Replicating Bursting Neurons that Signal Input Slopes with Izhikevich Neurons

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Introduction

- Pyramidal neurons commonly fire with short bursts of high frequency.
- Kepecs et al. [1] present a two-compartmental model of these neurons to understand if these firing patterns represent spatial neuronal coding.
- Their model fires bursts most often at the positive slopes of naturalistic inputs (and negative slopes when inverted showing bidirectional slope detection).
- Here, we simplify their model, with the view of a more efficient simulation and implementation on neuromorphic hardware.
- We investigate whether the same behaviours from [1] can be seen in an Izhikevich neuron [2].

Replicating the Input Signal

The input signal (figure 1) is a reflection of the input from [1].

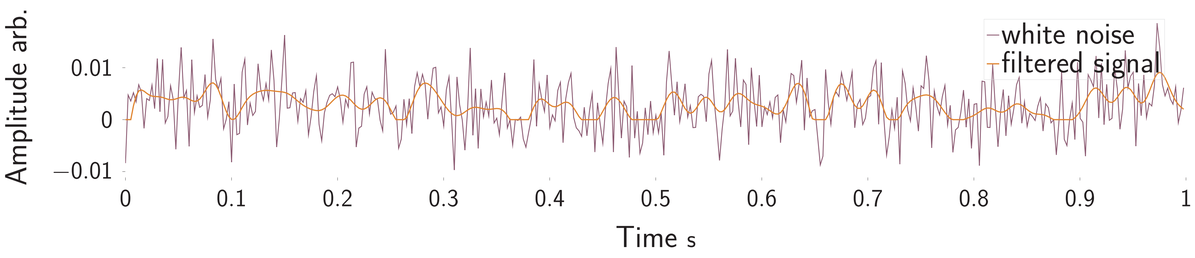

Figure 1: 1 s of Gaussian white noise ($\mu = 0.003$, $\sigma = 0.005$, sampling rate f_s =400 Hz). The Butterworth low-pass filter is applied with cutoff frequency f_c =35 Hz and then rectified.

Bursting Input Slope Detector (BISD)

Izhikevich [2] presents a 2 dimensional system of ordinary differential equations in the form

$$v' = 0.04v^2 + 5v + 140 - u + I \qquad (1)$$
$$u' = a(bv - u)$$

$$\text{if } v \geq 30\,\text{mV, then } \begin{cases} v \leftarrow c \\ u \leftarrow u + d \end{cases} \qquad (2)$$

- v, u are dimensionless variables
- a, b, c, d are dimensionless parameters
- $' = \frac{d}{dt}$ where t is time

Table 1: Parameter comparison

Behaviour	a	b	c	d	initial v	initial u
Chattering (CH)	0.02	0.2	-50	2	-70	-14
Fast Spiking (FS)	0.1	0.2	-65	2	-70	-14
Bursting input slope detector (BISD)	0.1	0.2	50	2	-70	-14

Bidirectional Slope Detection by Bursts

- We inject the filtered signal from Figure 1 into a BISD neuron and invert the signal to obtain the inhibitory response, investigating whether it is indeed a slope detector.

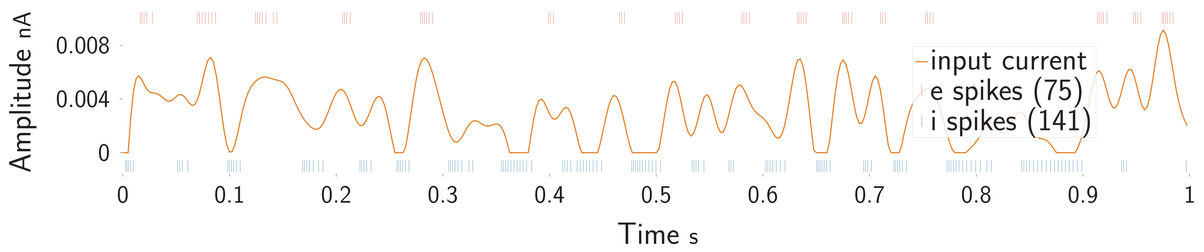

Figure 2: The BISD neurons' (see table 1) response to the first second of the stimulus (see Figure 1), showing the excitatory spiketrain and the inhibitory spiketrain.

Spike Triggered Average (STA) Analysis

- We comput the STA (figure 1) for different cutoff frequencies (f_c) to investigate whether the BISD fires bursts mostly on the positive slopes of the signal, or negative when inverted.

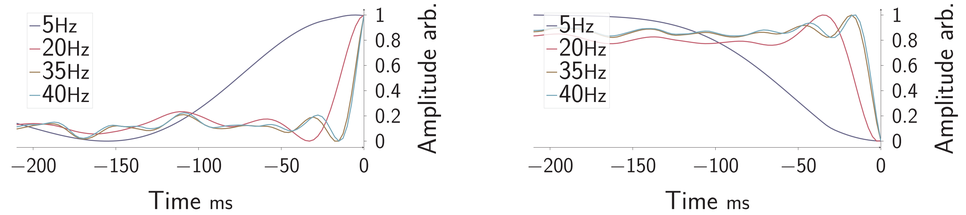

Figure 3: Normalized STAs for the given lowpass filter frequencies.

Conclusions

- Our results show the BISD neuron displays similar behaviours to Kepecs et al.'s model [1].
- Figure 2 demonstrates bidirectional slope detection, occurring at low-pass filter cutoff frequencies $f_c > 35Hz$ (figure 3).
- We are now conducting a systematic search of the parameter space for the optimal set.

Bibliography

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2. Izhikevich, E. M. Simple model of spiking neurons. *IEEE Transactions on Neural Networks* **14,** 1569–1572. ISSN: 10459227. doi:10.1109/TNN.2003.820440 (2003).

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