Neuronal variability vs. precise stimulus discrimination in an olfaction-inspired network: A neuromorphic case study

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Insects need to associate stimuli with the availability of food for efficient foraging. Olfactory cues play a vital role in this task, and the olfactory system is likely well adapted to encode stimuli in a way that enables downstream circuits to easily learn to discriminate between different cues. It has been shown that a firing-rate based olfaction-inspired network enhanced stimulus discrimination in a supervised learning framework (Schmuker & Schneider, 2007). In the same study, the practical applicability of this network to the classification of multivariate data has been demonstrated, a common task in data analysis and machine learning.

The motivation of the present work was to implement this network on a neuromorphic hardware system that supports high-speed emulation of spiking neuronal networks (Schemmel et al., 2006). This system combines analog microelectronic circuits mimicking the behavior of integrate-and-fire neuron models with a digital circuitry controlling network connectivity and synaptic strength. Neurons on this system run with a speedup factor of 10^4 compared to biological real-time, in other words, one second of neuromorphic computation corresponds to 10,000 seconds of biological time, which qualifies this device for high-speed computation with spiking neurons.

Our goal was to implement a network for classification of multivariate data on the hardware system. To this end, we designed a two-layer network. The first layer provides decorrelation of input channels through lateral inhibition. The second layer performs association to data classes in a winner-take-all fashion on the basis of the work of Soltani and Wang (2010).

We demonstrate how our model combines several functional principles of sensory computation in animals, that is, parallel processing of multiple input dimensions, their decorrelation through lateral inhibition, and the transformation from a dense representation in a low-dimensional input space to a sparse representation in a high dimensional neural space in order to achieve accurate stimulus classification even for nonlinear problems. Our implementation performed at level with standard machine learning techniques on a set of benchmark stimuli. However, discrimination of stimulus classes with partial overlap (that is, high similarity) was severely affected by the heterogeneity of neuronal transfer functions caused by the inevitable physical variability of analog electronic circuits in the hardware system. We restored the network performance using a combination of global and network-specific calibration steps. Our results indicate that reliable learning of fine discrimination between stimulus classes requires either precisely tuned neurons with little variance or network mechanisms that compensate for individual neuronal variation. Our work serves as a proof of principle for the successful implementation of a functional neural network on a neuromorphic hardware system that can readily be applied to real-world problems.

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