Building Representations Spike by Spike

Klaus R. Pawelzik, David Rotermund and Udo A. Ernst
Institut for Theoretical Physics
Department for Theoretical Neurophysics
Otto-Hahn-Allee 1
Germany, 28359 Bremen
pawelzik@physik.uni-bremen.de
http://www.neuro.uni-bremen.de

Brains enable animals and humans to rapidly recognize and classify sensory scenes using spikes as signals, that come from the receptors and from within the brain. It appears that on average one spike per neuron and processing step is sufficient to achieve a good performance. This is particularly astonishing when considering the apparent randomness of cortical spike trains.

Here we focus on the question how neuronal networks can build reliable representations from noisy input spike patterns in a time during which each input neuron fired only a small number of spikes.

We present a novel framework for neural computation which utilizes synaptic nonlinearities to extract most of the information contained in each stochastic spike. This is demonstrated in a network that iteratively builds a sparse and noise-robust representation spike per spike. The weights in this model can also be adapted on-line using an unsupervised Hebbian rule that optimizes the representation with respect to reconstruction error. Since our framework corresponds to a linear mixture model it decomposes the rate vectors underlying the inputs into independent causes thereby solving spatial deconvolution problems on the basis of stochastic input.

We tested the performance of our network, using different learning rules and reconstruction paradigms, by building representations for stochastic variants of Boolean functions (like e.g. X-OR) and find that *perfect* performance (e.g. zero error) is on average achieved from approximately two spikes per neuron. When applied to hand written digits data we obtain a performance that comes close to the benchmarks despite the stochastic nature of the input used. Furthermore, the performance is particularly robust with respect to pixel noise and partial coverage.

We interpret our rather general ansatz as a model for the cortex. When trained with natural stimuli, our framework reproduces many properties of visual cortical cells including simple cell receptive fields, and non-classical receptive fields. We also investigate, how the structure of long-range connections, as measured within the visual cortex, may emerge during learning by extracting correlations between sequences of inputs.

Our results indicate that many neuronal structures in the brain may realize iterative estimators that are optimally adapted for rapidly building representations from sensory scenes (or input patterns from other areas) from very few spikes per input neuron. The model predicts characteristic temporal evolutions of intracellular responses in visual cortex, that depend on various features of the input and context, which can be tested experimentally.

Topic: visual processing and pattern recognition
Preference: oral/poster