Inferring retinal cone locations and functional connectivity from ganglion cell recordings

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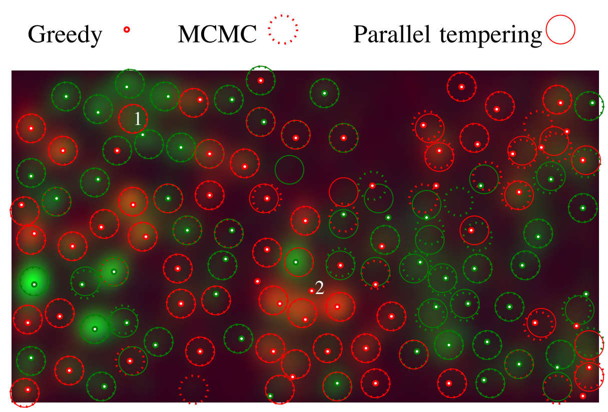
Inferring the functional connectivity in neuronal circuits is a fundamental goal in neuroscience. Recently, [1] showed that it is possible to map both the input (photoreceptor) and the output (ganglion) cells of macaque retinas, and the functional connections between these layers, thanks to extensive experimental access to both inputs and outputs of the system, and to the adequacy of simple generalized linear models (GLM) for predicting ganglion cell (RGC) output given random stimuli [2].

When sufficiently fine-grained stimuli are used to excite the retina, the spike triggered average receptive fields of RGCs appear to be composed of small islands of light sensitivity; these are in fact the receptive fields of individual cones. However, mapping these receptive fields remains challenging, since very high-SNR, long, stable recordings are required for adequate spatial resolution. In the present work, we develop Bayesian methods for inferring the locations and colors of cones, and their functional connections to RGCs, improving on the greedy approach originally used in [1].

Our approach pools the evidence from the observed spiking responses of the recorded RGCs in a GLM framework, with a strong prior on cone locations prohibiting cones from being closer together than anatomically plausible. Two modest approximations allow us to analytically compute the conditional expectation and marginal likelihood of the functional connectivity, under a reasonable prior. The resulting log-posterior on cone configurations is hard to sample from due to steep local maxima. We devise strategies to sample from this log-posterior using Markov chain Monte Carlo (MCMC) with parallel tempering adapted to this problem. The algorithm provides improved inferences of cone locations and colors, with errorbars, which were not available with previous approaches. We are currently pursuing applications of these improved functional connectivity maps to better understand nonlinearities and shared noise in early primate color vision.



Right: Superposition of configurations obtained by the greedy, MCMC, and parallel tempering methods. The background colorscale image is a depiction of the evidence for the presence of cones of different colors across visual space: cones do not appear in dark regions, where evidence for them is weak. The greedy method makes mistakes both by omission (1) and by spurious inclusion (2). In both cases, this is due to the fact that the greedy solution first laid down cones immediately below the markers, whose positions were subsequently not reconsidered when laying down additional cones.

[1] G. Field, J. Gauthier, A. Sher, M. Greschner, T. Machado, L. Jepson, J. Shlens, D. Gunning, K. Mathieson, W. Dabrowski, L. Paninski, A. Litke, and E Chichilnisky. Functional connectivity in the retina at the resolution of photoreceptors. Nature, 467(7316):673677, Oct 2010. 10.1038/nature09424.
[2] J. W Pillow, J. Shlens, L. Paninski, A. Sher, A. M Litke, E. J Chichilnisky, and E. P Simoncelli. Spatio-temporal correlations and visual signalling in a complete neuronal population. Nature, 454(7207):995999, Aug 2008.