Determinants of input amplitude and slope detection in bursting neurons

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Introduction

- Amplitude and slope are important dynamical features of sensory signals.
- We investigated the capability of a bursting point-neuron model to report amplitude vs. slope.
- Previously [2], we found that a bursting Izhikevich neuron [1] demonstrated bidirectional slope detection.
- Here, we conducted a systematic search of the Izhikevich parameter space for the optimal set.
- We investigated the determinants of input amplitude and slope detection in bursting neurons.

Systematic search of the Izhikevich parameter space

- We systematically searched for the optimal set of parameters, considering AUC (area under the curve) values from ROC (receiver operator characteristic) curves as our fitness function.

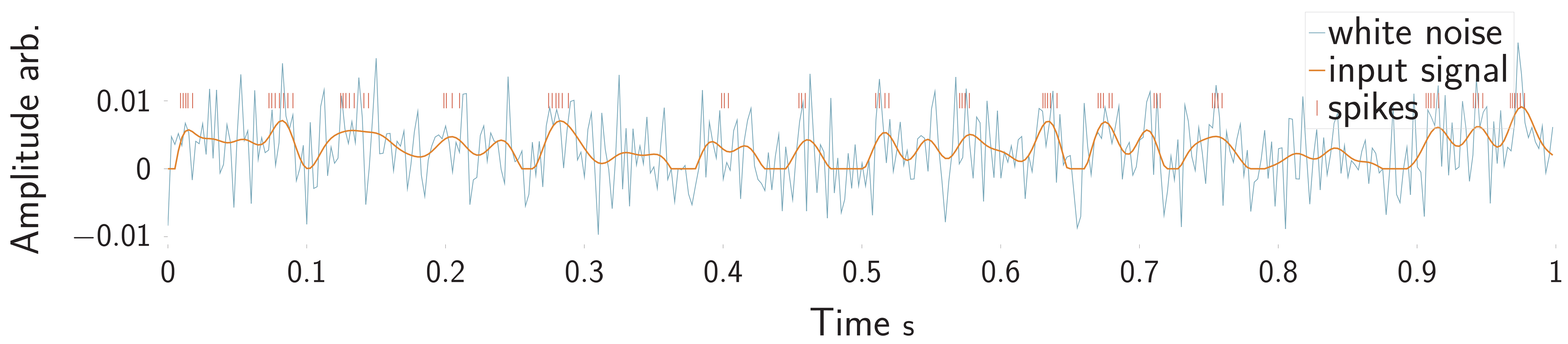

Figure 1: 1 s of 600 s Gaussian white noise ($\mu = 0.003$, $\sigma = 0.005$, sampling rate $f_s = 400$ Hz). The Butterworth low-pass filter was applied with cutoff frequency $f_c = 35$ Hz and then rectified. This was injected into each neuron in the parameter space. The spike train shows the result of a slope detector.

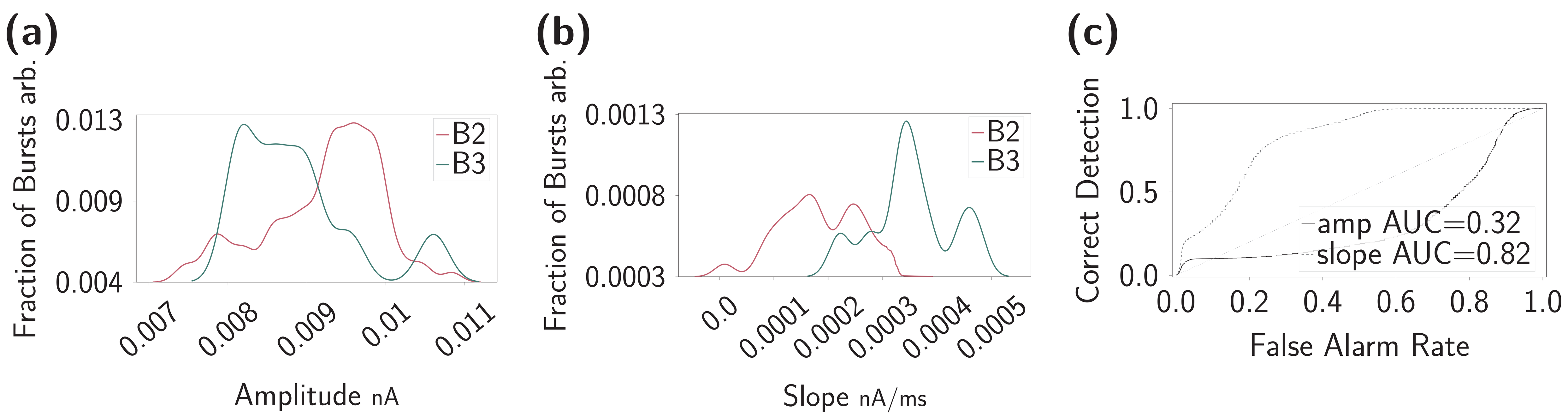

Figure 2: The figure shows the distribution of burst density over (a): the signal amplitudes; (b): the slopes of the signal. B2, B3 indicate 2- and 3-spike bursts, defined by ISI<10 ms. (c): the ROC curves showing discriminability between 2- and 3-spike distributions.

- Figure 2b shows the different burst lengths correspond to different slopes with little overlap.
- In contrast, the amplitude (figure 2a) provides no indication of signal slope.
- In other parameter combinations we did find amplitude detectors.

Determinants of input slope and amplitude detection

- We then questioned whether the burst onsets could signal slopes and amplitudes.

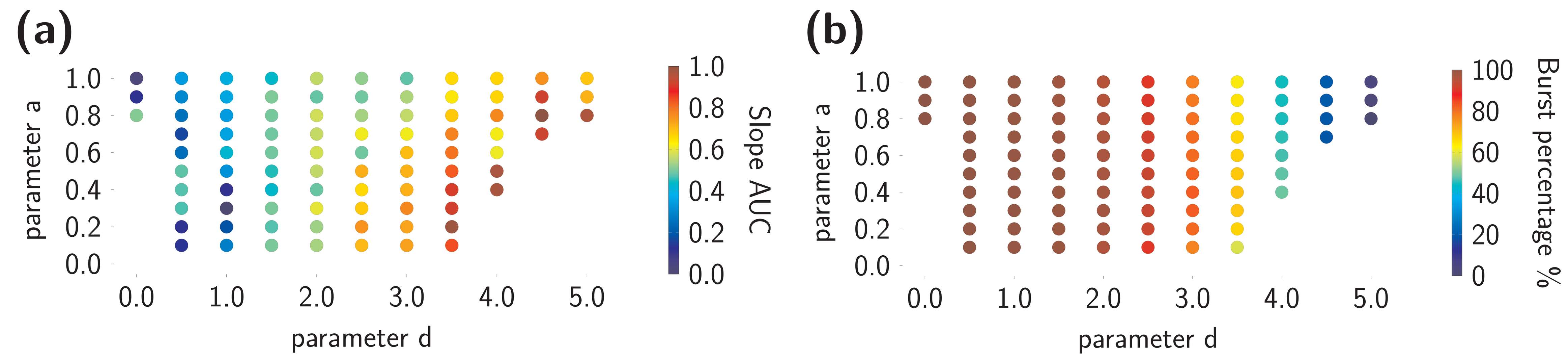

Figure 3: Small captures of a much larger parameter search. Here, parameter $c = -55$ mV and $b = 0.2$ (see equations 1, 2). (a): AUC results of 2- and 3-spike bursts over the slopes of the signal. (b): Burst percentage of the same focused parameter space, calculated by the total number of spikes over burst spikes. The blank spaces represent simulations which did not contain 2- and/or 3-spike bursts.

- Izhikevich [1] presented a 2 dimensional system of ordinary differential equations in the form:

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

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

v : membrane potential mV
u : recovery variable
I : external current
a : time scale ms^{-1} of u
b : sensitivity variable (dimensionless)
c : reset value of the membrane potential v
d : reset value of the recovery variable u
$'$: d/dt where t is time

- Figure 3a shows which parameters were most likely to create a slope detecting neuron.
- The neuron produced a higher burst percentages at lower d values (figure 3b).
- The figure shows no obvious connection between a slope detector and the burst percentage.

Future work

- We plan to explore whether there is a connection between a slope detecting neuron and its inter-spike intervals.
- We then plan to investigate whether our neuron can detect amplitudes and slopes of a signal recorded within a real-world environment.

Zoom room

Bibliography

1. 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).
2. Miko, R., Steuber, V. & Schmuker, M. *Replicating bursting neurons that signal input slopes with Izhikevich neurons.* in. **49** (2021), 160. doi:10.1007/s10827-022-00812-0.

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