Maximizing sensory information with an arbitrary size of neural populations

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One fundamental goal of sensory systems is to transmit sensory information efficiently under the condition that both the input and the neural representation are noisy, and that the number of available neurons is limited. Previous results based on this idea provide a great deal of insight into the optimality of sensory coding, in particular with regard to retinal receptive field structure and contrast sensitivity [1-4]. These results relied on the rather strong assumption that the retinal ganglion cell population is shift-invariant (i.e., receptive fields are centered on each photoreceptor and have identical profiles, regardless of their location). But mammalian retinas are clearly not shift-invariant: the cone mosaic is fairly irregular, the mapping from cones to ganglion cells is often convergent (i.e., the ganglion cells are sampled at lower density), and this convergence is also irregular and varies substantially with eccentricity. As such, ganglion cell receptive fields are highly irregular [5], making it difficult to directly compare the theory with experimental results.

In previous work [6], we relaxed the shift-invariance and the population size assumptions, solving for receptive fields that minimize the mean squared reconstruction error. Here, we relax those same assumptions in the context of maximizing the sensory information, deriving a set of conditions that the optimal receptive field populations should satisfy, and compute examples of receptive field populations that reach the theoretical limit of information rate. The basic problem setting is the same as the previous models [1-4]: obtain a population of linear receptive fields that maximize information transmitted about a signal that is solely characterized by its covariance. The input and neural noise are both assumed to be additive, independent, and Gaussian-distributed. The difference is that the individual receptive fields are allowed to vary, both in terms of their spatial extent (i.e., the subset of cones from which their responses are constructed), as well as their tuning properties (i.e., the weights applied to each cone). In addition, the number of ganglion cells is adjustable, and need not be the same as the number of cones. We are currently working to compare these results directly to a newly obtained experimental data set in which both cone locations and ganglion cell receptive field properties are known (with Chichilnisky lab). The theory may then be compared with the data in terms of information preserved, as well as the detailed properties of the receptive fields.

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