Input-driven timing reliability in mismatched neuromorphic neurons

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Abstract

Achieving reliable event timing for reliable sensory processing and motor coordination is a central requirement for neuromorphic systems intended to operate with nonlinear, low-power, and mismatch-prone analog hardware. When driven by constant inputs, excitable neuromorphic neurons typically enter autonomous oscillatory regimes, where device mismatch induces variability in firing rates, phases, and waveform shape, resulting in unreliable event timing across trials and across neurons. This unreliability arises because, under constant stimulation, neurons operate as autonomous oscillators whose limit-cycle dynamics are sensitive to parametric variations. In this work, inspired by previous biological and computational findings [1, 2], we demonstrate experimentally that time-varying inputs can enhance event timing reliability, not only across single-neuron trials, but also in a population of heterogeneous silicon neurons, overcoming hardware mismatch beyond careful circuit design and parameter tuning.

Using a 16-neuron array of mixed-feedback analog silicon neurons capable of both spiking and bursting excitability, and exhibiting significant transistor mismatch, we compare neural responses to constant (DC) stimulation and to repeated band-limited stochastic inputs of identical mean amplitude. Timing reliability is derived from SPIKE-distance metrics [3], across repeated trials of individual neurons and throughout the neuron population.

While DC inputs produce autonomous oscillations with high trial-to-trial variability and no inter-neuron coherence, fluctuating inputs drive neurons to behave as open, input-triggered excitable systems in which events are triggered by shared input fluctuations. In this regime, event timing becomes highly reproducible across trials, and better aligned across mismatched neurons, despite remaining heterogeneity in firing rates and waveform details. Thus, time-varying inputs reduce the mismatch-induced variability in event timing at the population level without requiring calibration, coupling, or network interactions.

We further discuss the existence of distinct optimal input timescales for spiking and bursting neurons, by observing that timing reliability depends on the input bandwidth. Spiking and bursting neurons both display an optimum input frequency for maximum reliability, but bursting neurons require significantly lower frequencies to obtain better timing reliability. This behavior is consistent with a trigger-based mechanism, where input variations must correspond to the intrinsic timescales of the excitable dynamics, while faster fluctuations will interfere with event formation.

These results demonstrate that appropriate input design can transform heterogeneous neuromorphic neurons from unreliable autonomous oscillators into robust event-triggered systems. More broadly, they highlight how excitable dynamics can be exploited to stabilize event-based computation under parametric uncertainty, offering a robust alternative to rate-based operation and explicit mismatch compensation in analog neuromorphic hardware.

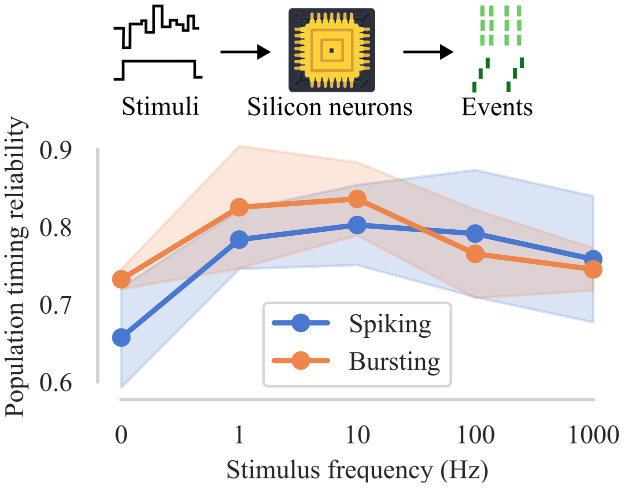

Figure 1: Event timing reliability increases across mismatched neurons under time-varying stimulation and shows different ideal input bandwidths for spiking and bursting. For each stimulus, population timing reliability is defined as $R = 1 - \overline{D}_{i\neq j}$ where $D_{i,j}$ is the SPIKE-distance averaged across pairs of trials of neurons i and j. Shading shows the standard deviation across neuron pairs.

References

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[3] T. Kreuz et al., “Time-resolved and time-scale adaptive measures of spike train synchrony,” Journal of Neuroscience Methods, vol. 195, no. 1, pp. 92–106, Jan. 2011.