1 Remaining

- Physiology behind the equations.
- Simple detector network.

But first (or at some point):

- Free will.
- God.
- Simplification.

2 Free will

How many of you believe in it?

vs. Determinism: Things could not have happened any other way (whether it's what outfit you wore today or what you'll have for lunch or what job/hobbies/people you devote your life to).

How is free will instantiated?

Does it require you to be a dualist?

3 Neurophysiology

The neuron is a miniature electro-chemical system:

1. Balance of electric and diffusion forces.
2. Principal ions.
3. Putting it all together.

4 Balance of Electric and Diffusion Forces

Ions flow into and out of the neuron under forces of electricity and concentration gradients (diffusion).

Net result is electric potential difference between inside and outside of cell — **the membrane potential** V_m.

This value represents an integration of the different forces, and an integration of the inputs impinging on the neuron.

5 Electricity

Ions have net charge: Sodium (Na^+), Chloride (Cl^-), Potassium (K^+), and Calcium (Ca^{++}).

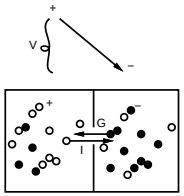
Positive and negative **charge** (opposites attract, like repels).

Current flows to even out distribution of + and - ions.

Disparity in charges produces **potential** (the potential to generate current).

6 Resistance

Ions encounter **resistance** when they move.
Neurons have **channels** that limit flow of ions in/out of cell.



The smaller the channel, the higher the resistance, the greater the potential needed to generate given amount of current (Ohm's law):

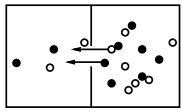
$$I = \frac{V}{R} \quad (1)$$

Conductance G = 1/R, so $I = GV$

7 Diffusion

Constant motion causes mixing – evens out distribution.

Unlike electricity, diffusion acts on each ion *separately* — can't compensate one + ion for another..



(same deal with conductance, potentials, etc)

$$I = -DC \quad (2)$$

(Fick's First law)

8 Equilibrium

Balance between electricity and diffusion:

E = **Equilibrium** potential = amount of electrical potential needed to counteract diffusion:

$$I = G(V - E) \quad (3)$$

Also:

Reversal potential (because current reverses on either side of E)

Driving potential (flow of ions drives potential toward this value)

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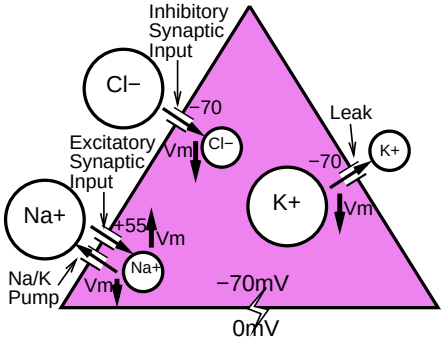
The Neuron and its Ions

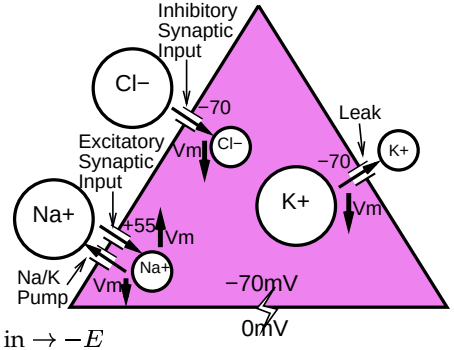


Na+ pumped out $\rightarrow -V_m$ and $+E$

Na+ channels open (glutamate or voltage-gated) $\rightarrow$ Na+ rushes in (electric and diffusion)

10

The Neuron and its Ions



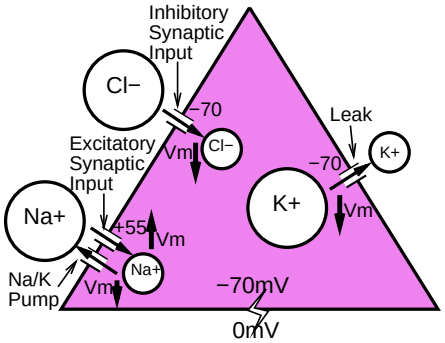
K+ pumped in $\rightarrow -E$

K+ channels open (voltage-gated, high V_m) $\rightarrow$ K+ rushes out (electric and diffusion)

Also, leak K+ channels (always open) $\rightarrow$ let K+ out

11

The Neuron and its Ions



Cl- driven out by $-V_m$ until balanced by diffusion force.

Cl- channels open (GABA) $\rightarrow$ Nothing!
(until $V_m \uparrow$ – shunting inhibition)

12

Putting it Together

$$I_c = g_c \bar{g}_c (V_m - E_c) \quad (4)$$

e = excitation (Na^+)
i = inhibition (Cl^-)
l = leak (K^+).

$$\begin{aligned} I_{net} &= g_e \bar{g}_e (V_m - E_e) + \\ &\quad g_i \bar{g}_i (V_m - E_i) + \\ &\quad g_l \bar{g}_l (V_m - E_l) \end{aligned} \quad (5)$$

$$V_m(t+1) = V_m(t) + dt_{vm} I_{net-} \quad (6)$$

13 Overall Equilibrium Potential

If you run V_m update equations with steady inputs, neuron settles to new *equilibrium potential*.

To find, set $I_{net} = 0$, solve for V_m:

$$V_m = \frac{g_e \bar{g}_e E_e + g_i \bar{g}_i E_i + g_l \bar{g}_l E_l}{g_e \bar{g}_e + g_i \bar{g}_i + g_l \bar{g}_l} \quad (7)$$

14 Bio Neural Nets

1. Compute weighted, summed *net input*:

$$\eta_j \approx \sum_i a_i w_{ij} \approx g_e \quad (8)$$

2. Compute V_m:

$$V_m = \frac{g_e \bar{g}_e E_e + g_i \bar{g}_i E_i + g_l \bar{g}_l E_l}{g_e \bar{g}_e + g_i \bar{g}_i + g_l \bar{g}_l} \quad (9)$$

3. Compute output as: Spikes, or rate code equiv.
Or, rate code via *sigmoidal* function:

$$a_j = \frac{1}{1 + (\gamma[V_m(t) - \Theta]_+)^{-1}} \quad (10)$$

15 How do we simulate neurons to explore their role in cognition and behavior?

- Neural activity (and learning) can be characterized by mathematical equations.
- We use these equations to specify the behavior of artificial neurons.
- The artificial neurons can then be put together to explore behaviors of networks of neurons.
- Simulation.

16 But...

- Free will.
- God.
- Simplification.