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:

\[ I_K = g_K \cdot n \cdot (V - E_K) \]

Capacitance:

\[ C \frac{dV}{dt} = I_{\text{cap}} \]

\[ = I - I_K - I_{\text{Na}} - I_L \]

Gate equilibrium:

\[ \tau \frac{dn}{dt} = n_\infty (V) - n \]
Morris-Lecar model is inspired by biophysics

\[ C \frac{dV}{dt} = I - I_K - I_{Na} - I_L \]

\[ \tau \frac{dn}{dt} = n_\infty(V) - n \]

\[ I_K = g_K \cdot n \cdot (V - E_K) \]
Dynamical Systems Theory can analyze and reproduce qualitative behaviors
Thank You!

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Excitation Mechanism
Andronov-Hopf bifurcation