Biophysical Neural Models

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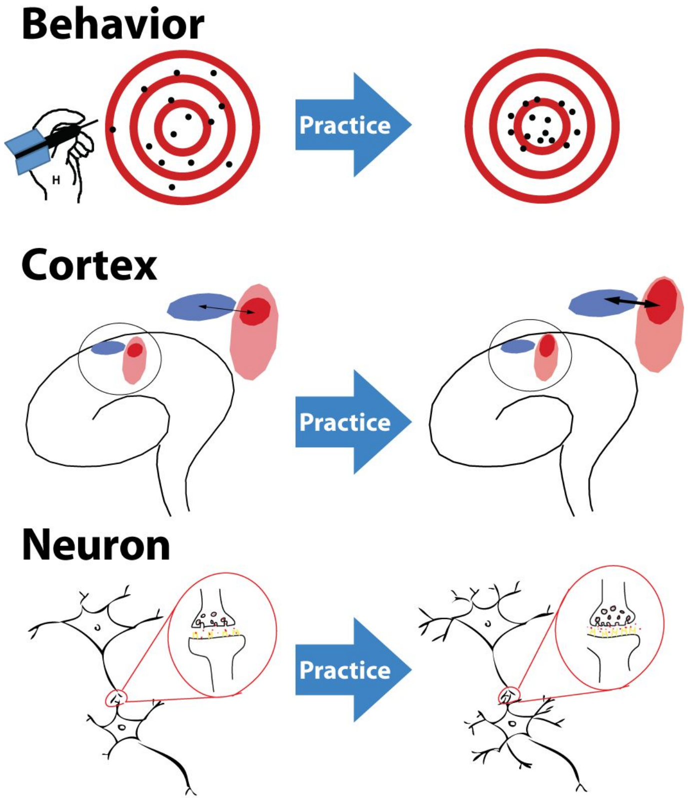
GOAL: Understand how neurons can be modelled and analyzed mathematically

- Motivation and Background
  - Computation: brain vs cpu
  - Neurons: structure and function
  - Neural communication
- Biophysics
  - Ion gates and channels
  - Morris-Lecar Model

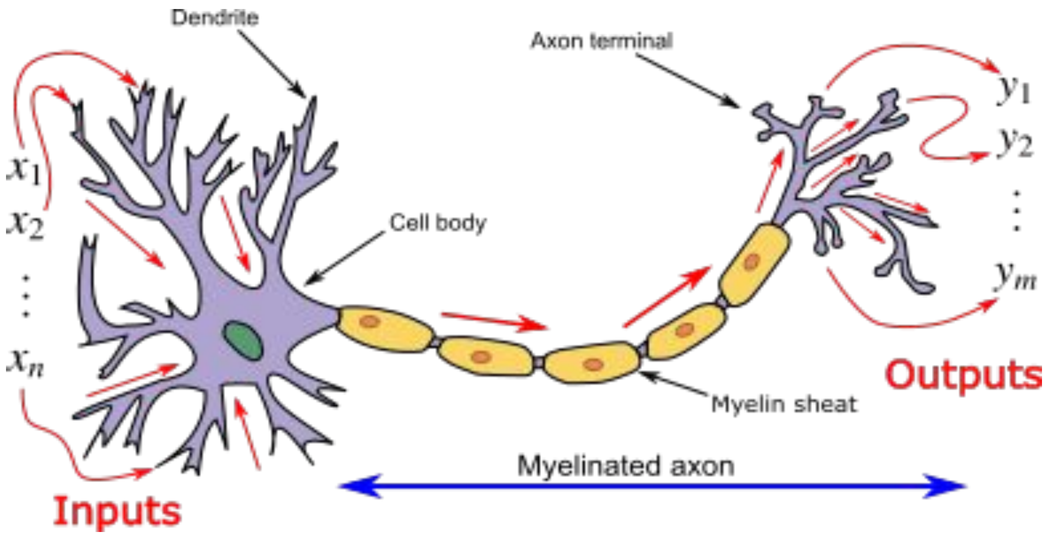
Brain computation is fundamentally different from silicon computation

The architecture of the brain is malleable

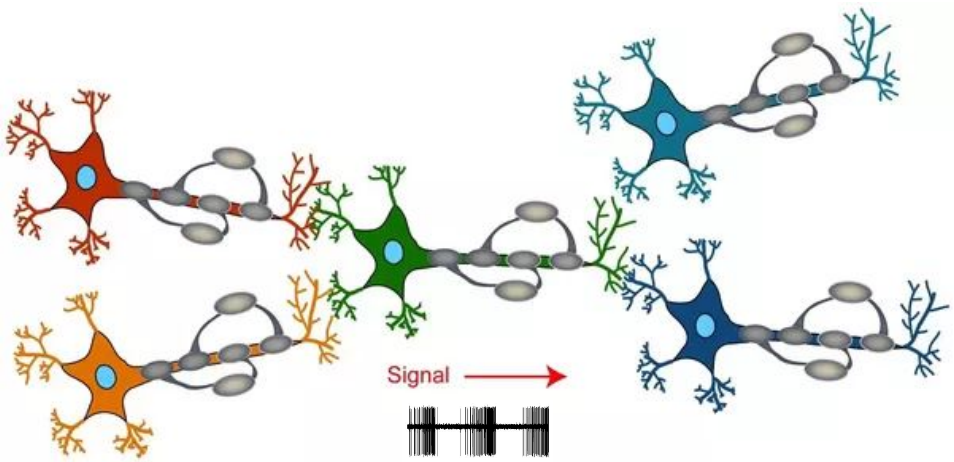
- Neuroplasticity
  - neural connections form, strengthen, weaken, depending on experiences
  - “programs” are encoded in the architecture
- CPU+RAM
  - architecture is immutable
  - programs are loaded onto the architecture



Neurons perform input/output computation



Neurons communicate via spike trains

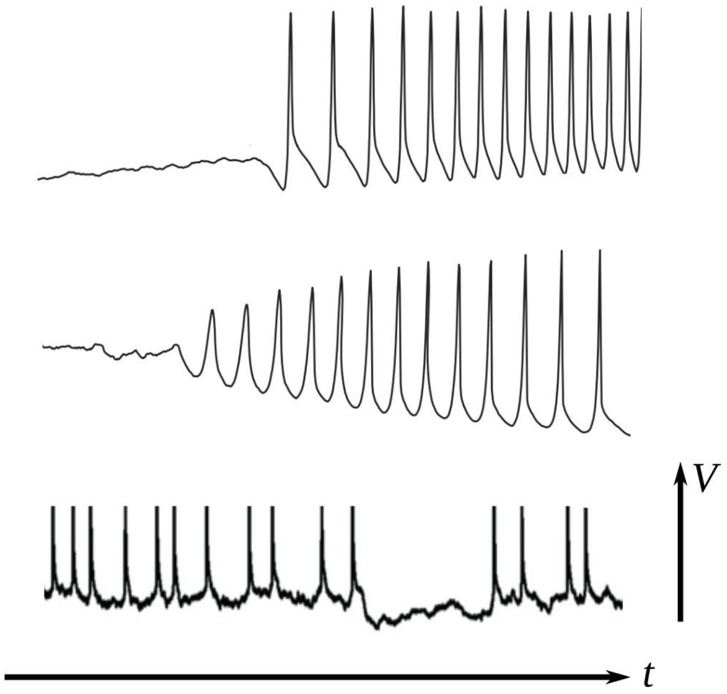


Different neuron types have diverse behavior

Constant amplitude,
increasing frequency

Constant frequency,
increasing amplitude

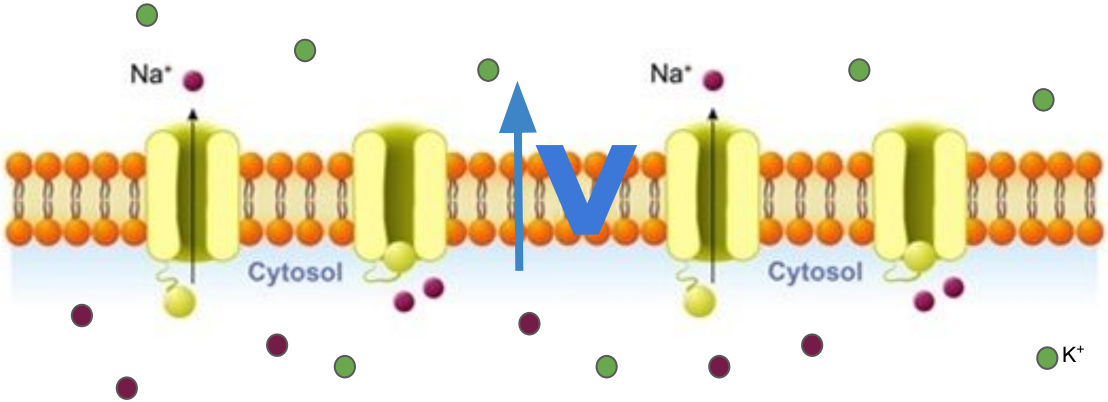
Nonlinear
superposition



Biophysics offers insight into constructing neuron models

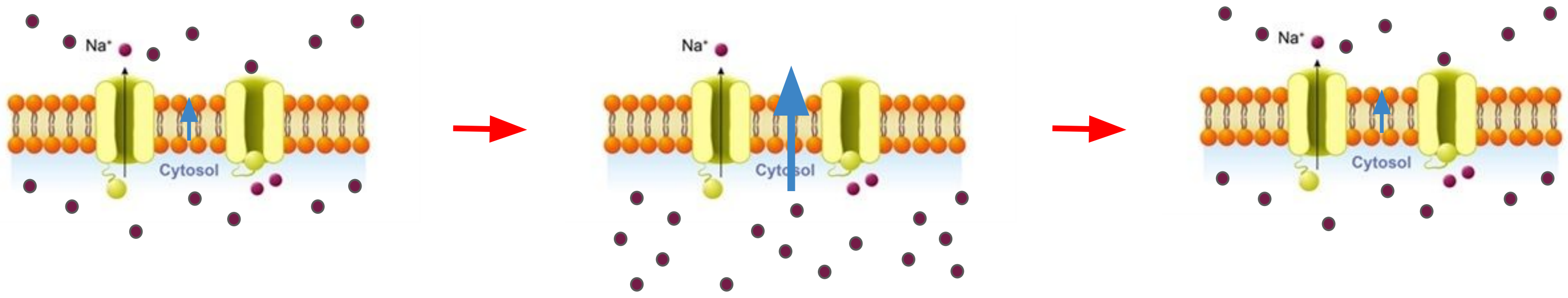
Ions flow through gated channels

Outside the cell



Inside the cell

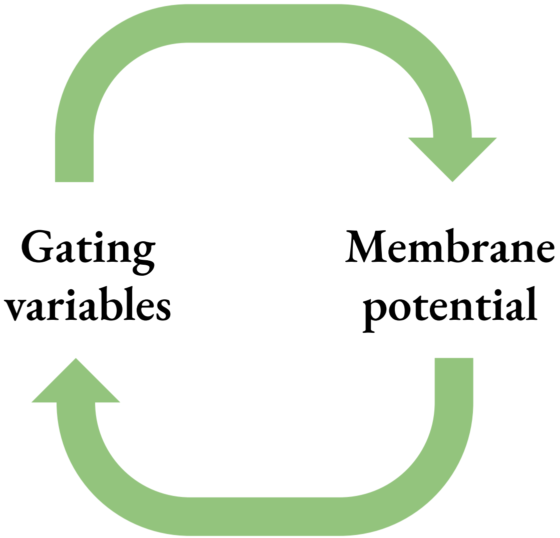
Spike = spike in membrane potential



Off-equilibrium SPIKE Equilibrium

Gating variable is coupled to V

- **n**: The fraction of K^+ gates that are open
  - Each ion has its own gating variable
  - Voltage-gated (sigmoid)
- **V**: membrane potential
  - Depends on ionic currents



Morris-Lecar model is inspired by biophysics

Ohm's Law:

Ionic current | 1/Resistance | Potential difference

$$I_{\mathrm{K}} = g_{\mathrm{K}} \cdot n \cdot (V - E_{\mathrm{K}})$$

Capacitance:

$$C\frac{\mathrm{d}V}{\mathrm{d}t} = I_{\mathrm{cap}}$$

Ionic currents

$$= I - I_{\mathrm{K}} - I_{\mathrm{Na}} - I_{\mathrm{L}}$$

Gate equilibrium:

Restoring strength | Equilibrium gate value

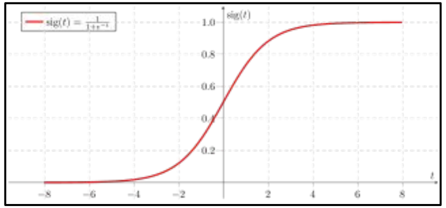
$$\tau\frac{\mathrm{d}n}{\mathrm{d}t} = n_{\infty}(V) - n$$

Morris-Lecar model is inspired by biophysics

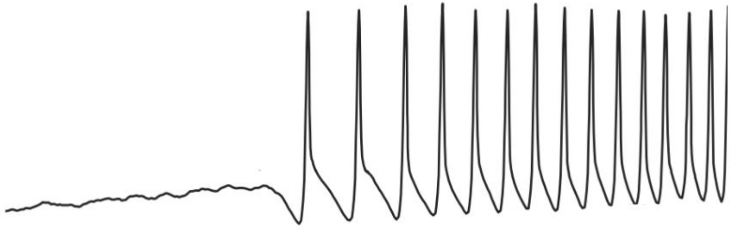
$$C \frac{\mathrm{d}V}{\mathrm{d}t} = I - I_{\mathrm{K}} - I_{\mathrm{Na}} - I_{\mathrm{L}}$$

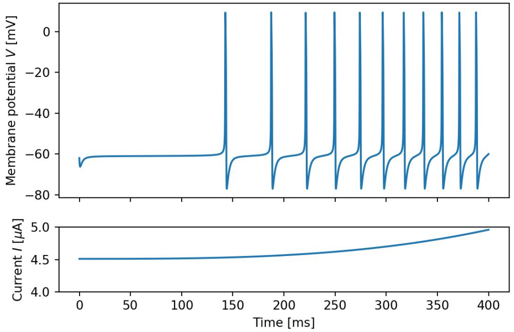
$$I_{\mathrm{K}} = g_{\mathrm{K}} \cdot n \cdot (V - E_{\mathrm{K}})$$

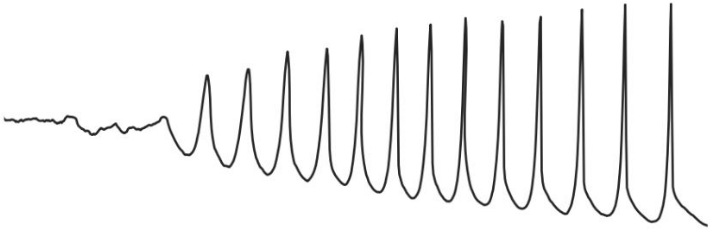
$$\tau \frac{\mathrm{d}n}{\mathrm{d}t} = n_{\infty}(V) - n$$

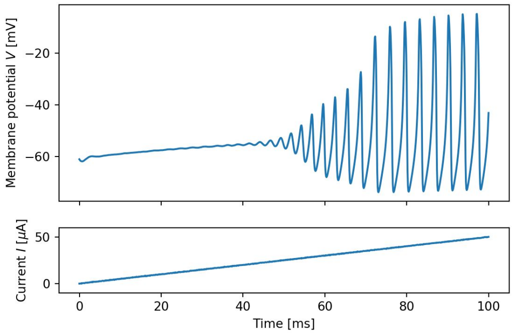


Dynamical Systems Theory can analyze and reproduce qualitative behaviors









Thank You!

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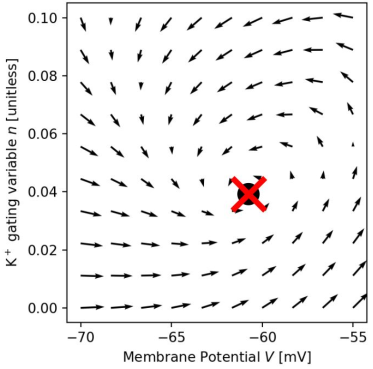
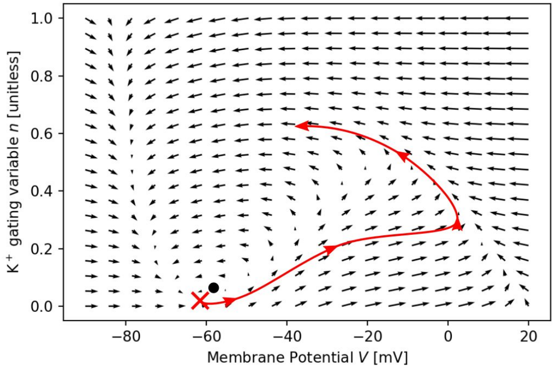
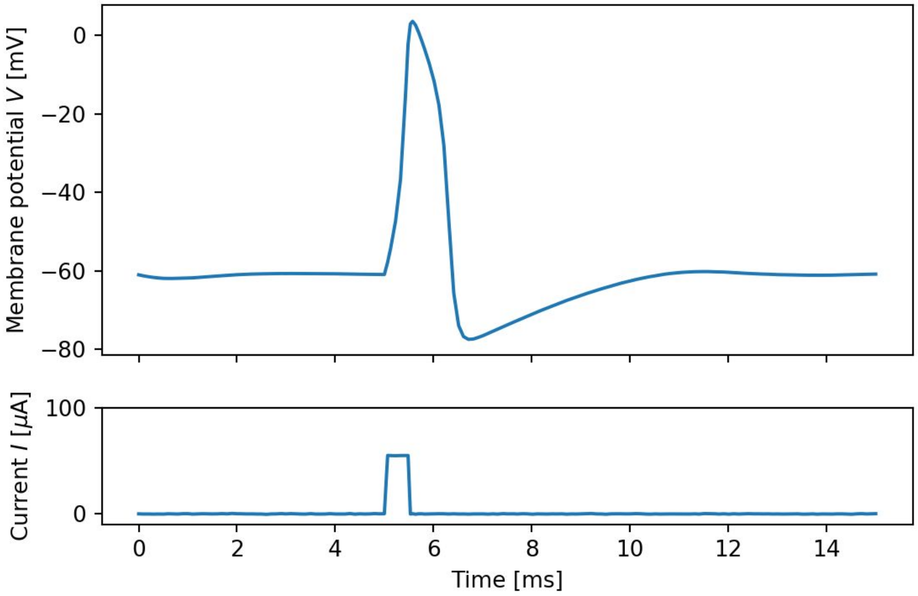
Supplemental Slides

Excitation Mechanism







Andronov-Hopf bifurcation