Estimating Neural Properties from Whole-Cell Electrophysiology

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1. Overview

Given a trace of the membrane potential of a neuron, how much can we infer about the statistics of its inputs?

While we are capable of recording from many neurons at a time, it is difficult to record from the input neurons to a specific neuron. If we can infer neural input properties from the voltage trace of the cell membrane we will gain increased understanding of neural dynamics

Beginning with a simulated neuron and advancing to fit data from Mouse Hippocampal CA1 pyramidal cells, we hope to be able to calculate a best-fit of parameters for the input population such as average firing rate.

2. Simulation

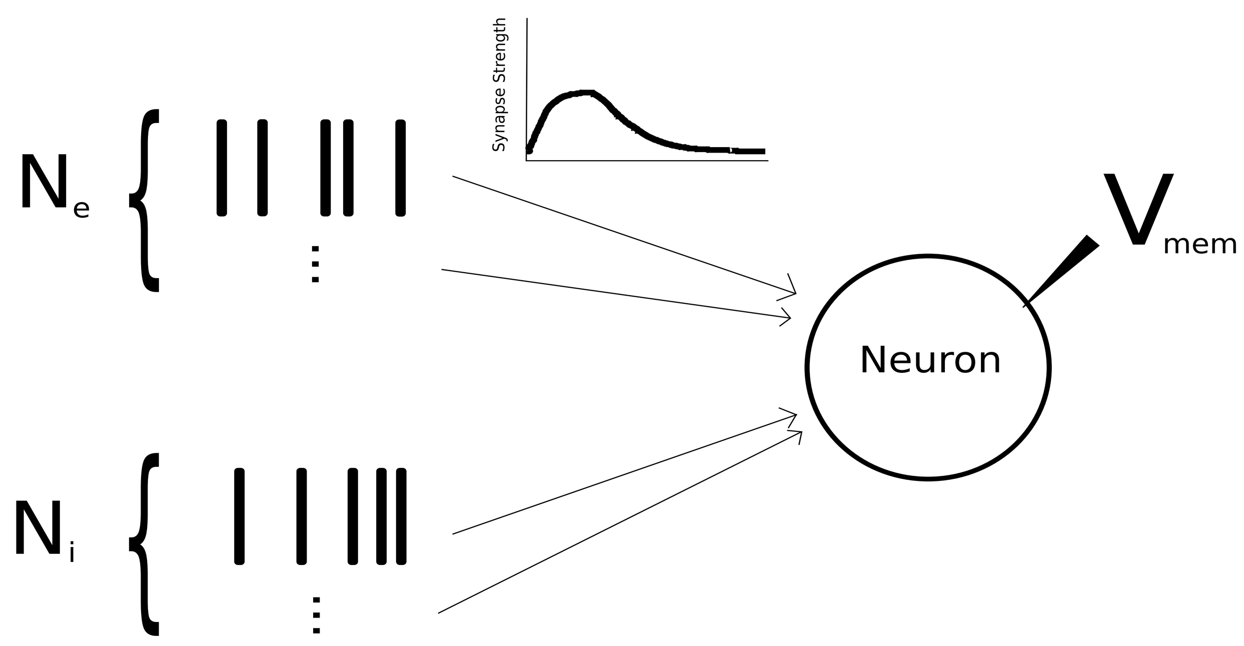

Figure 1 : Diagram of Neuron Simulation

A simulation was developed so the fitting could be tested on known parameter values. This consisted of 1000 poisson processes, approximating input neurons, feeding into a single leaky integrate and fire neuron, approximating the neuron we are recording from.

Simulation Equations

$$\tau_m \frac{dV}{dt} = R_m g_l (E_l - V) + R_m g_e (E_e - V) + R_m g_i (E_i - V)$$

$$\tau_e \frac{dg_e}{dt} = -g_e \qquad \tau_i \frac{dg_i}{dt} = -g_i$$

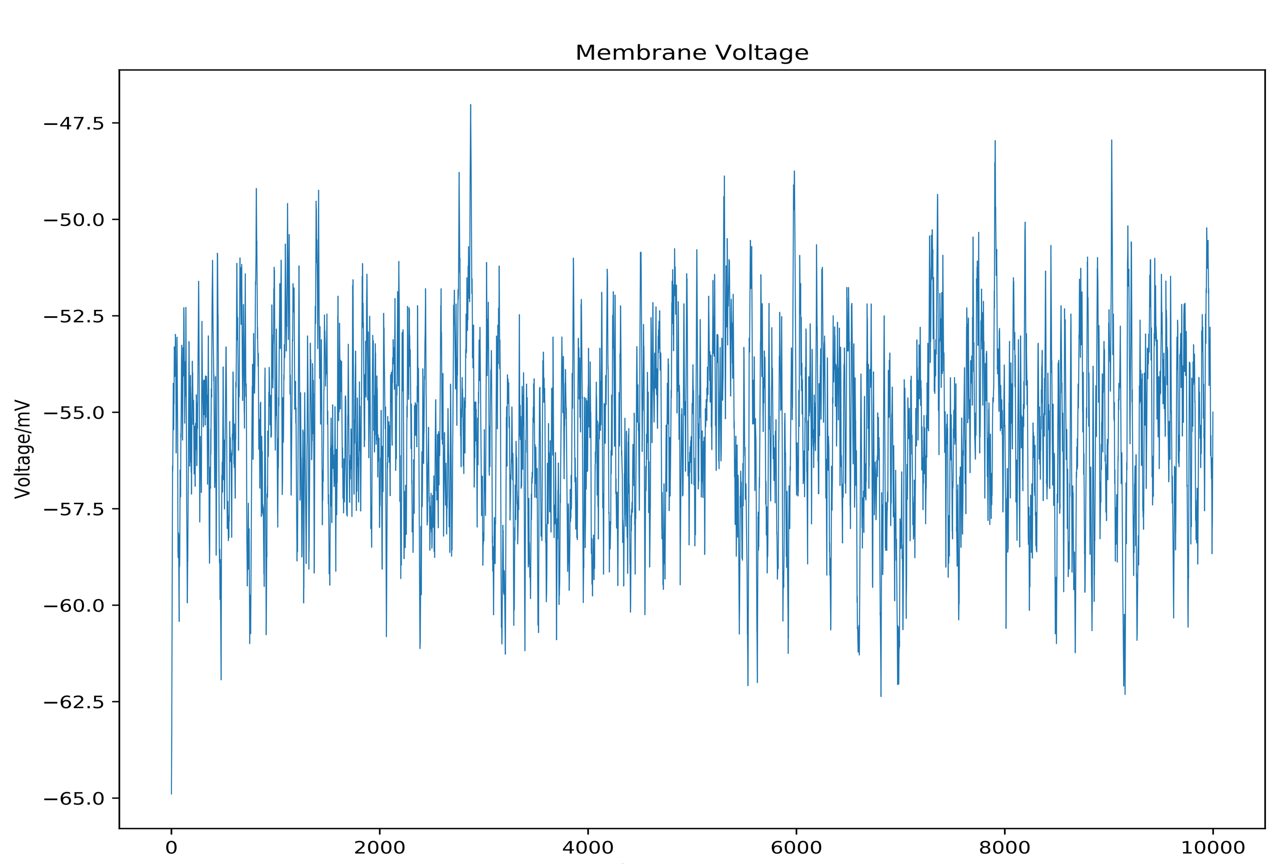

Figure 2 : Sample simulation Voltage trace

As this is a subthreshold model, it has no spiking dynamics and so does not attempt to model activity above ~-45mV as seen in Figure 3

3. Real-World Data

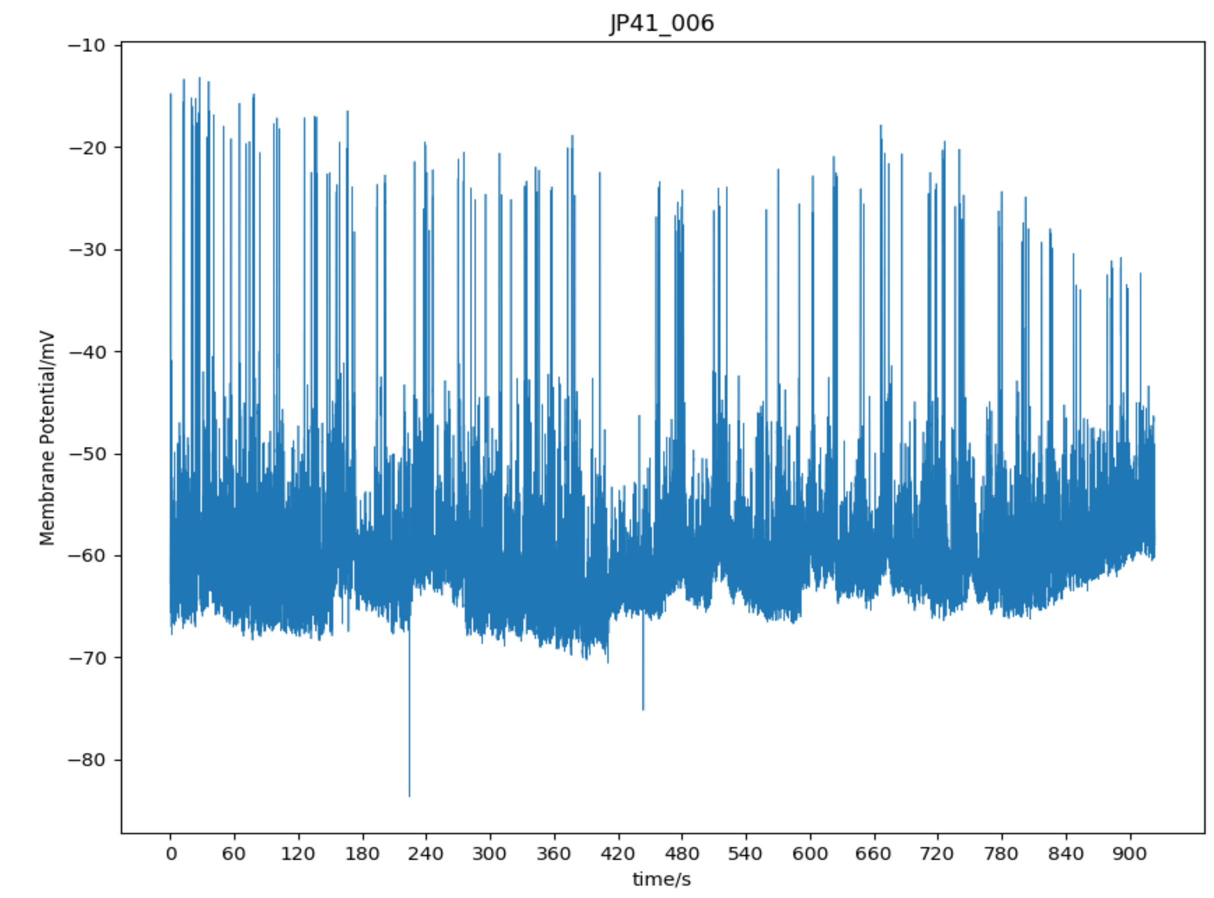

Figure 3 : Real-World Voltage trace

Figure 3 shows a trace from a mouse CA1 pyramidal cell. The model fits the subthreshold dynamics quite well. However the recording setup does introduce some noise into the trace so this may be an issue in fitting parameters.

4. Power Spectrum

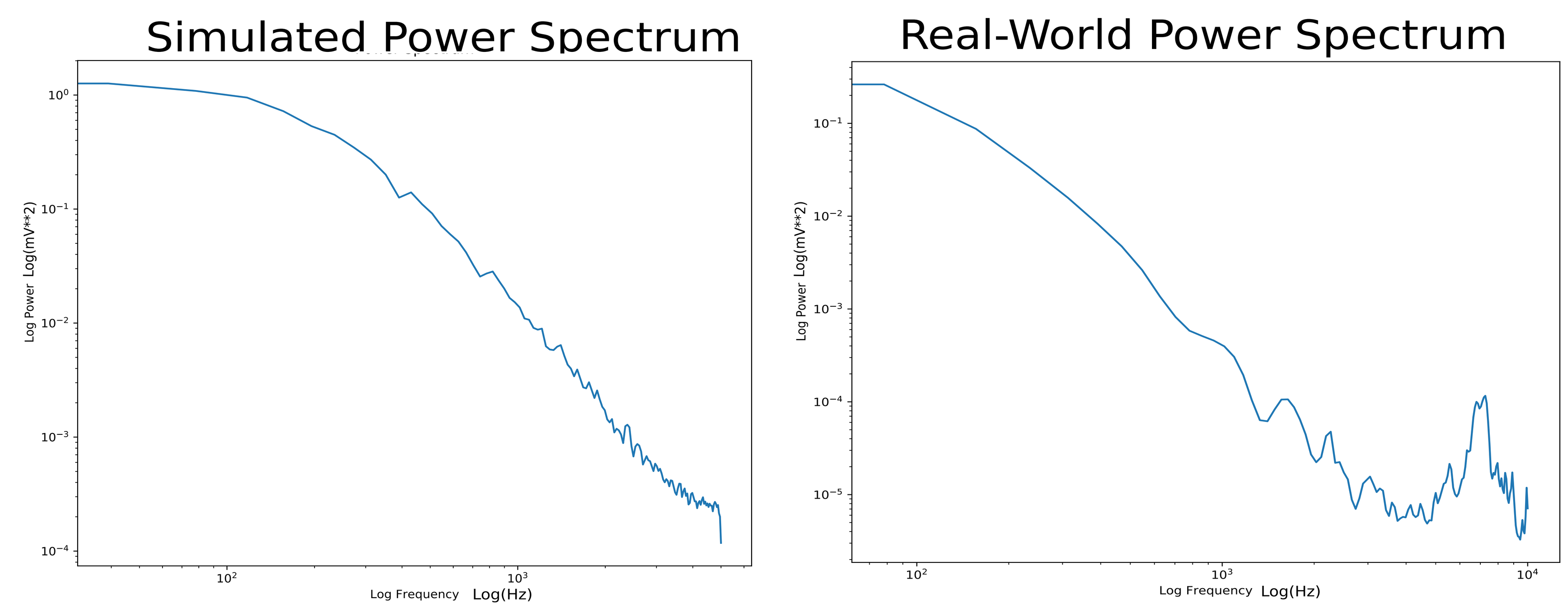

Figure 4 : Simulated compared to Real-World Power Spectral Density

Power Spectrum Equation

$$PS_V(f) = \left(\frac{R_{eff}^2}{1+(2\pi f \tau_{eff})^2}\right)\left(\frac{2\nu_e(\mu_e^2+\sigma_e^2)}{1+(2\pi f \tau_e)^2} + \frac{2\nu_i(\mu_i^2+\sigma_i^2)}{1+(2\pi f \tau_i)^2}\right)$$

ν_x - Baseline input rate

(μ_x, σ_x) - Conductance amplitude distribution parameters

Puggioni PhD Thesis (2015)

The above equation gives us a way to try and fit the neuron input parameters if we have a power spectrum, which we can calculate from the voltage trace.

5. Future Work

- Adjust simulation to bring power of signal down to better approximate real-world data
- Test optimisation algorithms to see which best suit the problem space
- Particularly looking into CMA-ES - a stochastic derivative-free approach