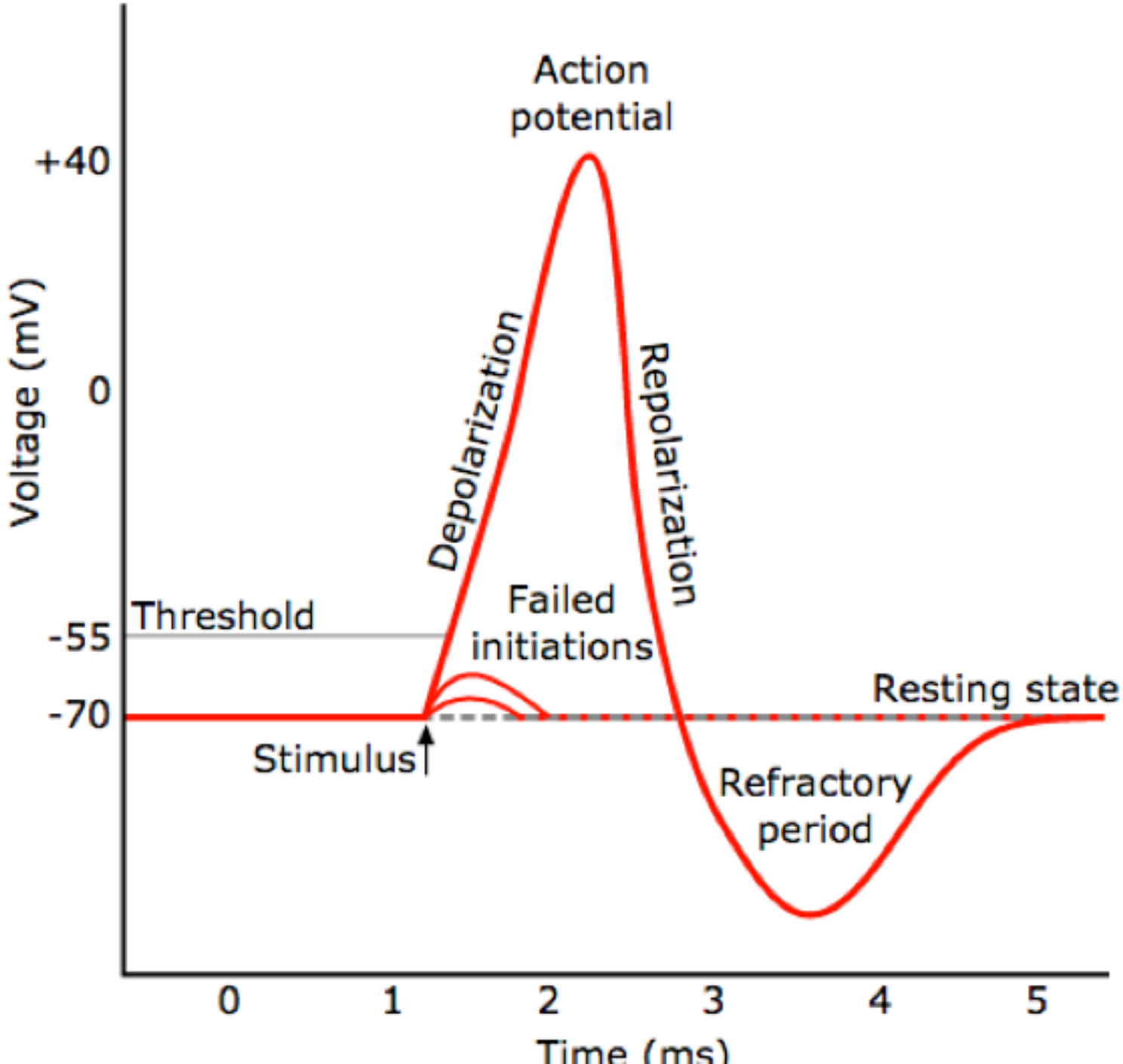


Ion channels

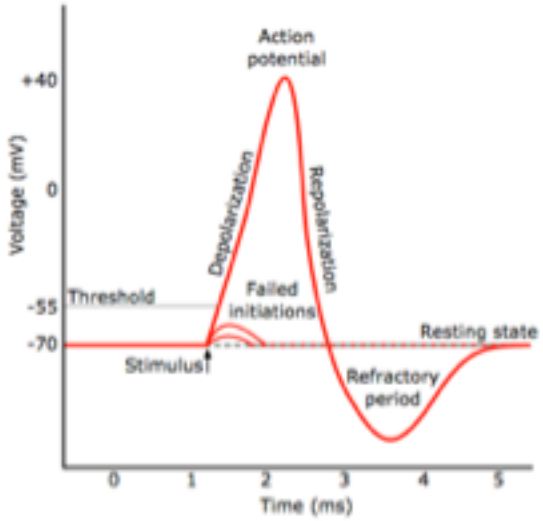
- Voltage gated, or
- Ligand gated (controlled by other neurotransmitters…)
- Glu lets X^+ in: excitatory
- GABA lets X^- in: inhibitory
- Ions define the membrane potential of the neuron



The spike

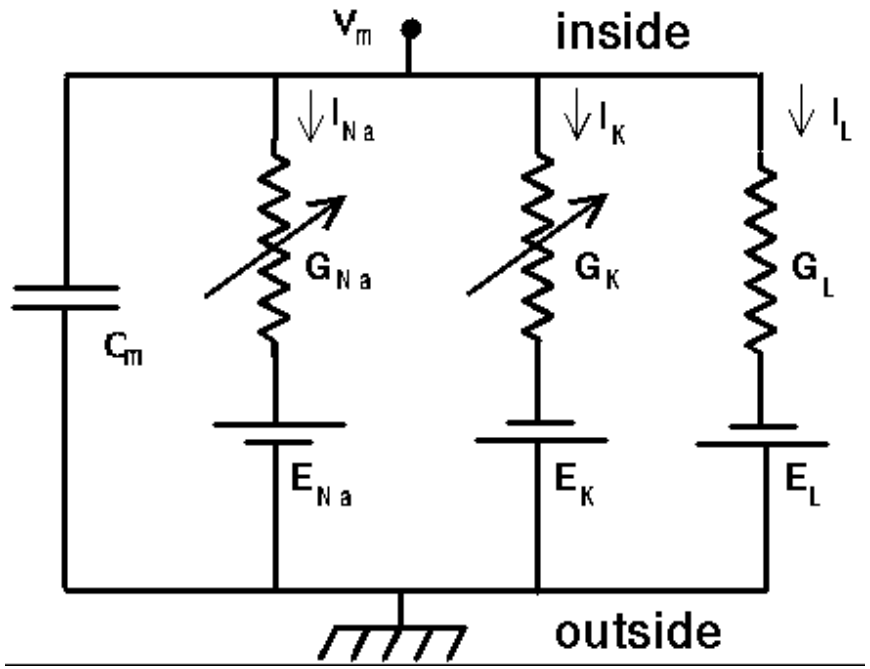

Action potential
+40
0
-55
-70
Voltage (mV)
Depolarization
Repolarization
Threshold
Failed initiations
Resting state
Stimulus
Refractory period
0
1
2
3
4
5
Time (ms)

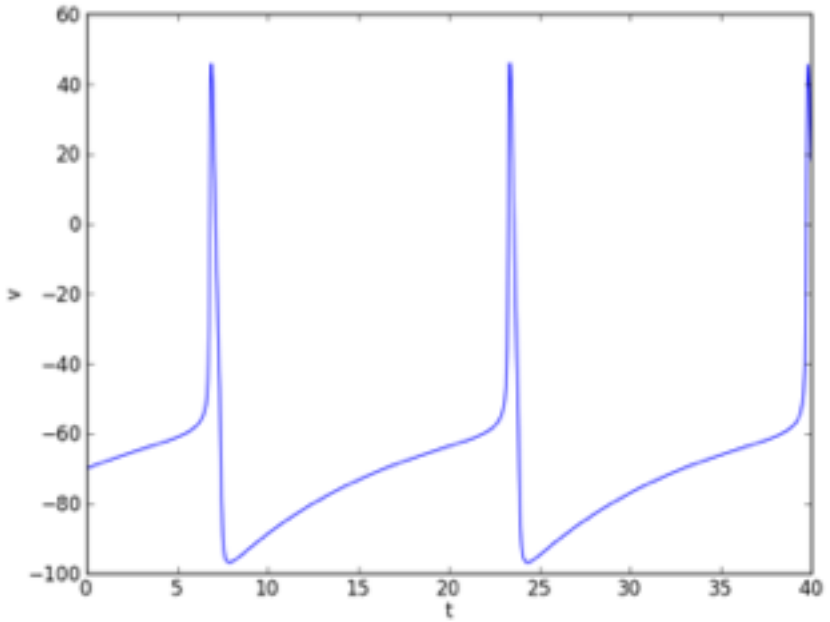
The spike, how?



- Resting potential = K^+ balance
- Accumulation of excitatory input raises potential
- When threshold passed, voltage-gated influx of Na^+ : depolarization
- 1ms later, a voltage-gated massive outflux of K^+: back to resting potential and beyond: hyperpolarization
- Refractory period ~1ms

The spike, how?



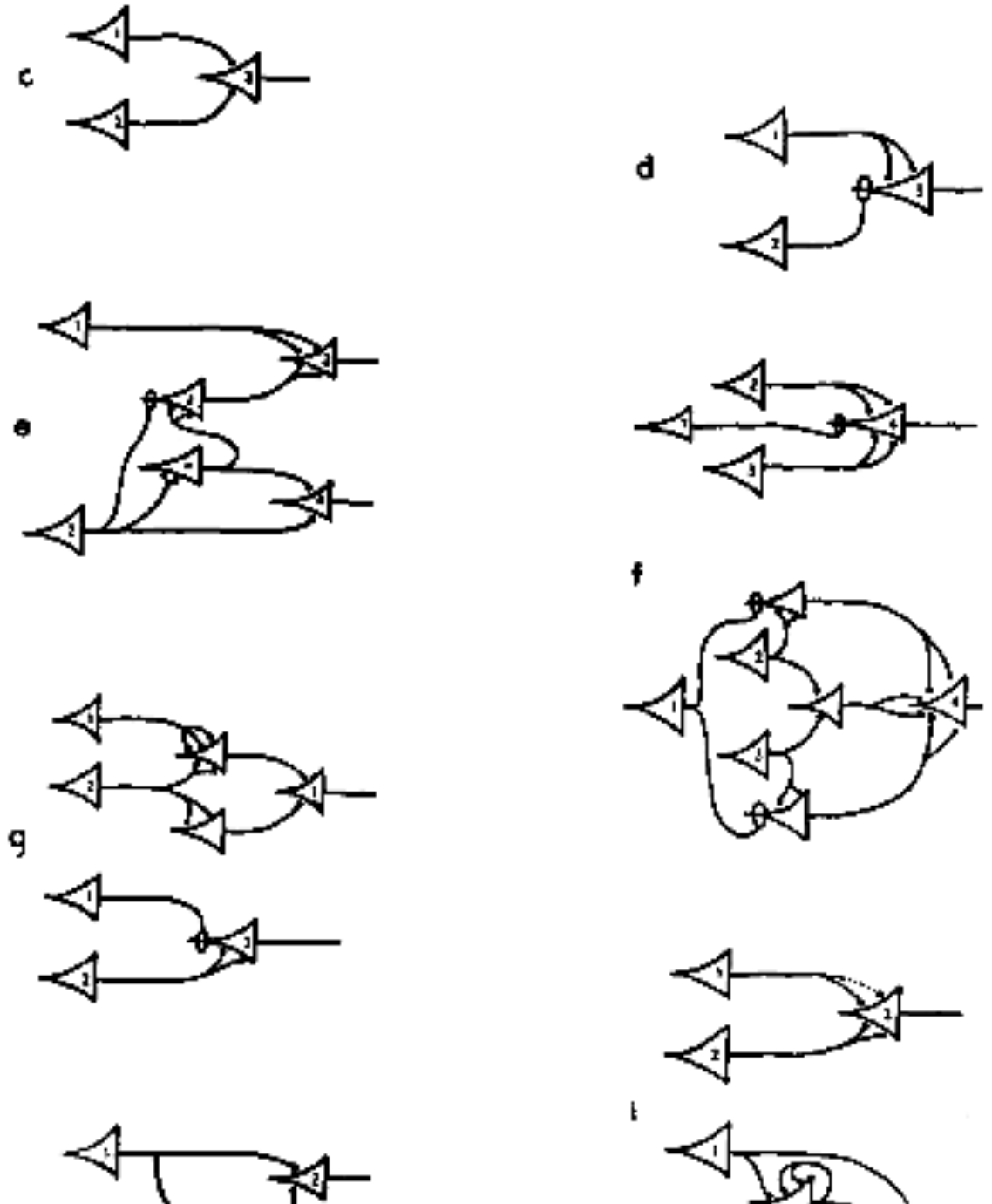


- The Hodgkin-Huxley differential equations (EE version)

Meanwhile at the (CS) farm…

- 1944: McCulloch – Pitts neuron

McCulloch-Pitts paper



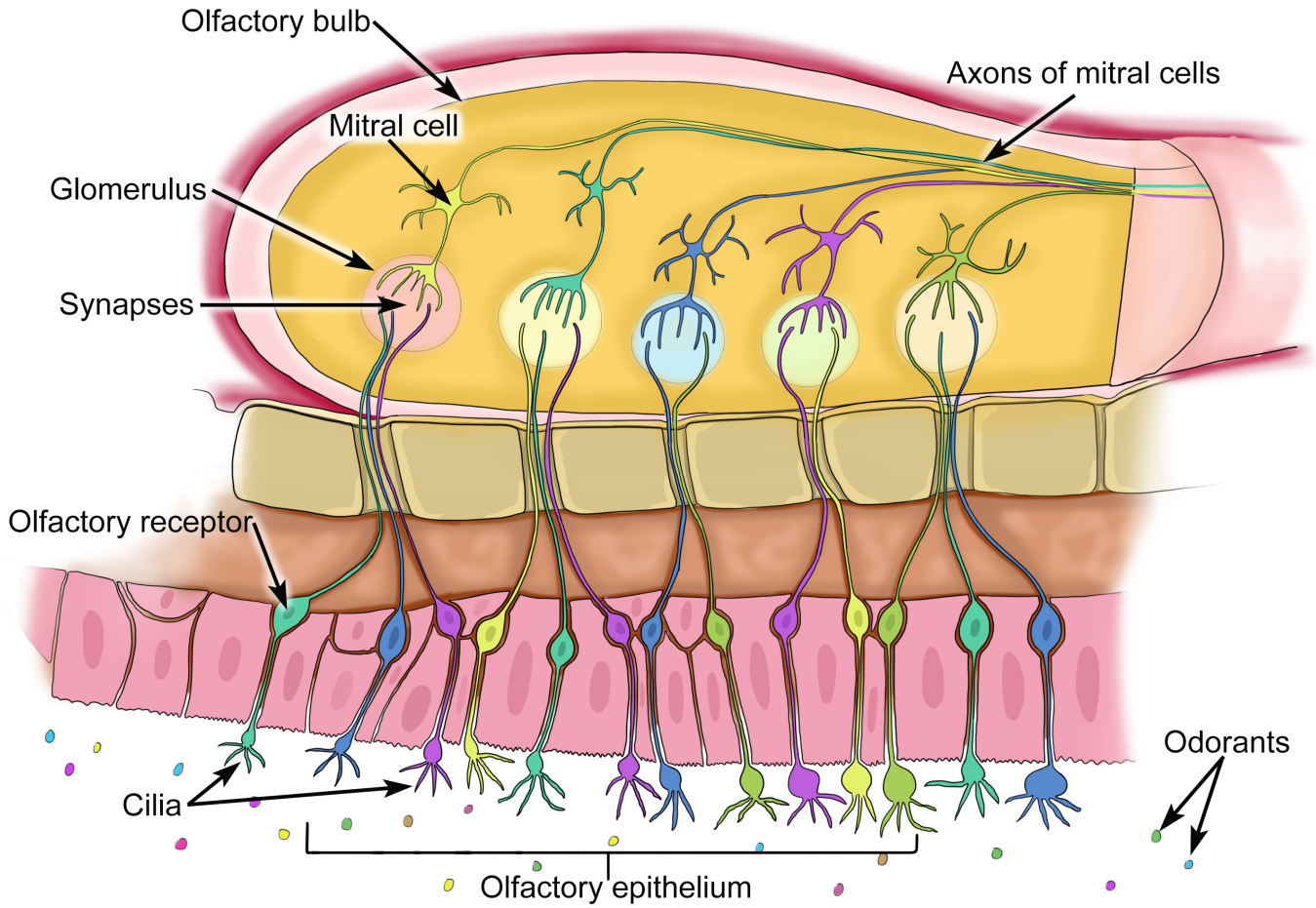
Meanwhile at the (CS) farm…

- 1944: McCulloch – Pitts neuron
- 1957: The Rosenblatt perceptron
- *"the embryo of an electronic computer that the Navy expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence."* NYT 1957
- 1960s: XOR and the first AI winter; the Minsky – Papert perceptron and the genesis of deep nets
- Also 1960s: "Neuroscience", "neurone"

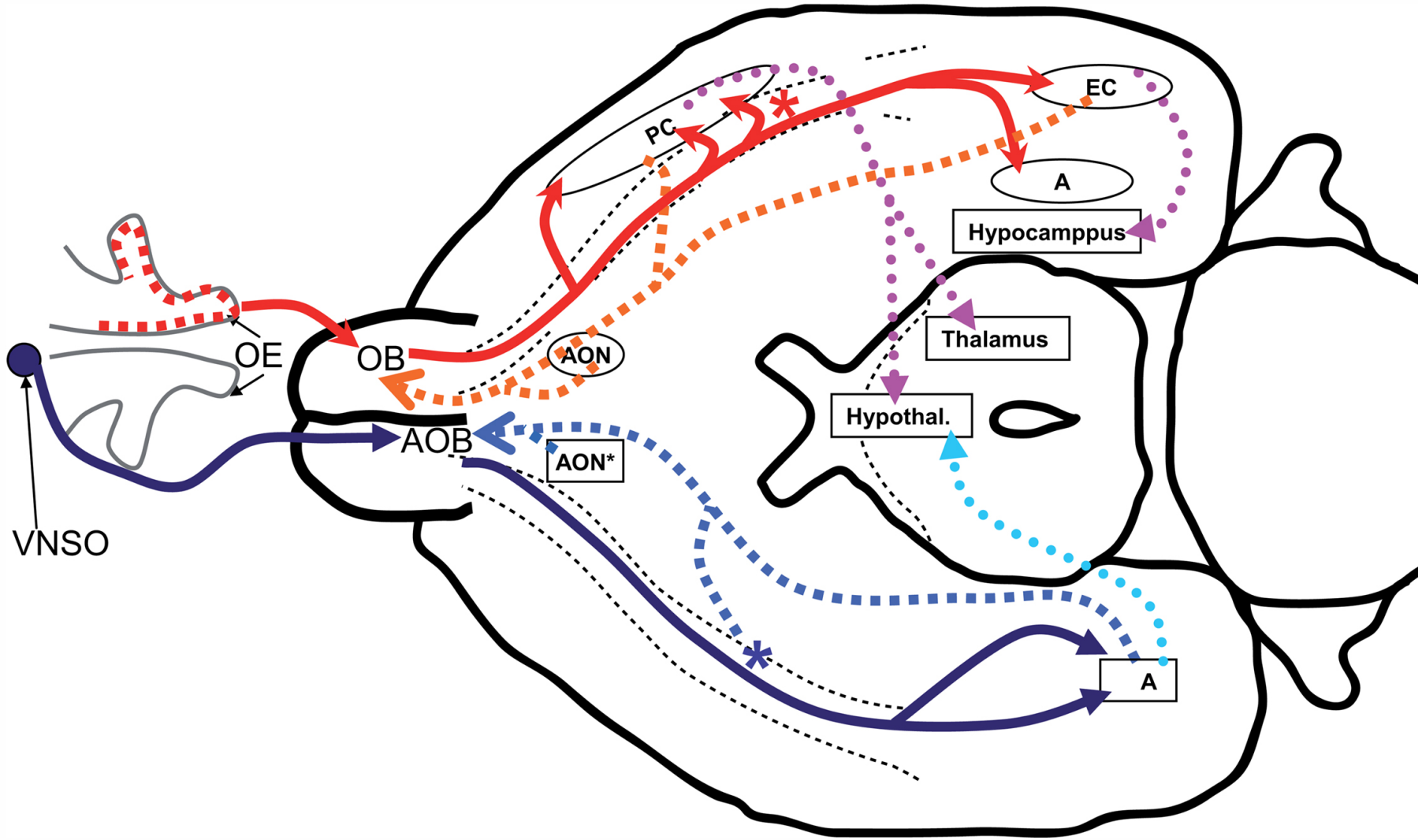
David Marr (1945 – 1980) and the genesis of computational neuroscience

The Three Step Program:
-specs
-hardware
-algorithm

Back to the Neuroscience laureates: Olfaction



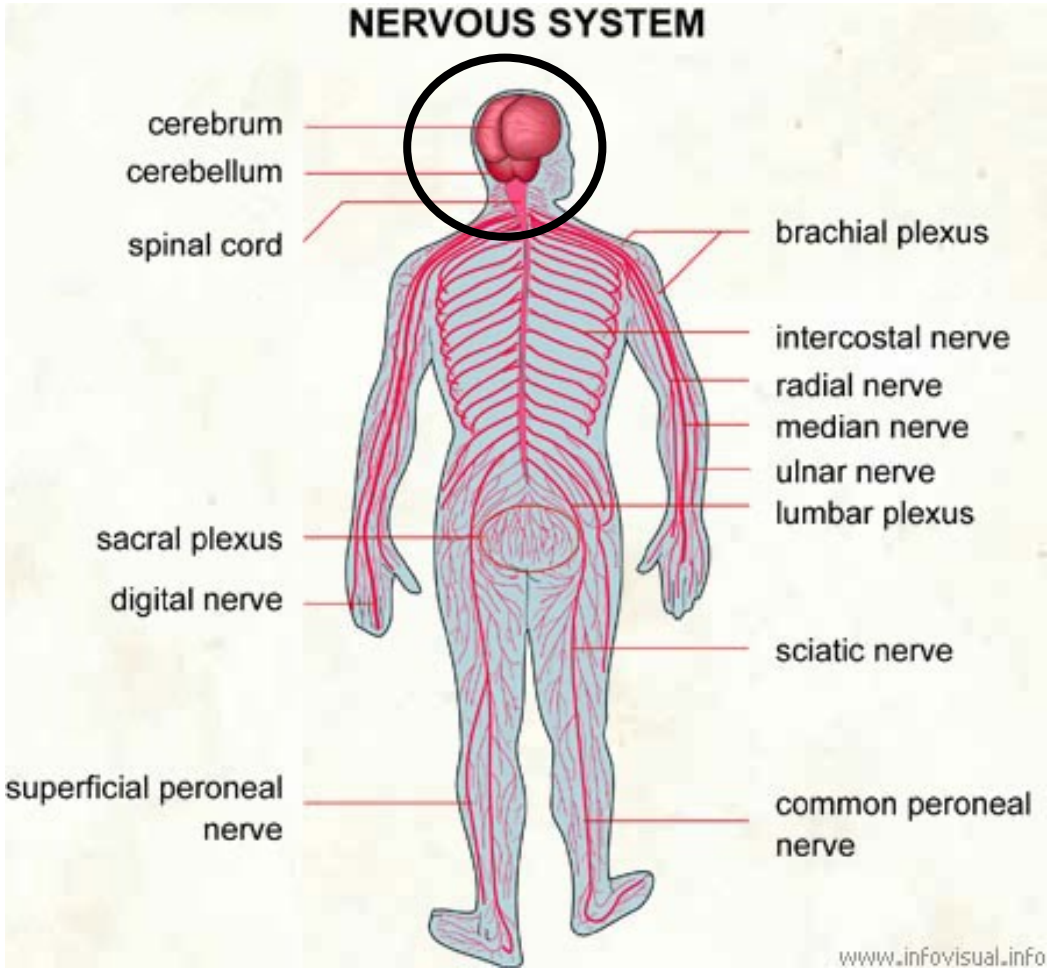
Olfaction


EC
PC
A
Hypocamppus
Thalamus
Hypothal.
OE
OB
AON
AOB
AON*
VNSO
A

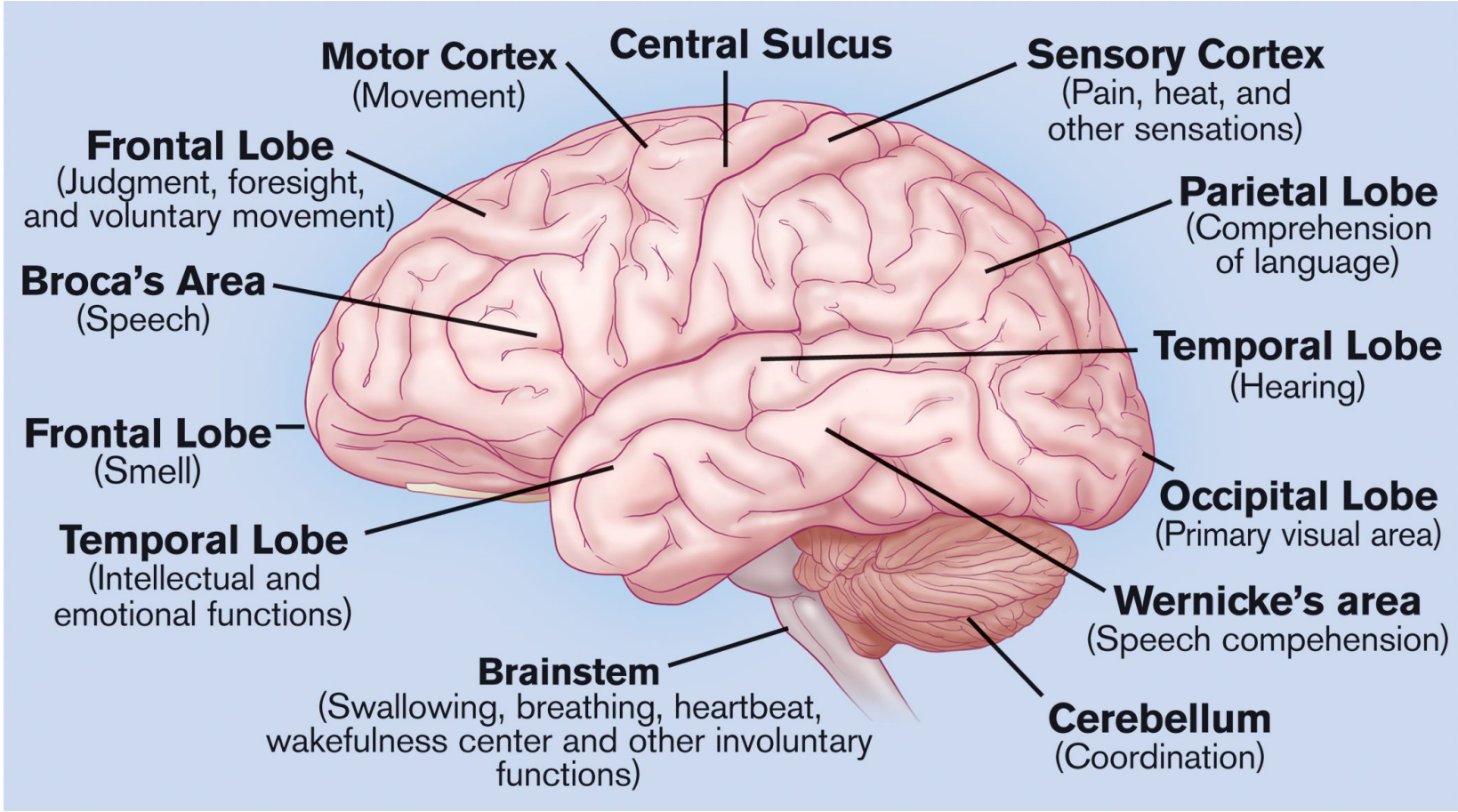
OK, what are the parts of the brain?

Oops, first, what are the parts of the computer?

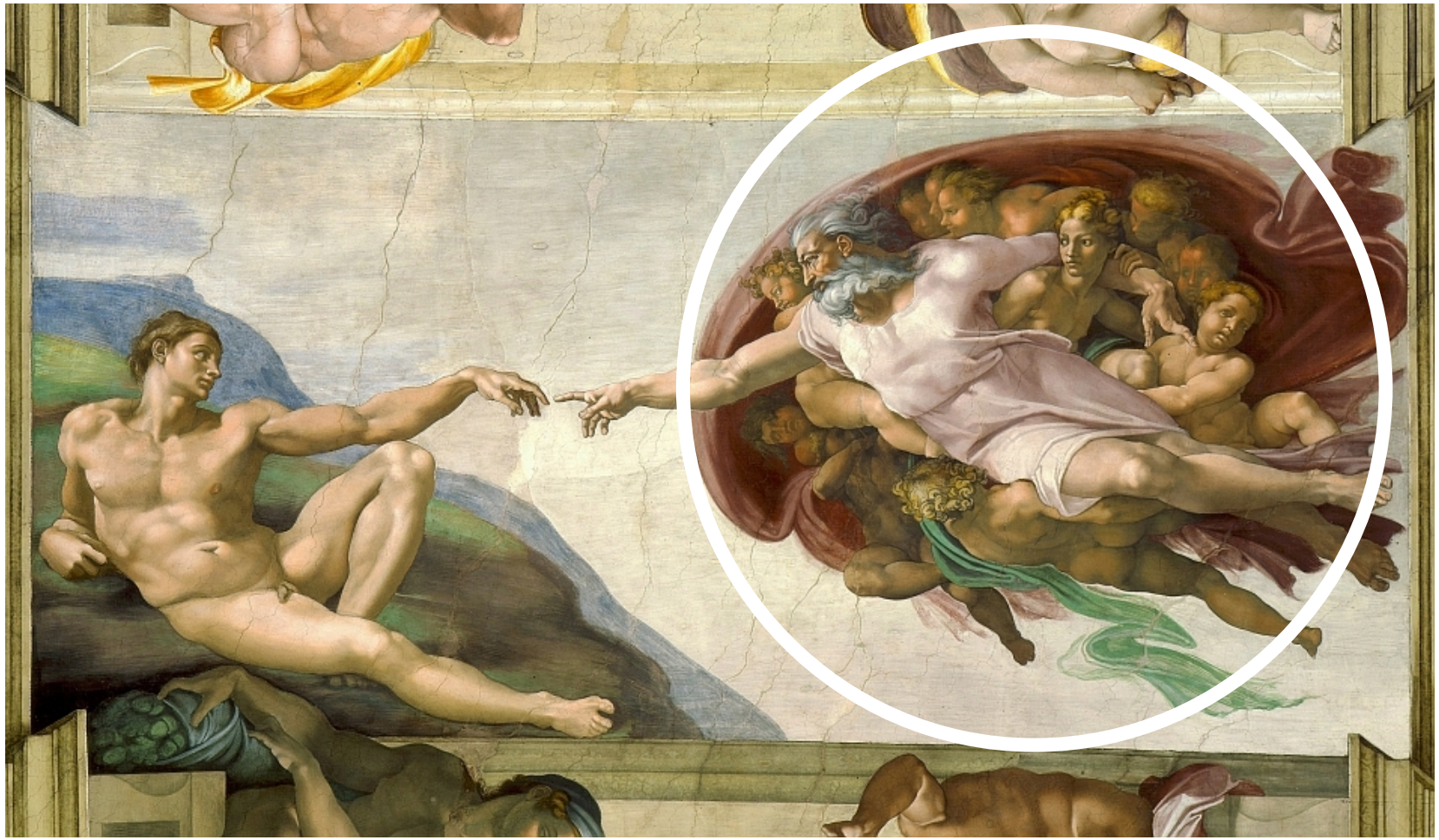
OK, back to the parts of the brain



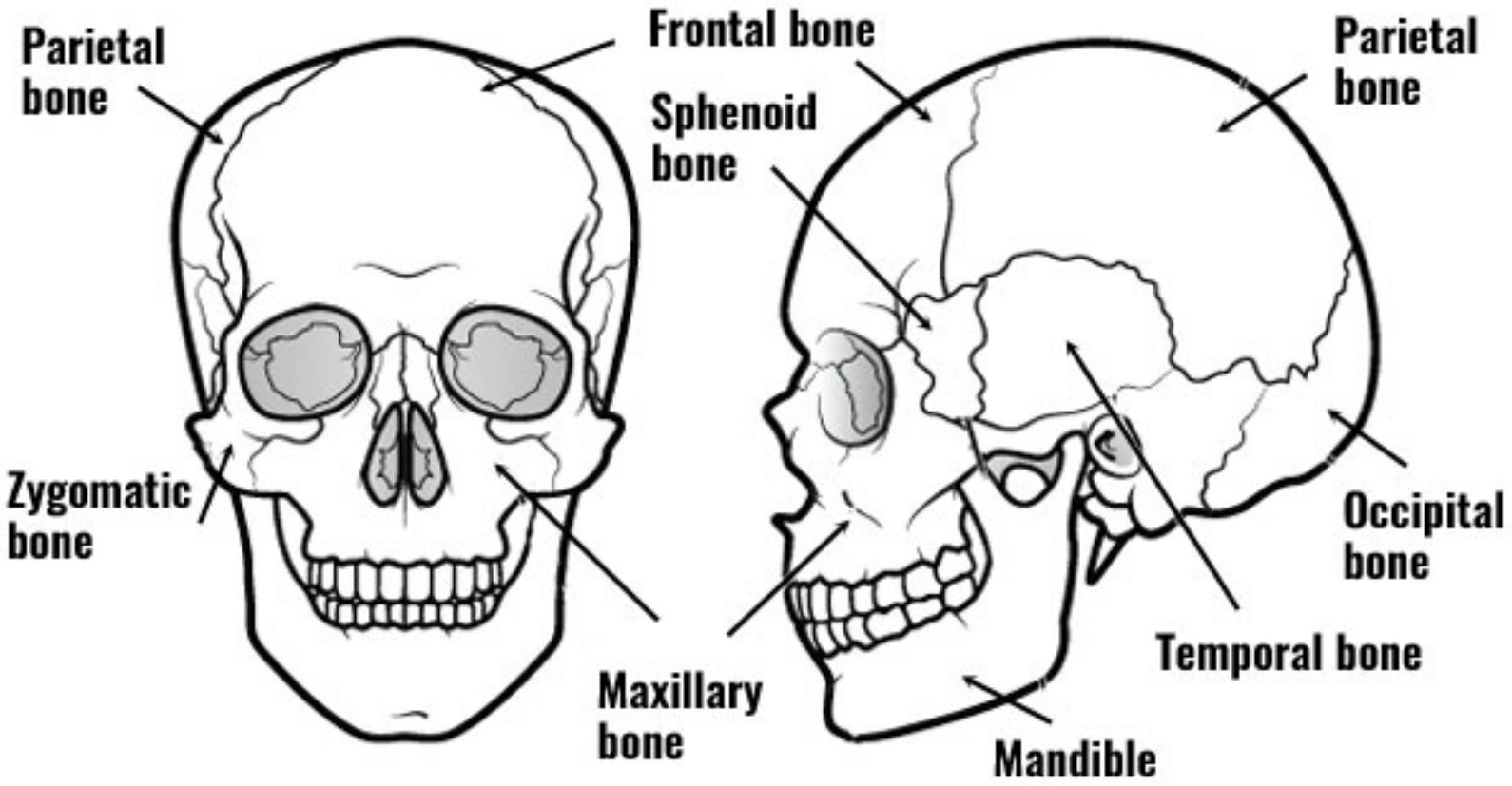
OK, the parts of the brain



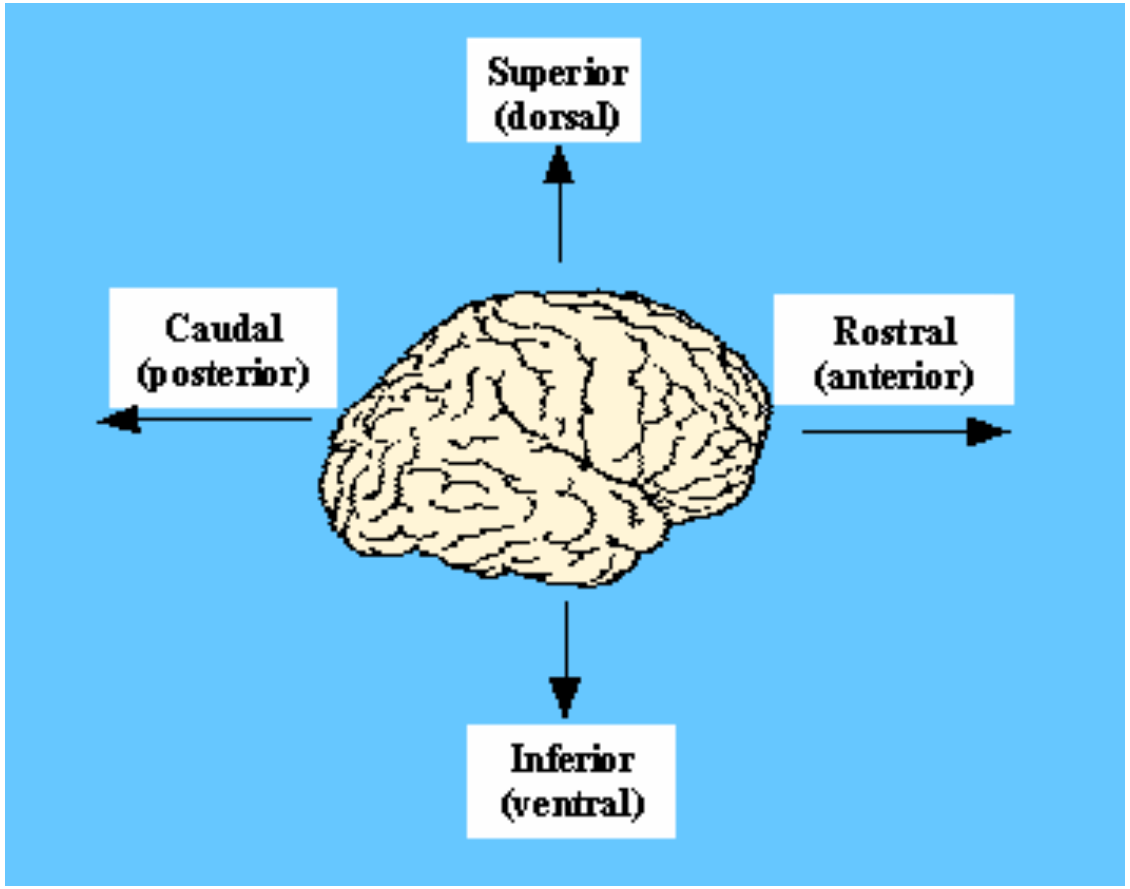
Btw, parts of the brain?

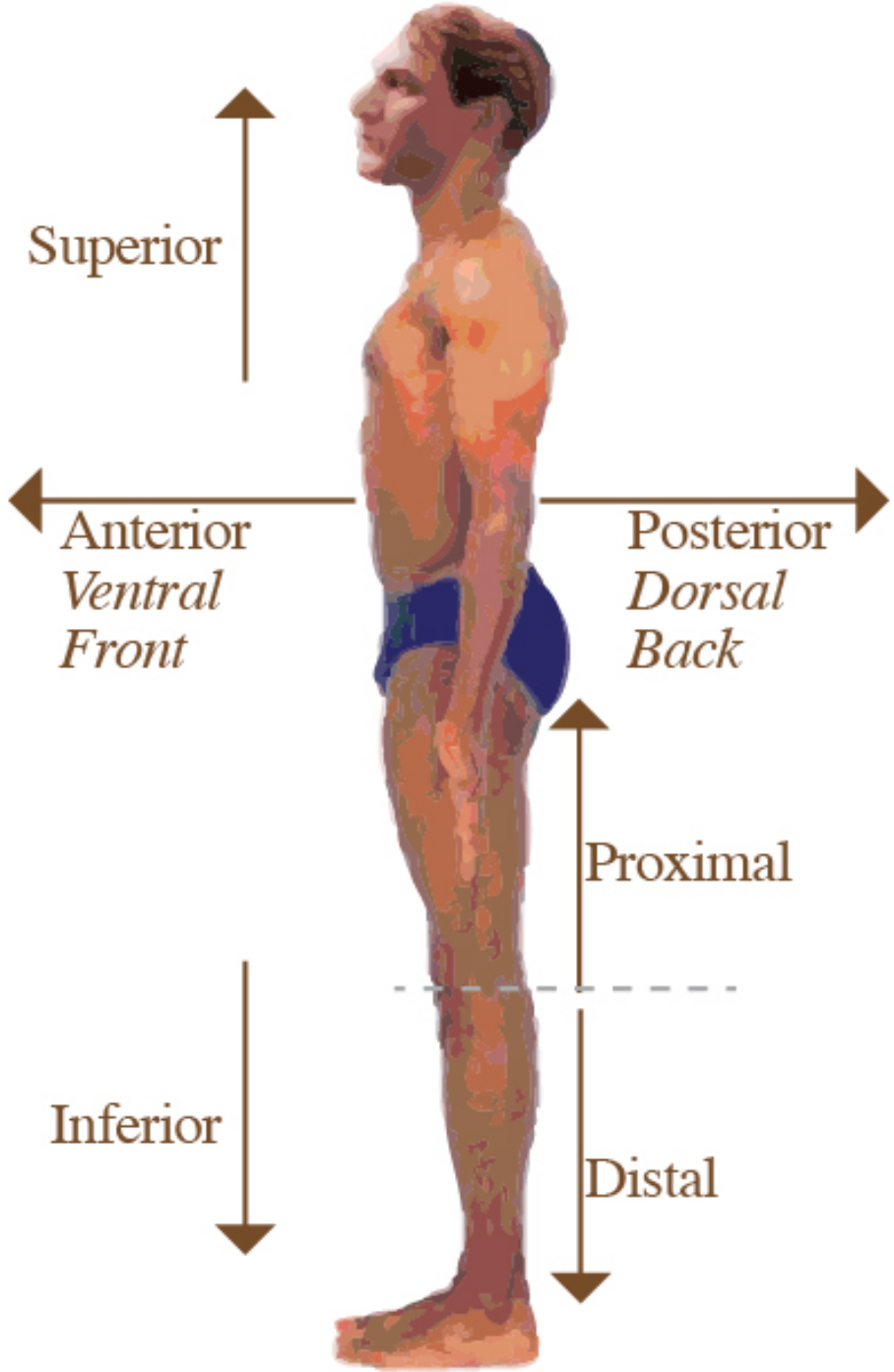


Parts of the brain names: Bones of the skull



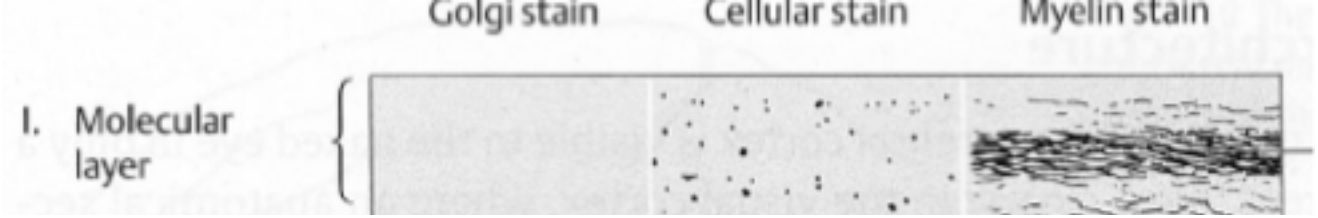
Parts of the brain names: directions

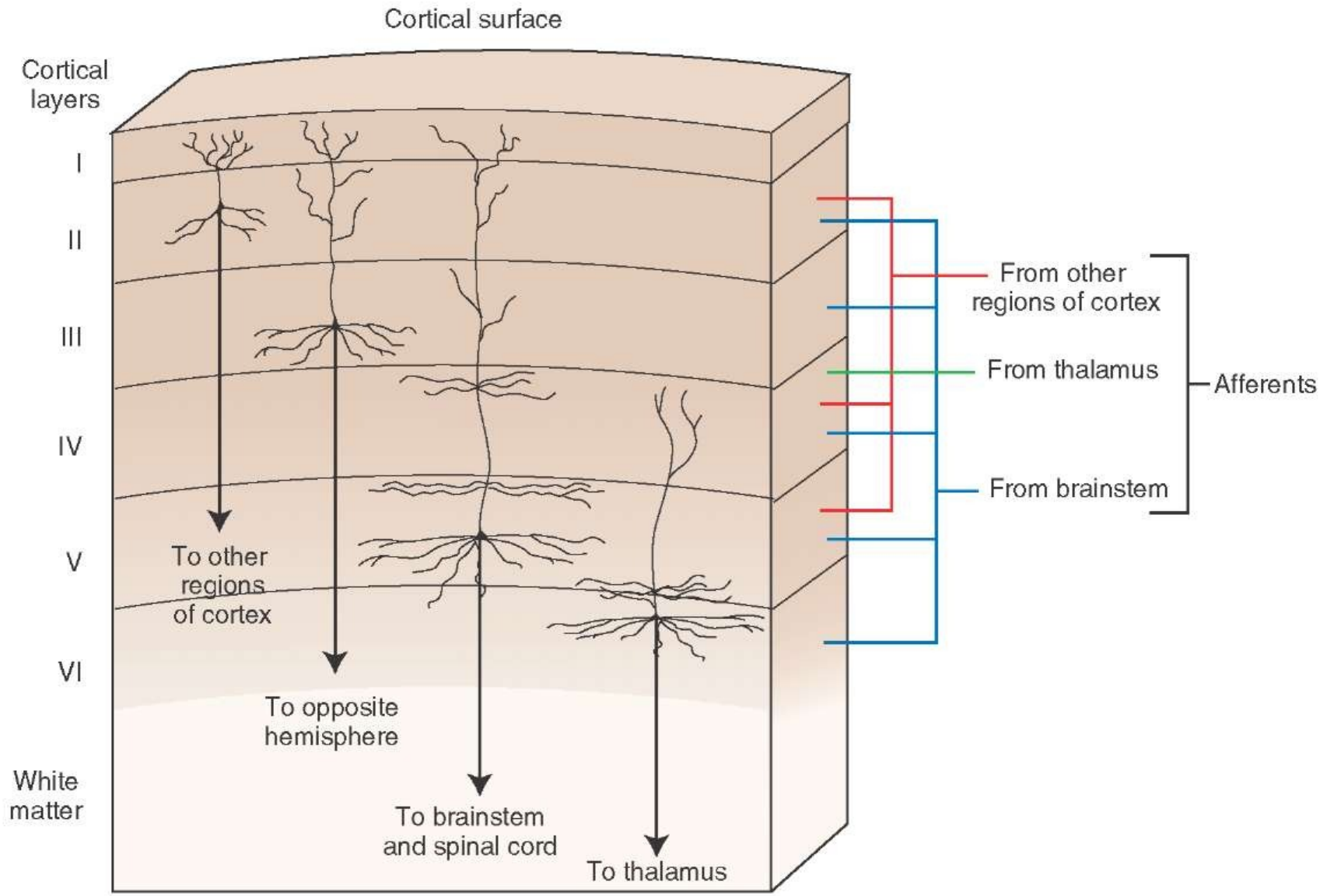




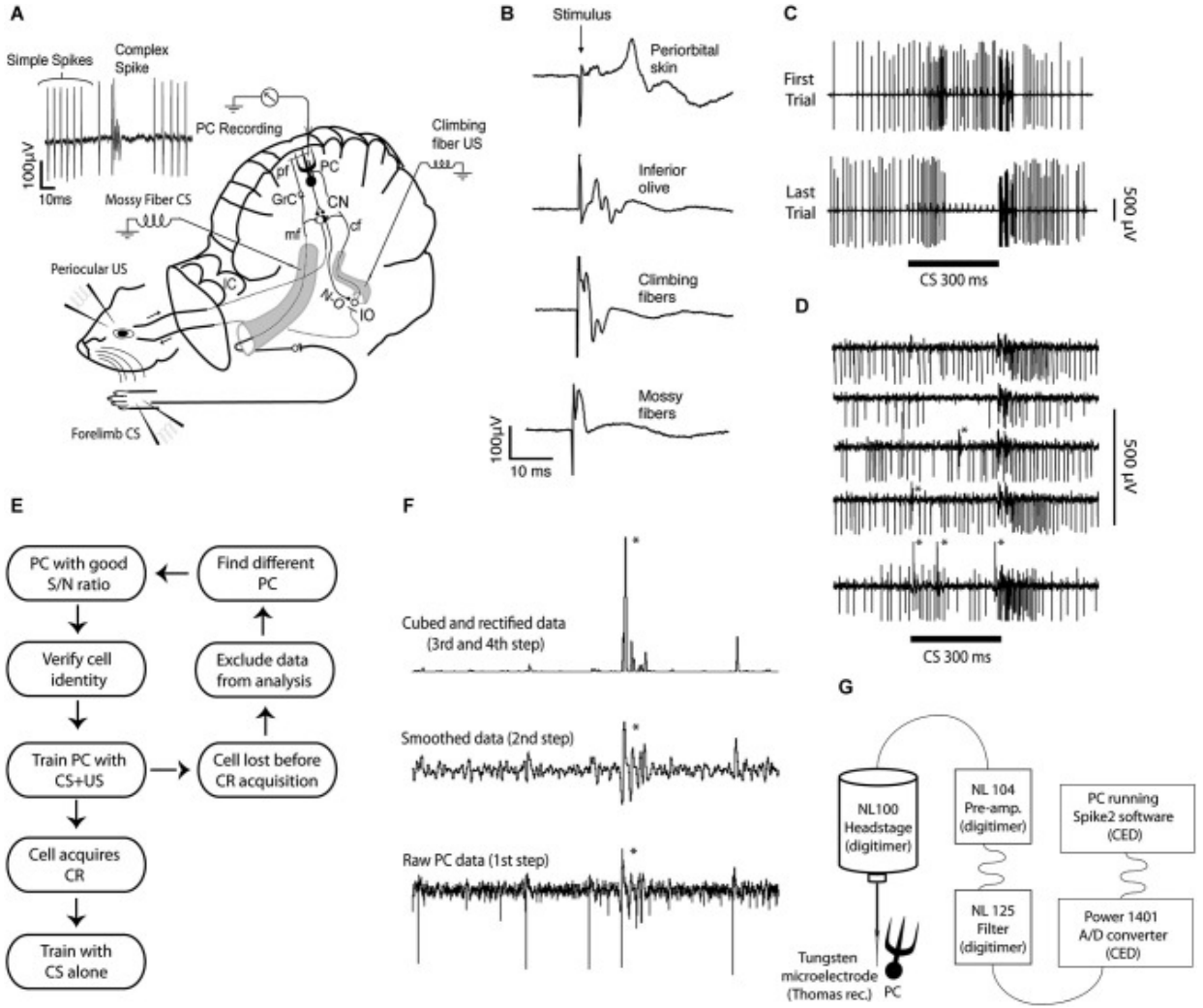
(Cerebral) Cortex: the engine

- 1.5 mm
- 2500 cm^2
- six layers
- 20B neurons



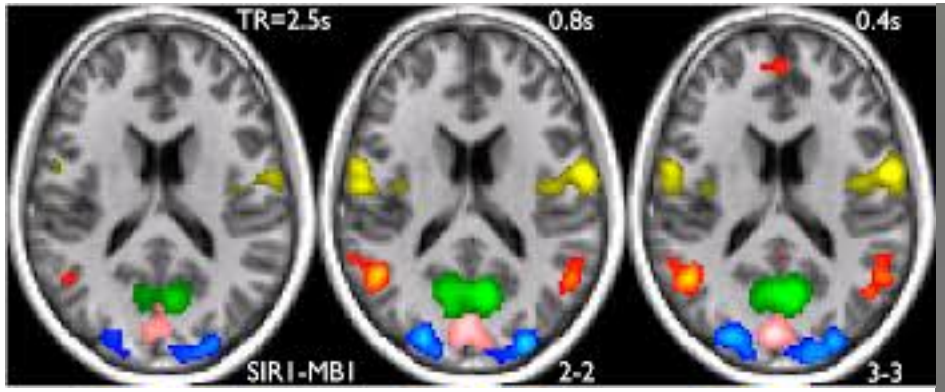


Finally: how do we record from the brain?
Single unit: ~ 1 neuron, ~ 1ms

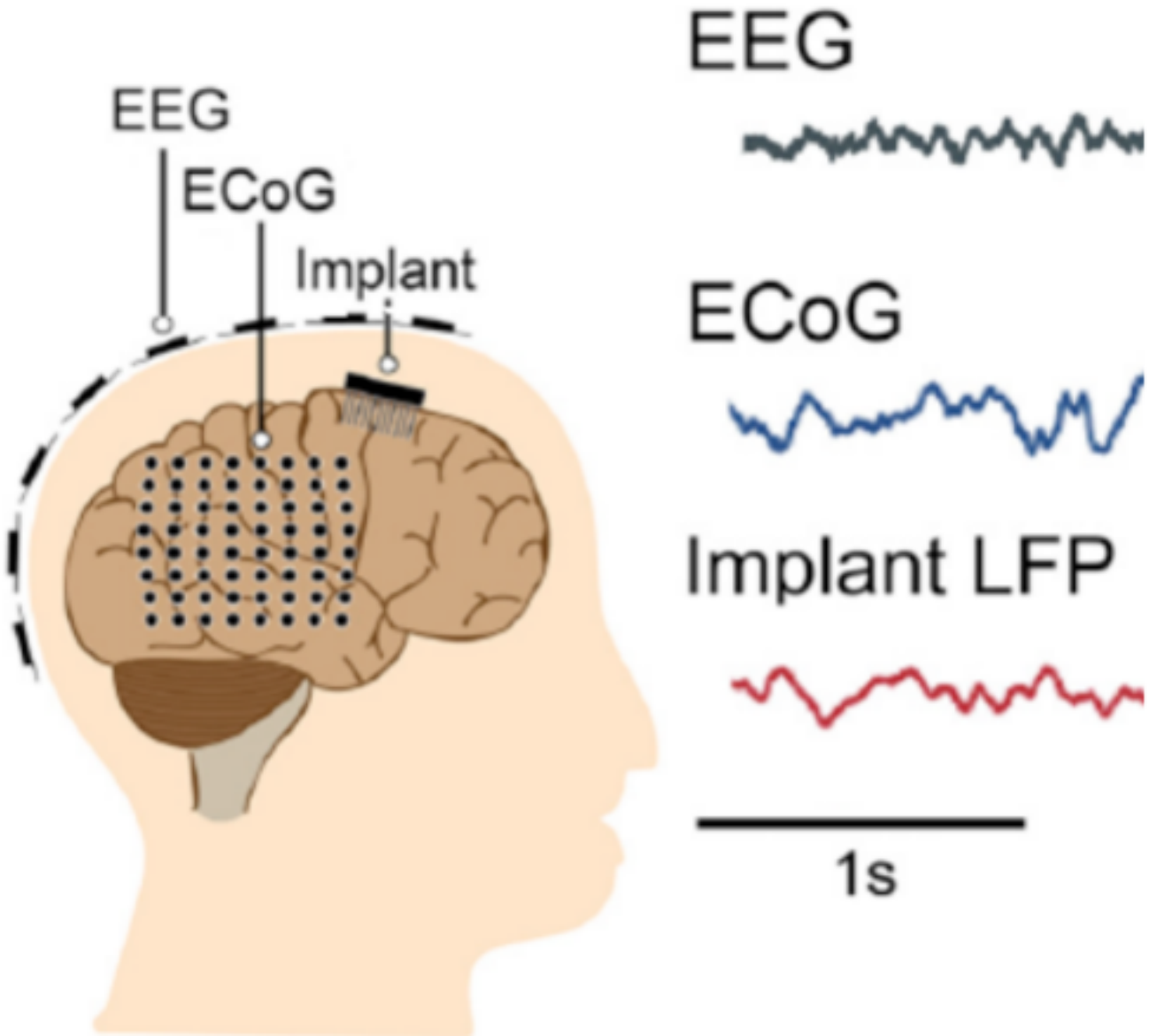


how do we record from the brain?
EEG: 1cm, 1ms

how do we record from the brain?
fMRI: ~ 1mm, ~ 1s (+ ML!)



how do we record from the brain?
ECoG



Place cells

- Neurons in the hippocampus that fire when the animal is in a particular place

- https://www.youtube.com/watch?v=STyd1qJr3yM

Place cells

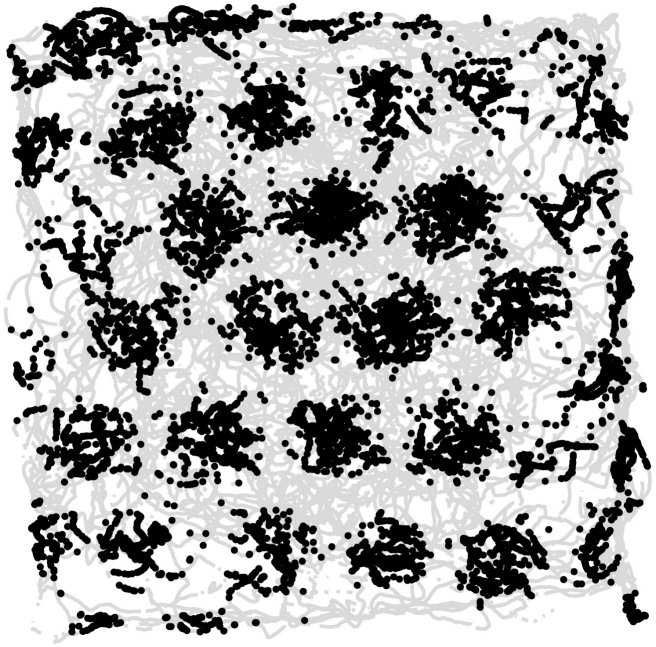
- Tuning curve of a place cell:

- A neuron in the hippocampus that fires when the animal is in a particular place

- https://www.youtube.com/watch?v=STyd1qJr3yM

Grid cells

- Tuning curve of a grid cell



- A neuron in the entorhinal cortex that fires when the animal is in any one of the nodes of a triangular grid
- The movie:
- https://www.youtube.com/watch?v=i9GiLBXWAHIons in