

Two-variable stochastic models of neuronal integration

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The computational power of the neocortex, the most recent part of the brain in evolutionary terms, arises from a combination of the rich response properties of neurons and the highly complex networks they form. Each cortical neuron can receive as many as 10,000 synapses. So, though the firing rate of individual neurons is low (around 0-5Hz) neurons are subject to a massive bombardment of synaptic current. This stochastic synaptic current, of strength σ can be reasonably modelled by a zero-mean, unit-variance gaussian white-noise process $\xi(t)$, with some leaky integration over a timescale τ . The voltage equation can therefore be written in the form

$$\tau \frac{dv}{dt} = -v + \sigma \sqrt{2\tau} \xi(t).$$

A threshold for spike generation at v_{th} with a subsequent reset to v_{re} completes the Ornstein-Uhlenbeck model of neuronal integration. This basic model has been studied since the 1970s. However, a variant, that includes an additional non-linear voltage term was recently shown by us (Badel et al, J. Neurophysiology 2008) to be an accurate model of biological neurons (see the figure).

The model that we used to fit to the data has a single variable for the voltage. Neurons, however, are geometrically extended cells that are composed of a cell body, the *soma* with long tree-like, branching *dendritic* structures attached. Synapses from other neurons form onto these dendrites in a well organised fashion, with certain classes of neuron making synapses near the cell body and others far out at the end of the dendrites. Because of this distribution of inputs along the dendrites, neurones are compartmentalised, in the sense that streams of information may be independently integrated at the dendrites or cell body. The net response of neurons is therefore highly complex due to the interaction of the stochastic synaptic streams with the spatially heterogeneous non-linear electrical response of the dendrites and cell body.

The aim of this 12-week project will be to construct a two-variable model of neuronal integration corresponding to a coupled somatic and dendritic compartment, of the form:

$$\begin{aligned} \tau_1 \frac{dv_1}{dt} &= -v_1 + \gamma(v_2 - v_1) + \sigma_1 \sqrt{2\tau_1} \xi_1(t) \quad \text{and} \\ \tau_2 \frac{dv_2}{dt} &= -v_2 + \gamma(v_1 - v_2) + \sigma_2 \sqrt{2\tau_2} \xi_2(t). \end{aligned}$$

The project will require mathematical and programming skills and an interest in applying theoretical approaches to understand biological data. If you are interested in this project you are encouraged to contact me at the Systems Biology Centre to discuss the possibilities.

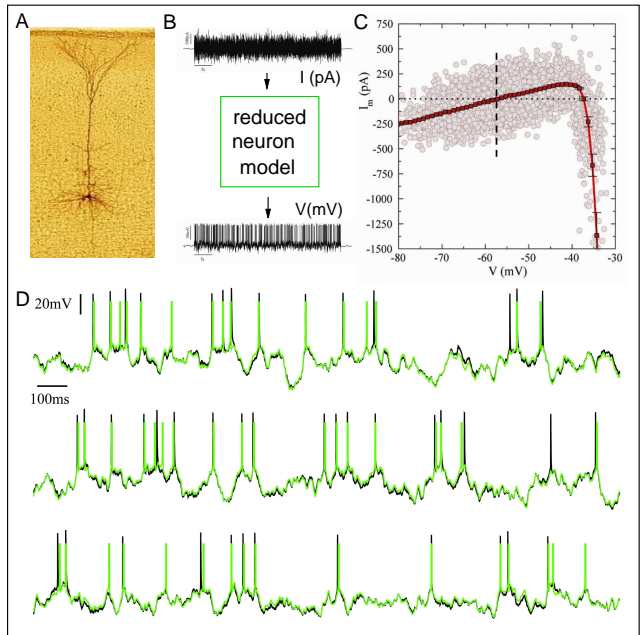


Figure 1: Fitting reduced-neuron models to voltage traces of layer-5 cortical pyramidal cells (panel A). The model is derived by matching current and voltage traces (panel B) to yield the I-V curve (panel C) measured under stochastic current injection. The agreement between model (green) and experiment (black) is the current state-of-the-art for reduced model fitting.