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425/525
Brain Inspired Computing

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Computational Brain Lab

Computer Science | Rutgers University | NJ, USA

Lecture 4 | NeuroBackground | Tuesday February 5th 2019

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CS Conference – Comments?

Important Dates - Project

- NOW

Propose a term—project topic

- Week of Monday, February 18

Pitch Talks (offline)

- Tuesday, February 26:

1st assignment is due

- Tuesday, March 12:

2nd assignment is due

- Tuesday, April 30:

Submit a 5-page term—project report <u>with results</u>

Prepare for your Pitch Talk

- Send us ***one*** email with
  - Your team
  - Your 2 ideas (titles)
  - Time slot (TBA) – Prepare a presentation – Make it short
  - Answer the main questions:
    - Why we should care?
    - What you want to discover?
  - FIFO

Pitch Talks

Please send us **1** email

Where: to Guangzhi Tang tangguangzhi.cs@gmail.com and *CC me*: konstantinos.michmizos@cs.rutgers.edu

Title: ***CS 425/525 - Team Project ***

Body:

a) names of your team members - with their NETIDs and their grad/undergrad status e.g., John Point, jp123, graduate

b) Two titles for the best 2 ideas that you have:

c) Two possible **20 min** slots for coming to discuss with us your ideas

These time slots should be between Monday and Thursday, the week after next (from 10 to 5)

What's next: You should receive from one of us a confirmation about your time slot

Please note that:

Note: 10% of your total course grade will be given on the presentation of your ideas - Please think about your project thoroughly and have an alternative idea

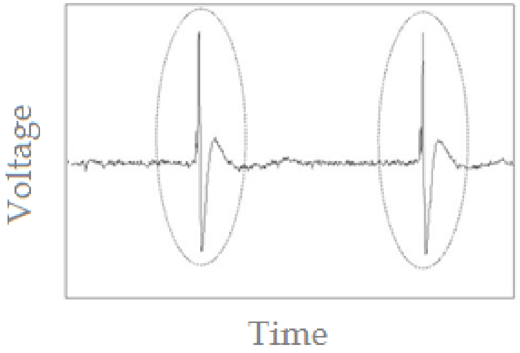
Potential Project ideas (1/2)

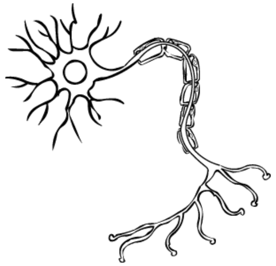
- Spike-based image encoding / decoding
- Spike-based image segmentation
- Spike-based image classification
- Linear Regression
- Spike-based bubble-sort algorithm
- Basic Logical Operations (AND, OR, X-OR etc.)
- Spike-based learning rules

Potential Project ideas (2/2) – Comp Vision

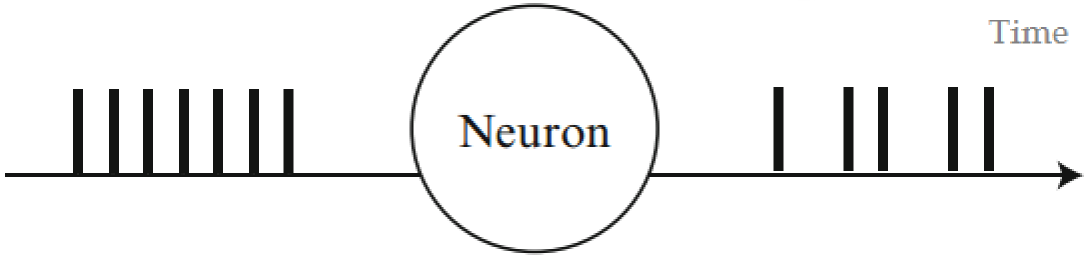
- Image encoding (neural representation)
- Image segmentation (edge detection via on center/off surround cells)
- Image binary classification (faces vs. houses, happy vs. sad people)
- Image recognition (0, 1, 2, …)

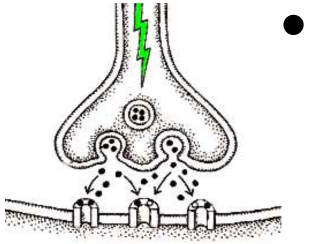
What we have covered so far





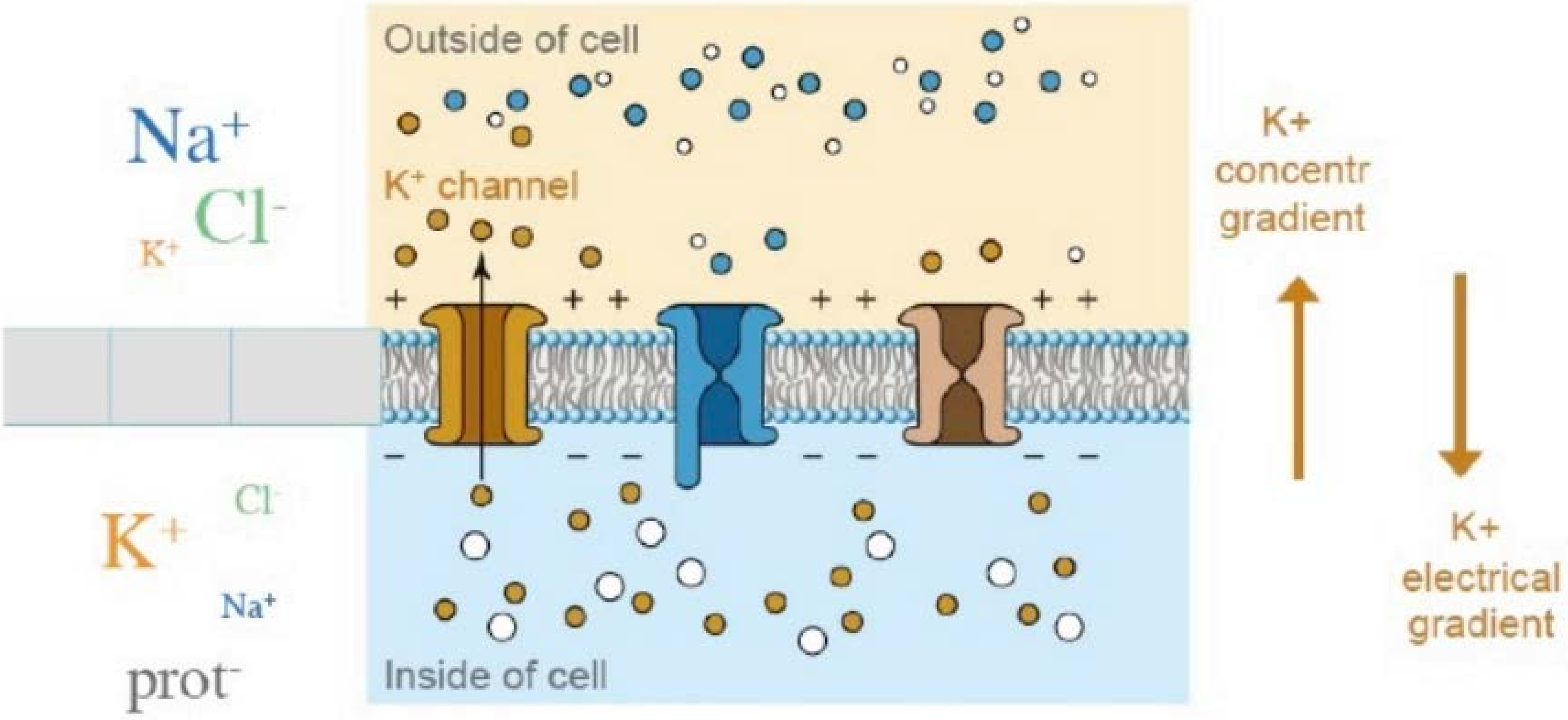
- The neuron anatomy
  - dendrites, soma, axon

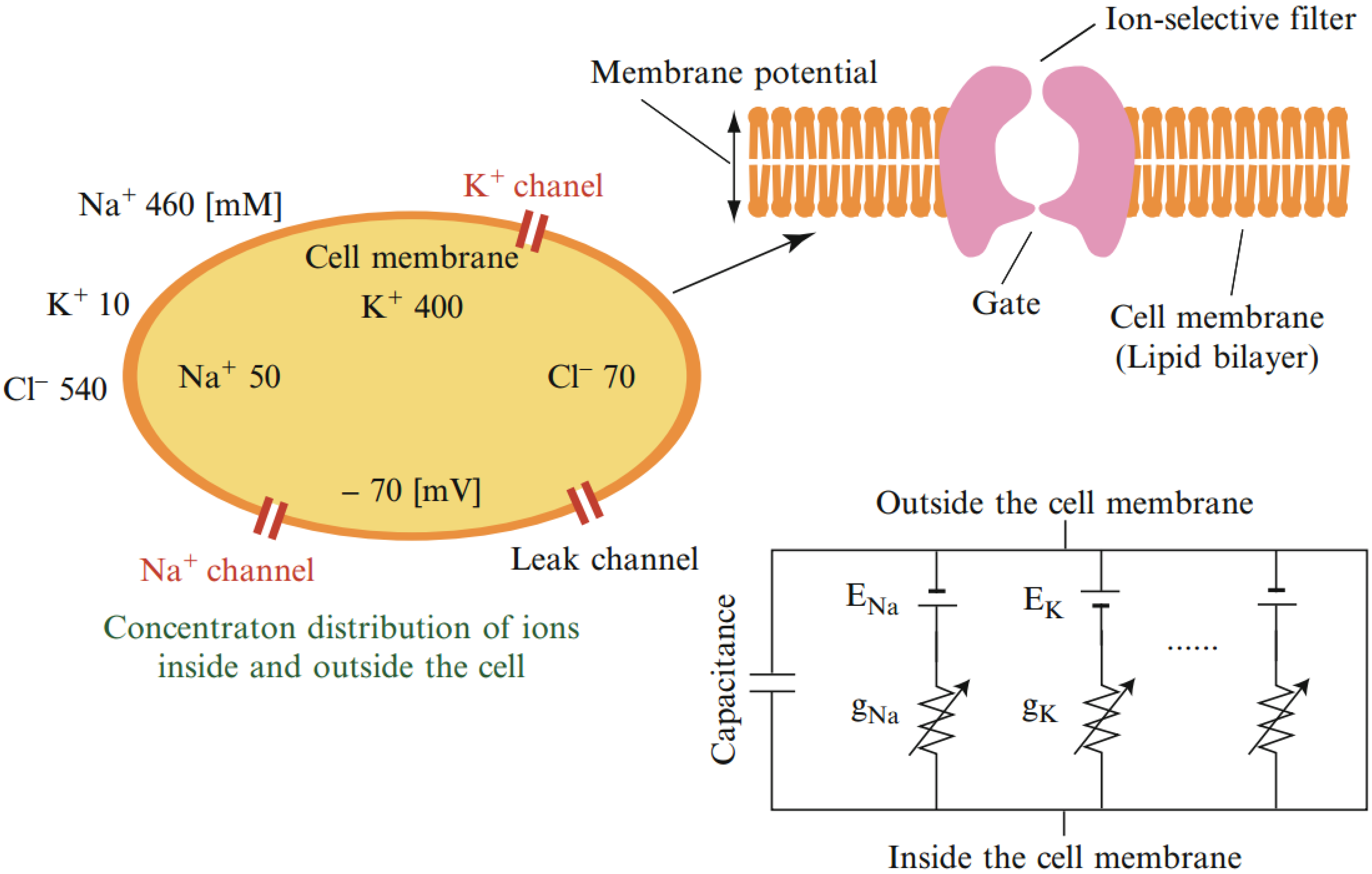




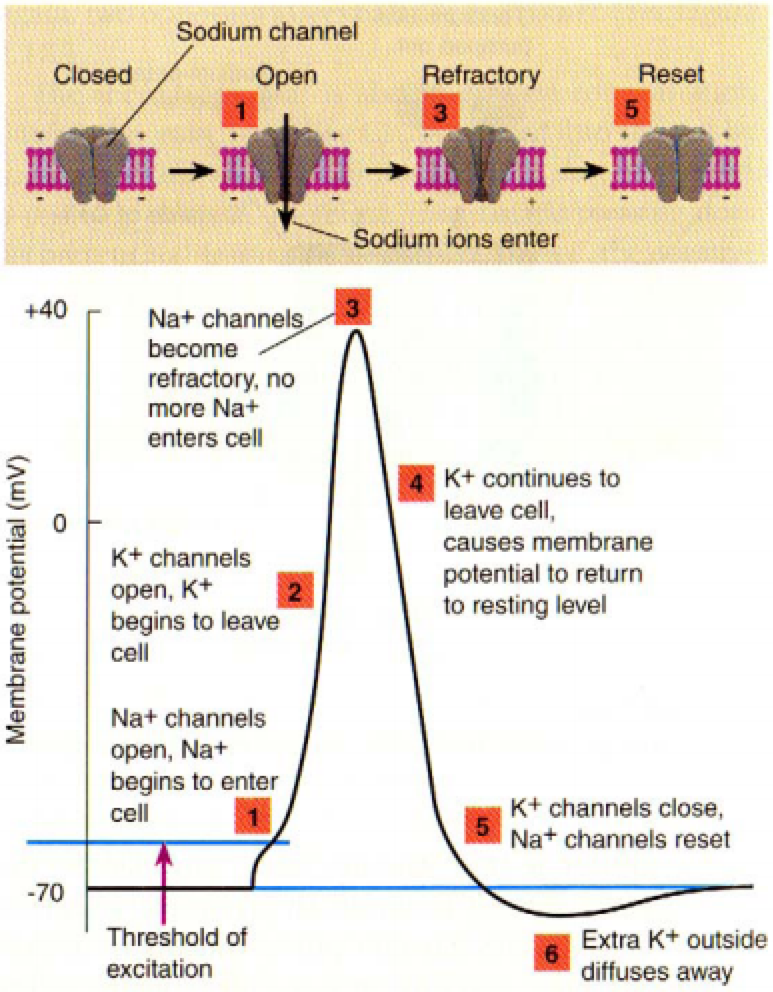
- The neuron physiology
  - Ion concentration difference, membrane potential, abrupt change in membrane potential, spikes, synapses, neurotransmitter
- The neural encoding
  - Firing rate, spike time encoding, neural representation of an "entity"

Electrochemical equilibrium and the neural membrane



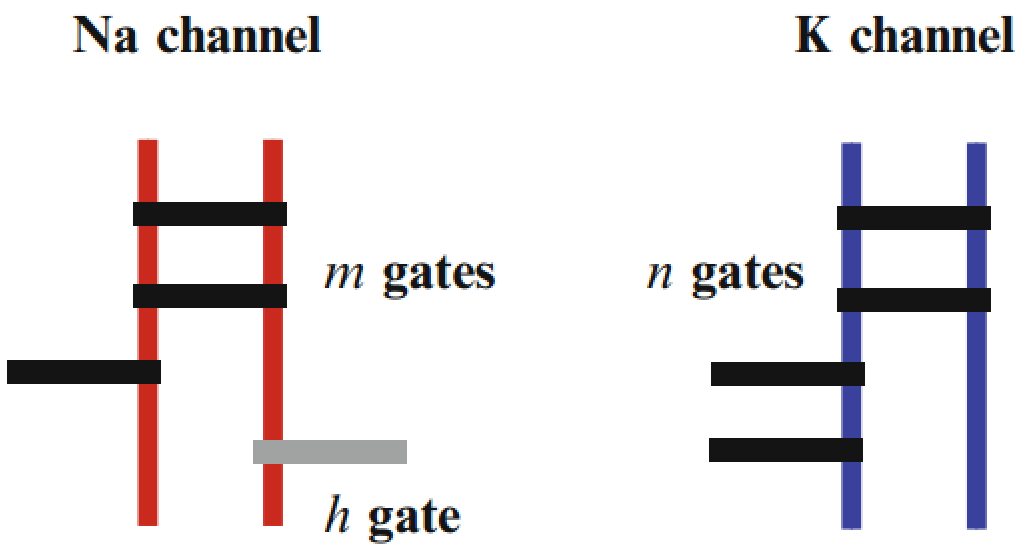

Ion-selective filter
Membrane potential
Gate
Cell membrane
(Lipid bilayer)
Na+ 460 [mM]
K+ chanel
Cell membrane
K+ 10
K+ 400
Cl− 540
Na+ 50
Cl− 70
– 70 [mV]
Na+ channel
Leak channel
Concentraton distribution of ions
inside and outside the cell
Outside the cell membrane
Capacitance
E_Na
E_K
g_Na
g_K
......
Inside the cell membrane

How the Action Potential is generated



- Axon membrane potential difference
  $V = V_{in} - V_{out}$
- When the axon is excited, V spikes because sodium Na^+ and potassium K^+ ions flow through the membrane

Gate Dynamics



Open and close of a gate

$$\frac{dm}{dt} = (1 - m)\, a_m(V) - m b_m(V)$$

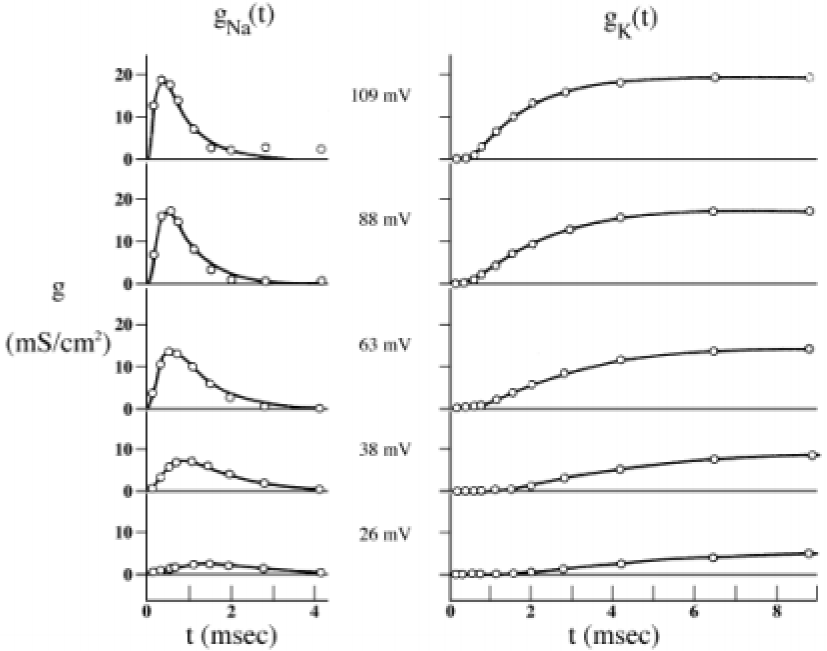
$$\text{Open} \underset{a_m(V)}{\overset{b_m(V)}{\rightleftarrows}} \text{Close}$$

The Hodgkin – Huxley model

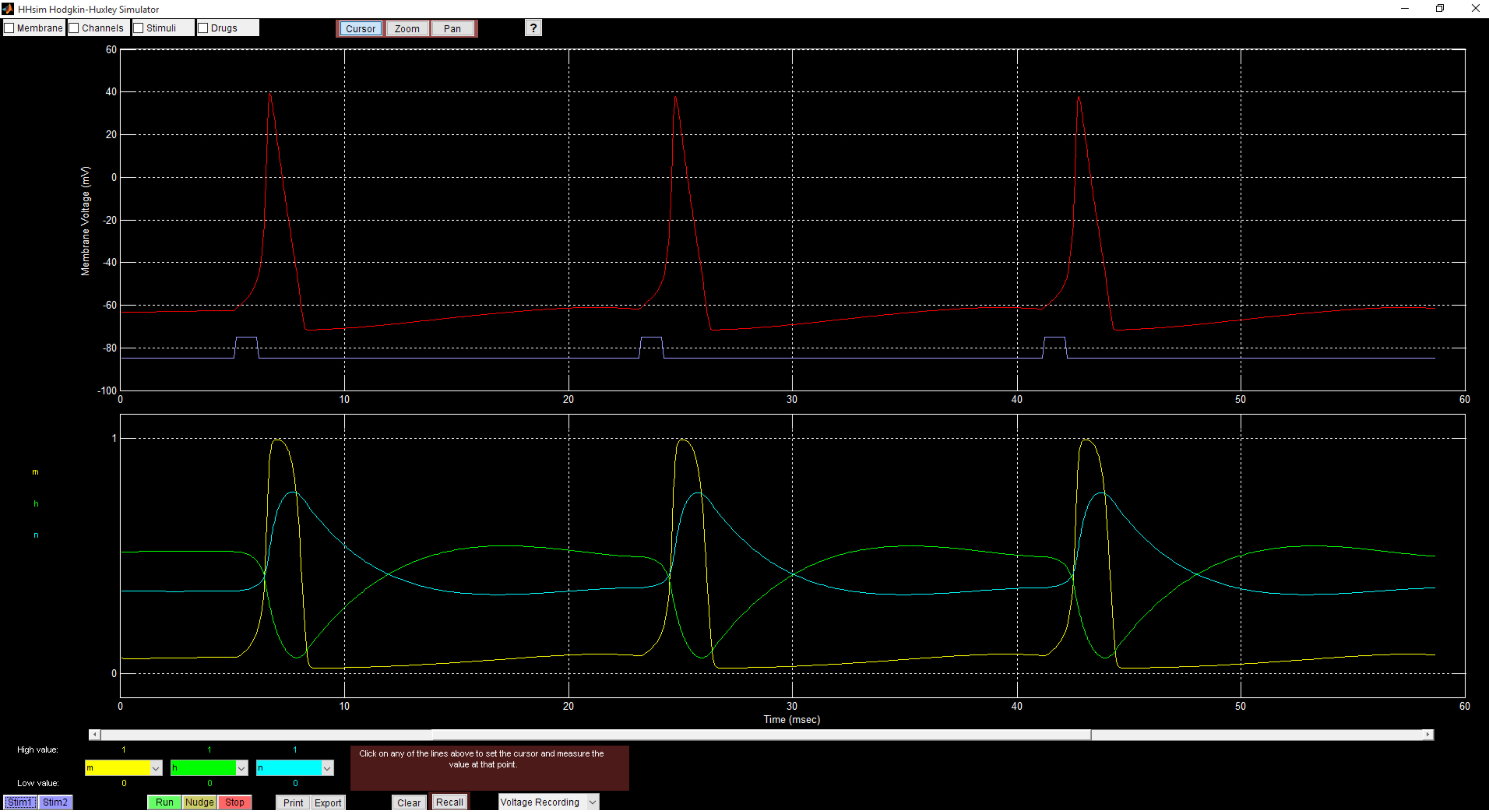
$$
\begin{aligned}
C\frac{dv}{dt} &= I - g_{Na}m^3h(V - V_{Na}) - g_K n^4(V - V_K) - g_L(V - V_L) \\
\frac{dm}{dt} &= a_m(V)(1-m) - b_m(V)m \\
\frac{dh}{dt} &= a_h(V)(1-h) - b_h(V)h \\
\frac{dn}{dt} &= a_n(V)(1-n) - b_n(V)n \\
a_m(V) &= .1(V+40)/(1-\exp(-(V+40)/10)) \\
b_m(V) &= 4\exp(-(V+65)/18) \\
a_h(V) &= .07\exp(-(V+65)/20) \\
b_h(V) &= 1/(1+\exp(-(V+35)/10)) \\
a_n(V) &= .01(V+55)/(1-\exp(-(V+55)/10)) \\
b_n(V) &= .125\exp(-(V+65)/80)
\end{aligned}
$$

$$\begin{aligned}\dot{n} &= \alpha_n(V)(1-n) - \beta_n(V)n \\ \dot{m} &= \alpha_m(V)(1-m) - \beta_m(V)m \\ \dot{h} &= \alpha_h(V)(1-h) - \beta_h(V)h\ ,\end{aligned}$$

rate constants were fitted by Hodgkin & Huxley:



$$\begin{aligned}\alpha_n(V) &= 0.01\frac{10-V}{\exp(\frac{10-V}{10})-1}\ , \\ \beta_n(V) &= 0.125\exp\left(\frac{-V}{80}\right)\ , \\ \alpha_m(V) &= 0.1\frac{25-V}{\exp(\frac{25-V}{10})-1}\ , \\ \beta_m(V) &= 4\exp\left(\frac{-V}{18}\right)\ , \\ \alpha_h(V) &= 0.07\exp\left(\frac{-V}{20}\right)\ , \\ \beta_h(V) &= \frac{1}{\exp(\frac{30-V}{10})+1}\ .\end{aligned}$$



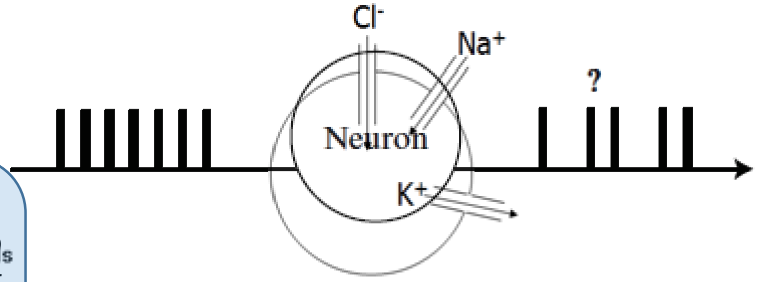
HHsim Hodgkin-Huxley Simulator
Membrane
Channels
Stimuli
Drugs
Cursor
Zoom
Pan
?
Membrane Voltage (mV)
60
40
20
0
-20
-40
-60
-80
-100
0
10
20
30
40
50
60
1
0
m
h
n
Time (msec)
High value:
1
1
1
Low value:
0
0
0
Click on any of the lines above to set the cursor and measure the value at that point.
Stim1
Stim2
Run
Nudge
Stop
Print
Export
Clear
Recall
Voltage Recording

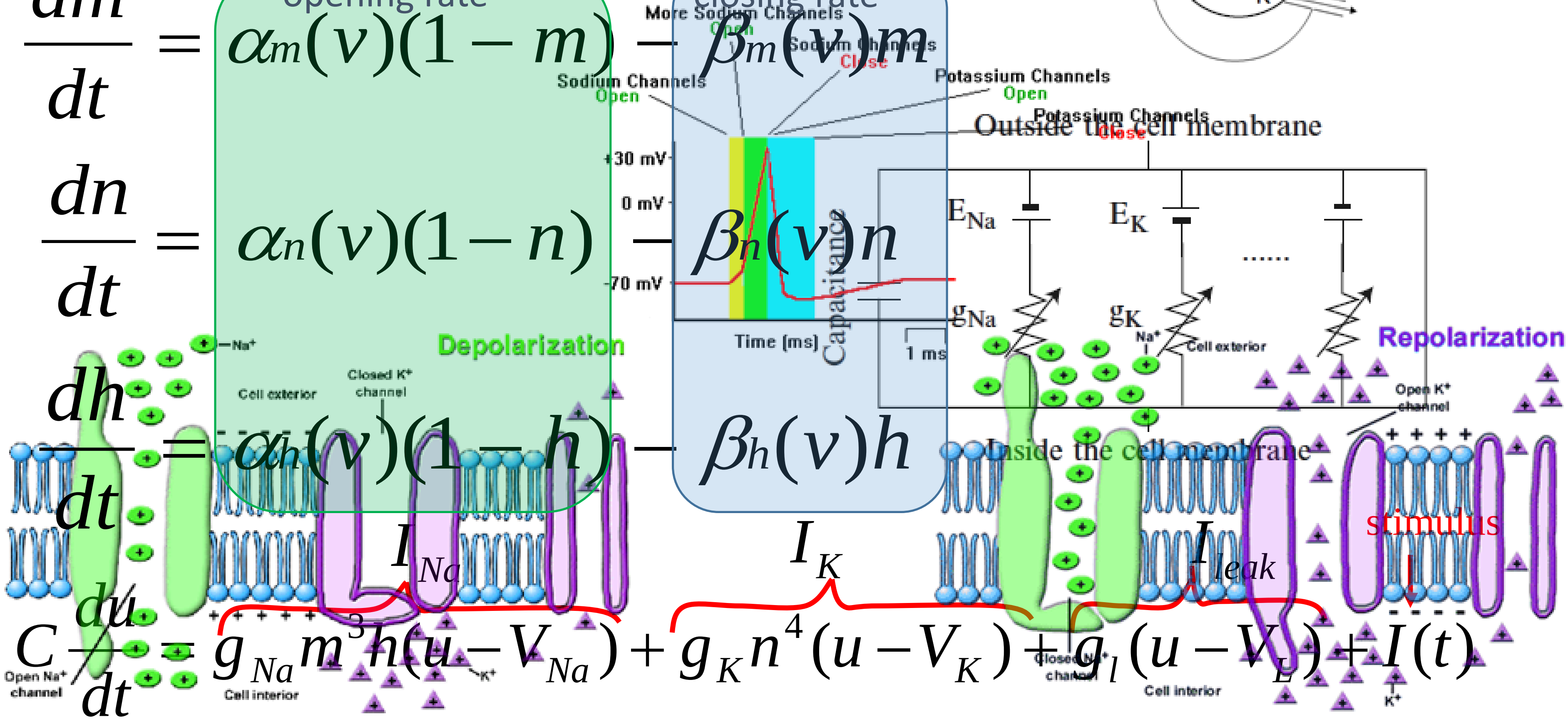
NERVE-CELL ENIGMA SOLVED

The British scientists, A. L. Hodgkin and A. F. Huxley, experimenting with the nerve fibers of squids and lobsters.

biophysically principled computational neural model of somatosensory cortex

Hodgkin – Huxley neuron model





opening rate

closing rate

$$\frac{dm}{dt} = \alpha_m(v)(1-m) - \beta_m(v)m$$

$$\frac{dn}{dt} = \alpha_n(v)(1-n) - \beta_n(v)n$$

$$\frac{dh}{dt} = \alpha_h(v)(1-h) - \beta_h(v)h$$

stimulus

$$C\frac{du}{dt} = \overbrace{g_{Na}m^3h(u-V_{Na})}^{I_{Na}} + \overbrace{g_K n^4(u-V_K)}^{I_K} + \overbrace{g_l(u-V_L)}^{I_{leak}} + I(t)$$

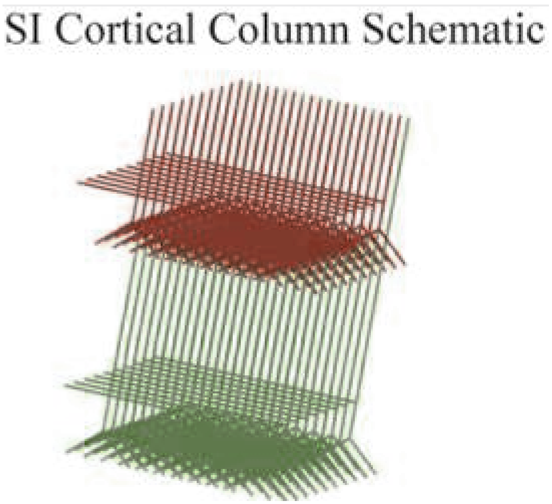
A network of HH neural models simulating the somatosensory cortex

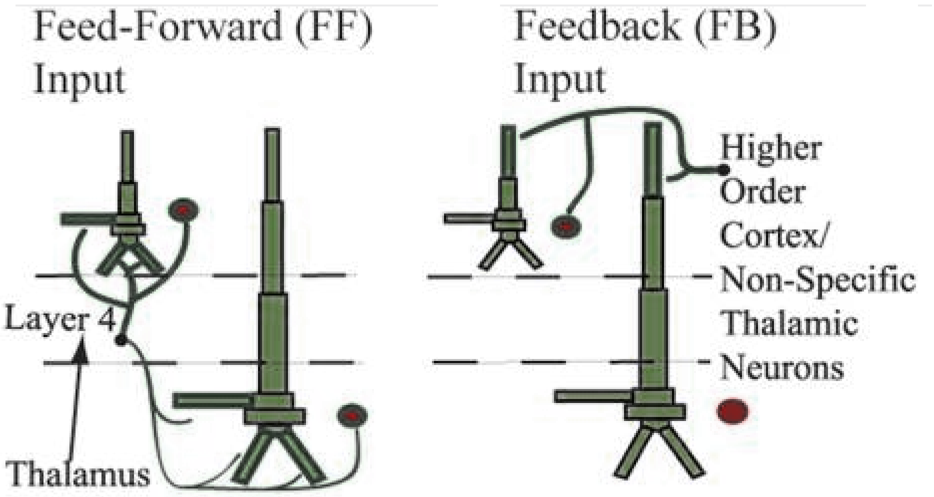
neurons

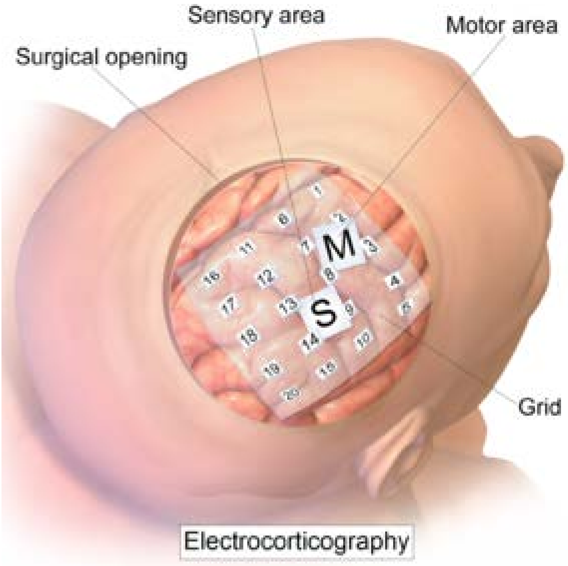
- Hodgkin-Huxley type
- inhibitory and excitatory

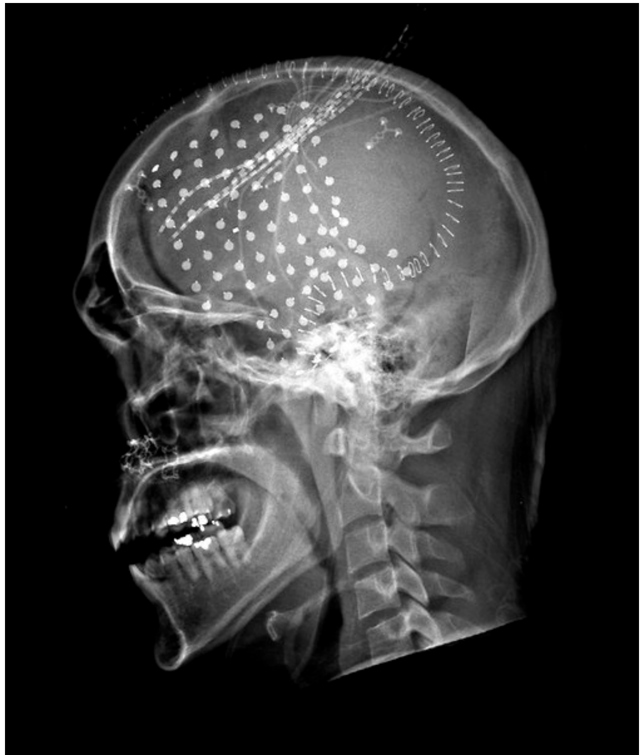
inputs

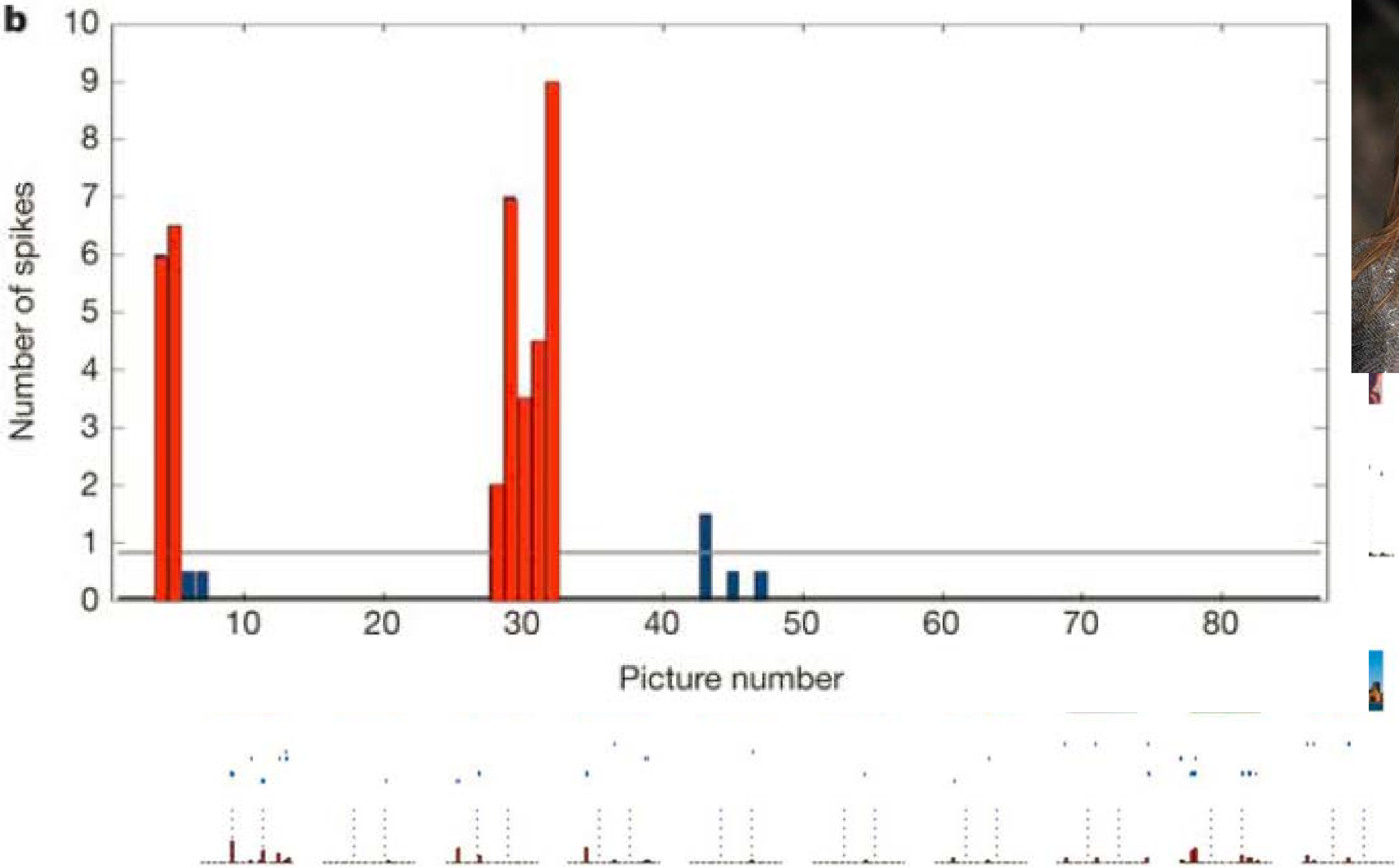
- FeedForward (FF) : representative of lemniscal thalamic drive
- FeedBack (FB) : representative of higher order cortical drive or nonlemniscal thalamic nuclei

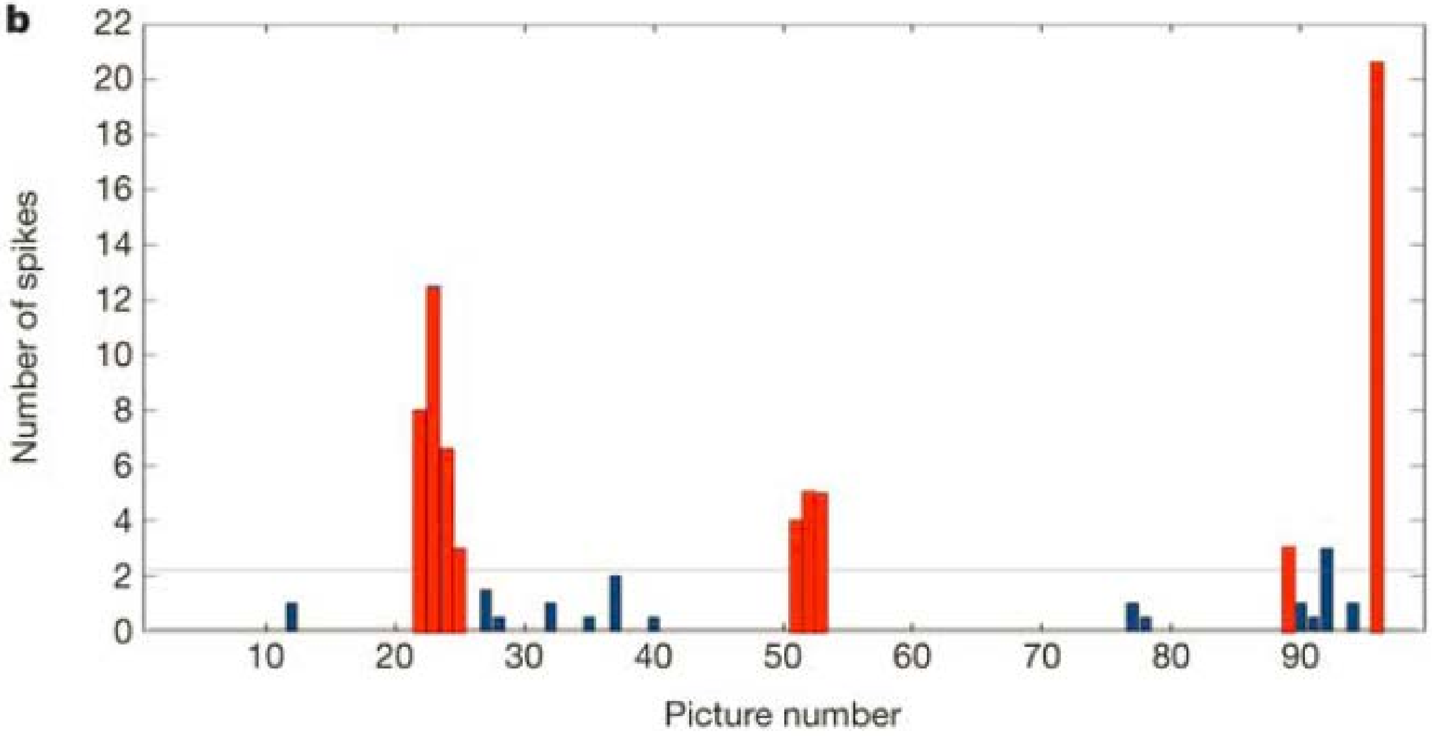




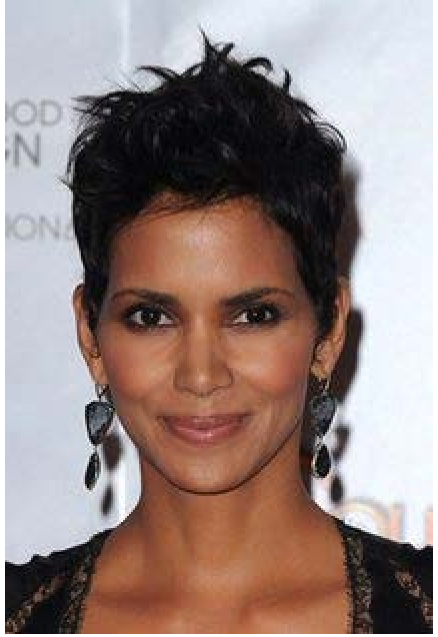

Sensory area
Motor area
Surgical opening
M
S
Grid
Electrocorticography



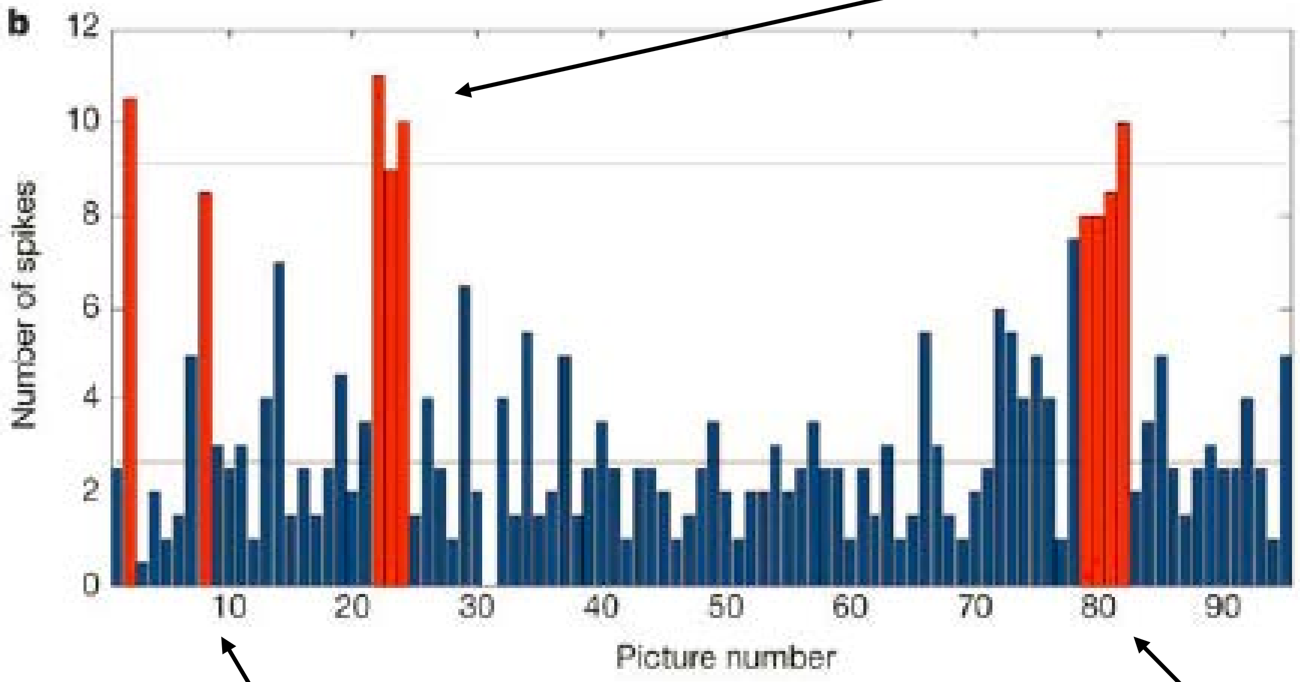

b
Number of spikes
0
1
2
3
4
5
6
7
8
9
10
10
20
30
40
50
60
70
80
Picture number



b
Number of spikes
Picture number
0
2
4
6
8
10
12
14
16
18
20
22
10
20
30
40
50
60
70
80
90



“Halle Berry”



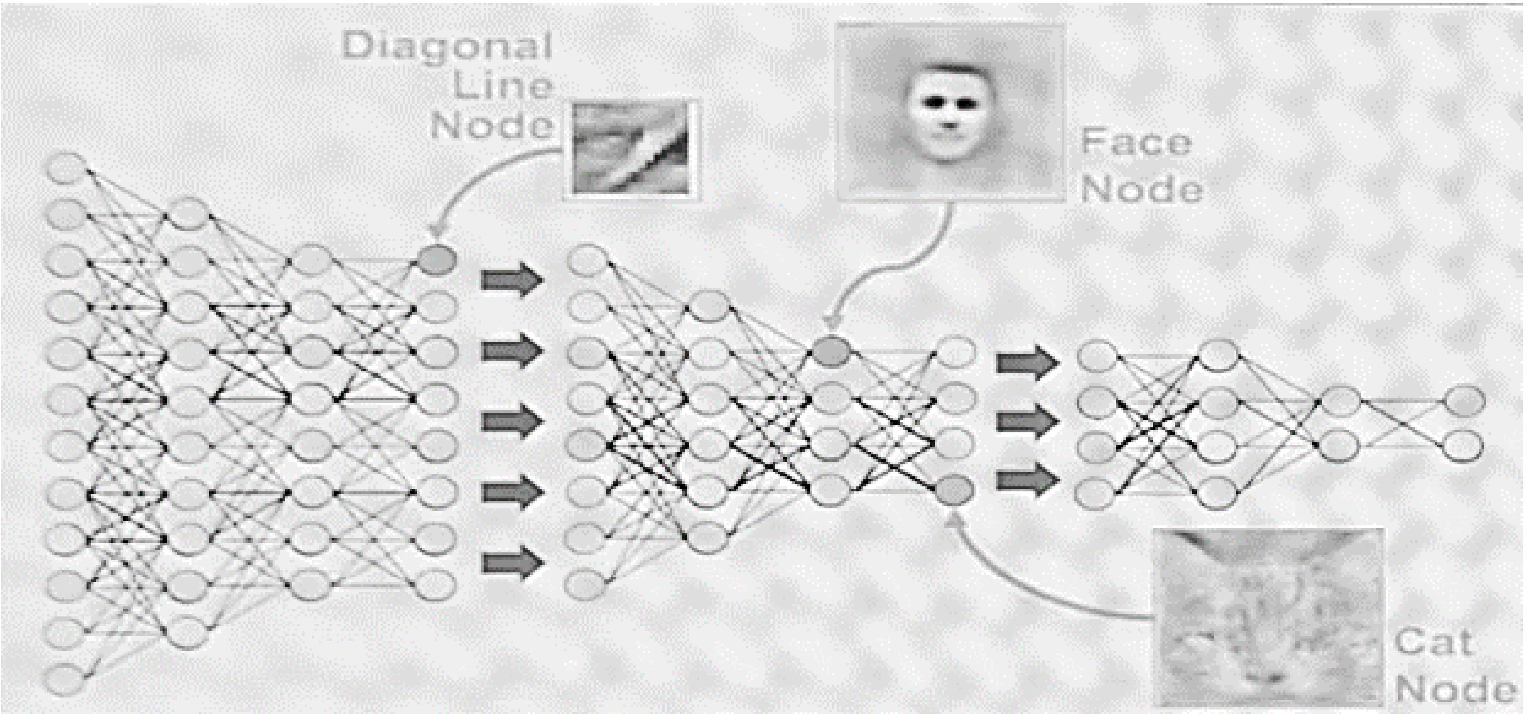
“Sydney opera”

Bahá'í House of Worship

Deep Learning

A series of neurons (nodes) with successive layers and the information is combined within each neuron

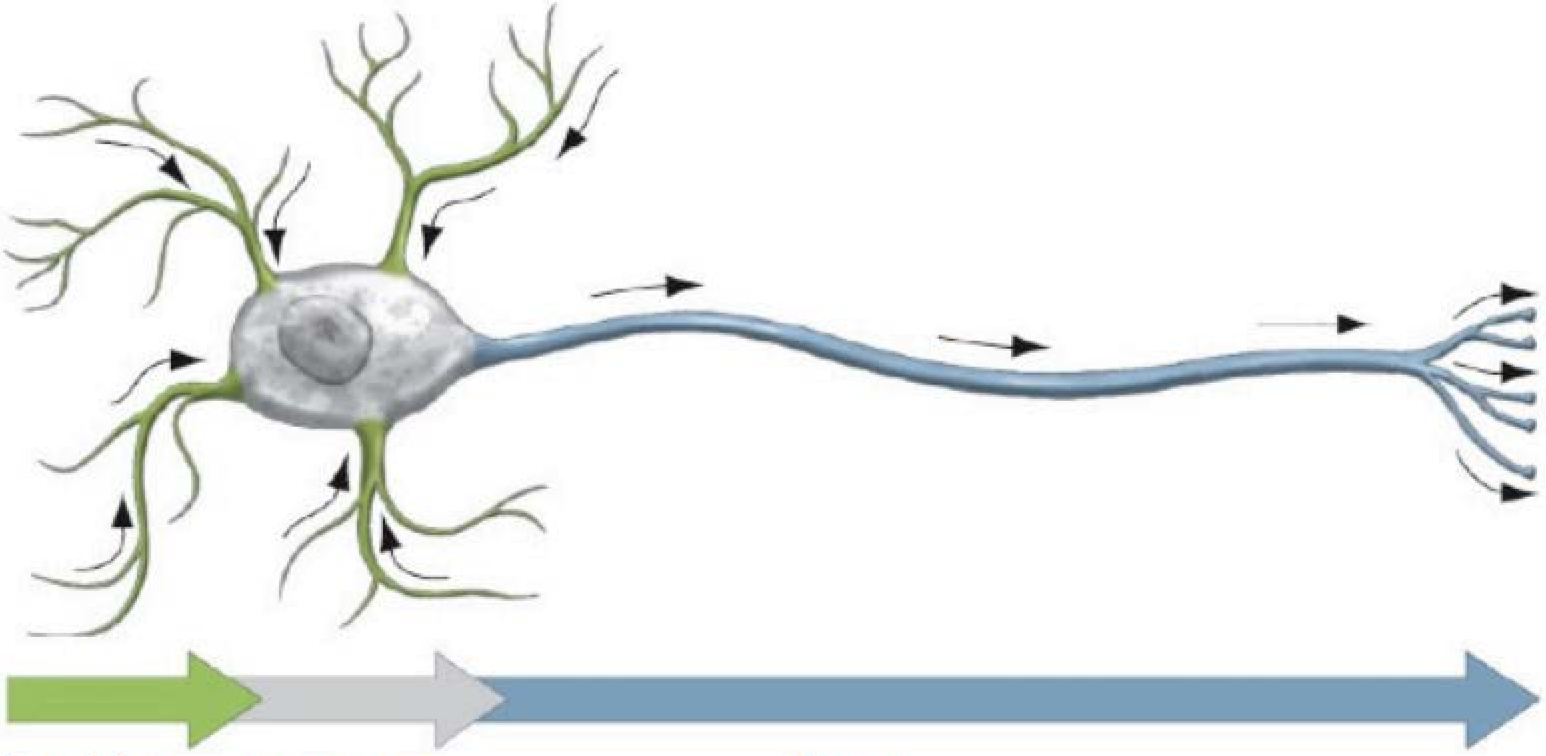
In the end, you can train one of the nodes to recognize a feature



Take – home message

Neurons might be encoding an *abstract representation* of an “entity”

Last Time

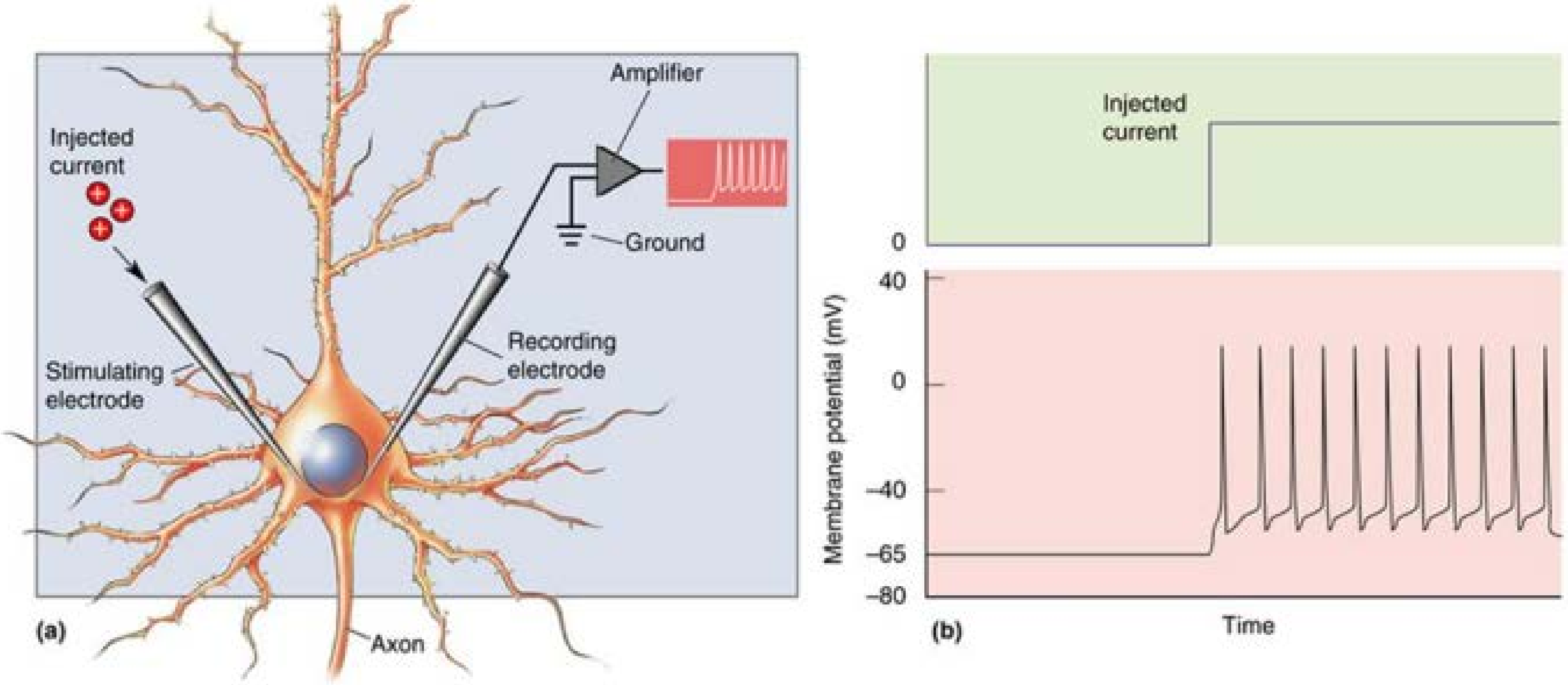


Dendrites
Collect electrical signals

Cell body
Contains nucleus and organelles

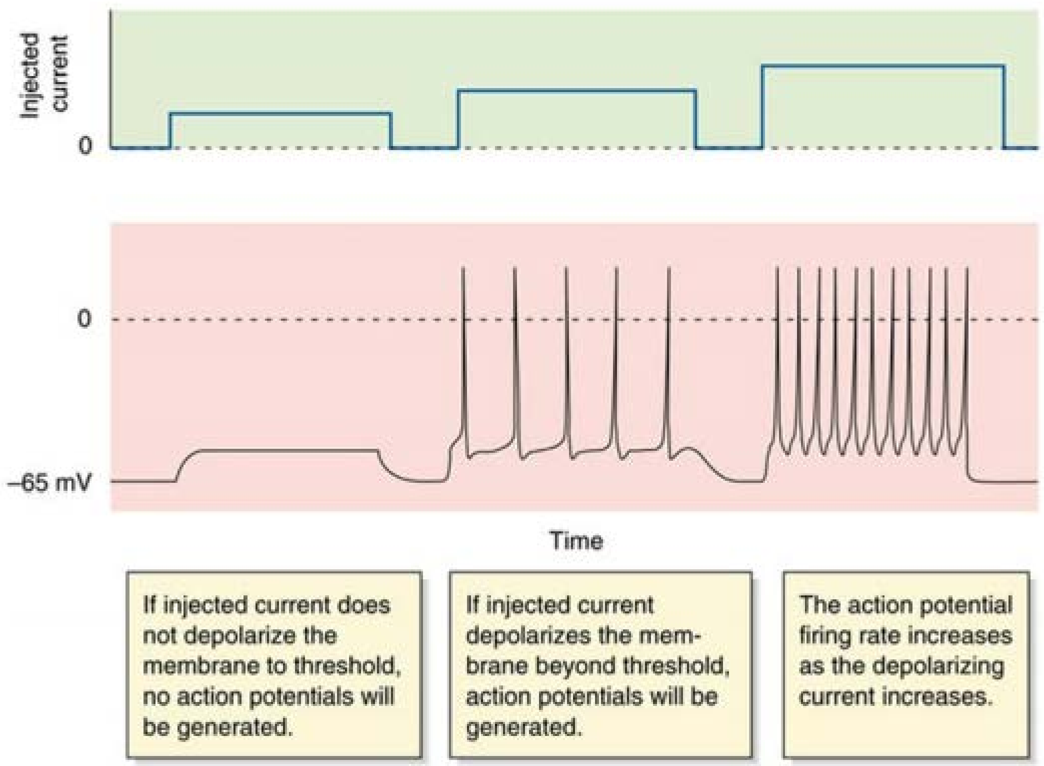
Axon
Passes electrical signals on to dendrites of another cell or to an effector cell

Important for Assignment #1



Important for Assignment #1

Real Data

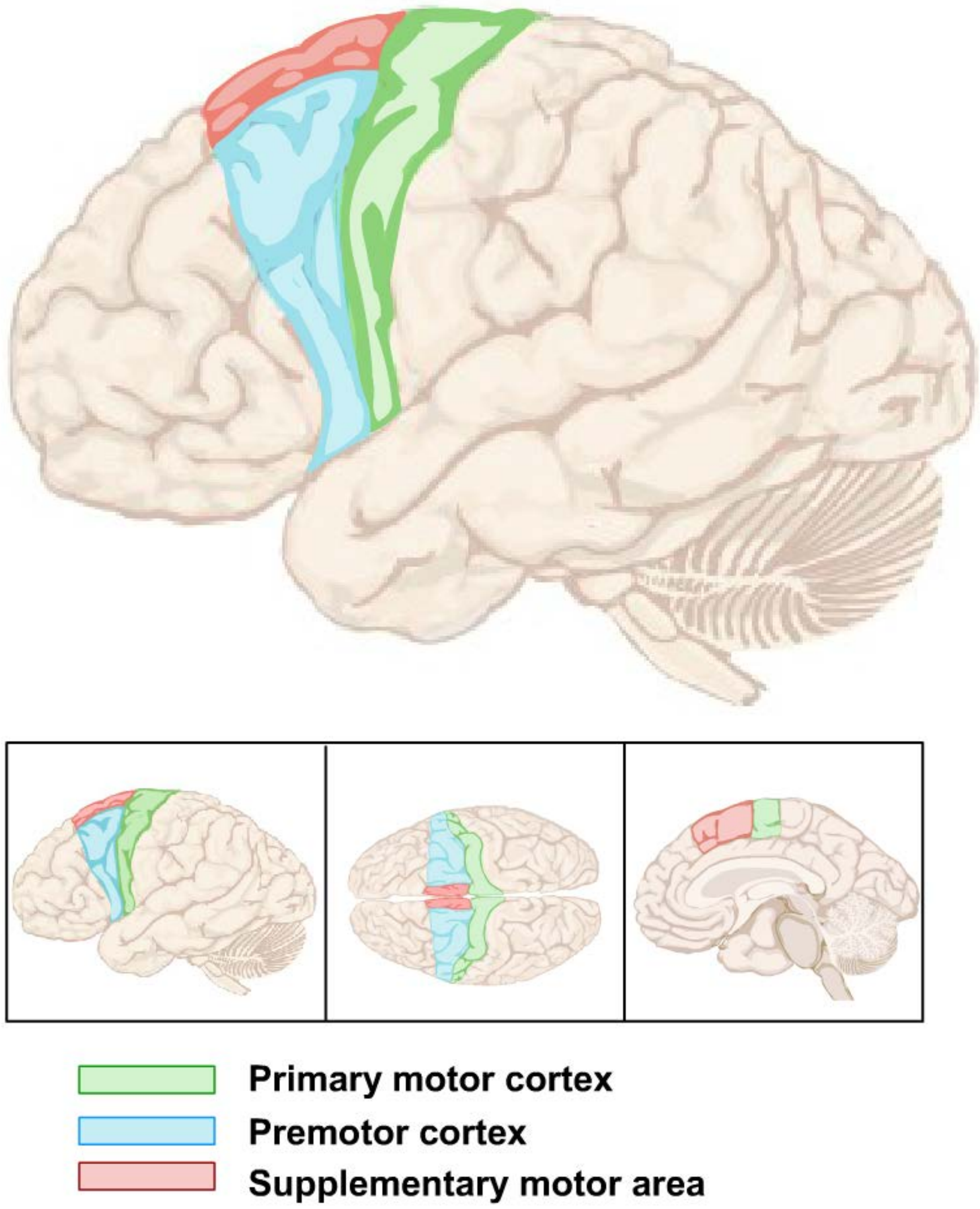


Motor Cortex

- Electrical stimulation of the primary motor areas elicits movements of particular body parts.

- Of the three motor cortex areas, stimulation of the primary motor cortex requires the least amount of electrical current to elicit a movement. Low levels of brief stimulation typically elicit **simple movements** of individual body parts

- Stimulation of premotor cortex or the supplementary motor area requires higher levels of current to elicit movements, and often results in **more complex movements** than stimulation of primary motor cortex.



Primary Motor Cortex

- The primary motor cortex is somatotopically organized
- If we move a stimulating electrode across the precentral gyrus from dorsomedial to ventrolateral, movements are elicited progressively from the torso, arm, hand, and face (most laterally).
- The representations of body parts that perform precise, delicate movements, such as the hands and face, are disproportionately large compared to the representations of body parts that perform only coarse, unrefined movements, such as the trunk or legs.