Project Trinity

Exploring the Morris-Lecar Neuron Model

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Introduction

Project Trinity explores the dynamics of the Morris-Lecar model, a seminal biophysical model in computational neuroscience. The model aims at studying the excitability and spiking dynamics of neurons. This model simulates the electrical activity of neurons by accounting for ion channel dynamics, specifically focusing on calcium (Ca^{2+}) and potassium (K^+) conductance. The project's goal is to understand how variations in these conductances influence neuronal behavior.

Methodology

The Morris-Lecar model is formulated through a set of nonlinear differential equations. Our implementation in Python leverages NumPy and SciPy for numerical solutions and Matplotlib for data visualization. The model parameters, including membrane capacitance (C), maximum conductances (g_{Ca}, g_{K}), and reversal potentials (V_{Ca}, V_{K}, V_{L}), are chosen based on standard biophysical properties of neurons.

Implementation

We developed an interactive Jupyter Notebook that allows for dynamic exploration of the model. In particular, we have defined the key variables with some predefined parameters:

- V_w (Tuple[float, float]): represents the state of the neuron at a specific moment in time.
- V, denotes the membrane potential.
- w, is the recovery variable.
- t (float): the time variable.

- I_ext (float): the applied current from external sources.
- C (float): Capacitance of the neuron's membrane.
- g_Ca, g_K, g_L (float): Maximum conductances for calcium currents.
- V_Ca, V_K, V_L (float): Reversal potentials for calcium currents.
- phi (float): The temperature factor.

Returns: The function returns a tuple containing the derivatives representing the rates of change of membrane potential and recovery variable over time, respectively. The ODEs are solved using the 'odeint' function from SciPy, and the results are visualized in real time.

Results and Analysis

By solving the differential equations, we obtain a time course of V and w, revealing how the neuron responds to external input and modulates its internal variables. Our simulations reveal that higher g_{Ca} values enhance the neuron's excitability, leading to more frequent spiking. Variations in g_{K} significantly affect the recovery dynamics and spike frequency. The model exhibits a range of behaviors from quiescent states to periodic spiking, depending on the conductance values. Through data analysis, we identified key characteristics such as maximum/minimum membrane potentials and recovery variables. The estimated threshold potential provides insights into the neuron's activation dynamics.

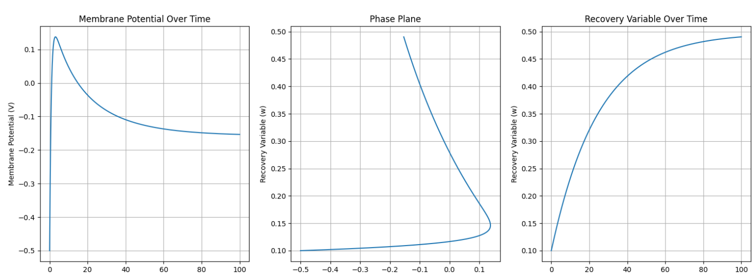

Figure 1: I_{ext}: 0.1 - g_{Ca}: 1.0 - g_{K}: 2.0

Conclusion

Project Trinity demonstrates the versatility of the Morris-Lecar model in capturing essential features of neuronal behavior. We observed that parameter sensitivity and its influence on the excitability and firing patterns are common features of all spiking neurons models. The simplicity of the Morris-Lecar model makes it extremely computationally efficient. Our interactive approach facilitates an intuitive understanding of how ion conductances modulate neuronal activity. Future work could expand on this model by incorporating stochastic elements or exploring network dynamics.