

Perceptual learning as improved Bayesian inference in early sensory areas

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Extensive training on simple tasks like 2-AFC orientation discrimination results in large improvements in performance, a form of learning known as perceptual learning. Psychophysical experiments manipulating external noise strongly suggest that perceptual learning is due to improved decision-making. In contrast, single cell recordings have demonstrated that the response properties of neurons in early sensory areas are modified by training, suggesting a change in early sensory representations as opposed to decision making. No model has successfully managed to reconcile these contradictory conclusions.

We believe that the problem stems from the fact that all models treat sensory processing and decision making as different types of computations: nonlinear filtering (or feature extraction) for sensory processing and Bayesian inference for decision making. We propose instead to consider both sensory processing and decision making as instances of Bayesian inference. Indeed, in both cases, the goal of the computation should be to infer a probability distribution over the variable of interest, say orientation, given the statistics of the incoming spikes. The main difference is that sensory processing should keep the posterior distribution while decision making should collapse the distribution onto an estimate. If we are correct, the two processes are exceedingly difficult to tease apart with behavioral methods alone. Any change that improves Bayesian inference in early sensory area will appear to affect decision making and vice-versa.

We apply our approach to the case of orientation selectivity. We show that it is possible to derive an analytical expression for Fisher information in a network of spiking neurons receiving input spikes---a difficult problem that had eluded a solution until now. This expression allow us to determine the impact of any network parameters on Fisher information and, therefore, on the efficiency of the Bayesian inference. It reveals in particular that increasing the amplitude of feedforward connections in early sensory areas, along with specific changes in lateral connectivity, can increase Fisher information and change the tuning curves of sensory neurons in a way consistent with what has been found experimentally. Importantly, we also show that, at the behavioral level, the system behaves as if the decision stage had been improved, even though the changes took place early in the model.

In addition, this work sheds new light on the nature of noise in the nervous system. The main source of variability in the nervous system is believed to be the Poisson-ness of firing in cortex. We show that in our model, this factor barely contributes. Instead, the main factor is the suboptimal nature of the inference performed by cortical circuits due to incomplete knowledge of the statistics of incoming spikes.

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