The Role of Stimulus Correlations for Population Decoding in the Retina

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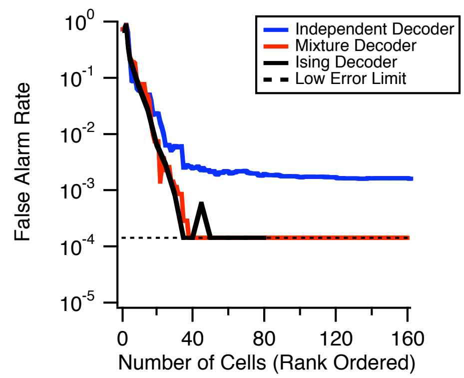
All information about the visual world passes through the optic nerve, so with access to the spike trains of a large number of retinal ganglion cells, one should be able to construct a decoding algorithm to discriminate different visual stimuli. Despite the inherent noise in the response of the ganglion cell population, everyday visual experience is highly deterministic. We have designed an experiment to study the nature of the population code of the retina in the "low error" regime.

We presented 36 different black and white shapes, each with the same number of black pixels, to the retina of a tiger salamander while recording retinal ganglion cell responses using a multi-electrode array. Each shape was presented over 100 trials for 0.5 s each and trials were randomly interleaved. Spike trains were recorded from 162 ganglion cells in 13 experiments. We removed noise correlations by shuffling trials, as we wanted to focus on the role of correlations induced by the stimulus (signal correlations).

We designed decoding algorithms for this population response in order to detect each target shape against the distracter set of the 35 other shapes. Binary response vectors were constructed using a 100 ms bin following the presentation of each shape. First, we used a simple decoder that assumes that all neurons are independent. This decoder is a linear classifier. A second decoder, which takes into account correlations between neurons, was constructed by fitting Ising models[1] to the population response using up to 162 neurons for each model. We also constructed the statistically optimal decoder based on a mixture model, which accounts for signal correlations.



Using populations of many neurons, the optimal and Ising decoders performed considerably better than the "independent" decoder. For certain shapes, the optimal decoder had 100 times fewer false positives than the independent decoder at 99% hit rate, and, in the median across shapes, the performance enhancement was 8-fold. While the decoder using an Ising model fit to the pairwise correlations did not achieve optimality, it was up to 50 times more accurate than the independent decoder, and 3 times more accurate in the median across shapes. Some shape discriminations were performed at zero error out of 3500 trials using the optimal and Ising decoders on only a subset of the recorded cells while none reached this "low error" level using the independent decoder even on all 162 cells (see figure).

We find that discrimination with very low error using large populations requires a decoder that models signal correlations. Linear classifiers were unable to reach the "low error" regime. The Ising model of the population response is successfully applied to groups of up to 162 cells and offers a biologically feasible mechanism by which downstream neurons could account for correlations in their inputs.

References

[1] E Schneidman E, Berry II MJ, Segev R, Bialek W. (2006). Weak pairwise correlations imply strongly correlated network states in a neural population. *Nature* 440, 1007-1012.