A generalized linear model for estimating receptive fields from midbrain responses to natural sounds

A. Calabrese, J.W. Schumacher, D.M. Schneider, S.M.N. Woolley, and L. Paninski.

Understanding neural responses to natural stimuli has become an essential part of characterizing neural coding. For this reason, it is becoming increasingly important to develop unified models for neural responses to stimuli with a wide range of statistical properties, from white noise to the fully natural case.

In the auditory system, the stimulus-response properties of single neurons are often described in terms of the spectrotemporal receptive field (STRF), a linear kernel relating the spectrogram of the sound stimulus to the instantaneous firing rate of the neuron. STRFs provide useful information about neurons' tuning properties, such as the spectral and temporal acoustic patterns to which neurons are maximally responsive. Traditionally, STRFs have been estimated as the spike-triggered average multiplied by the inverse of the stimulus covariance matrix to account for pairwise correlations in the stimulus [1]. However, when nonlinear neurons are probed with natural stimuli, which contain strong higher-order correlations, normalized reverse correlation methods (NRC) produce systematic biases (or deviations) in the estimates of the underlying filter. Furthermore, due to nonlinear effects, the calculation of the STRF depends on the corpus of the stimuli.

Recently, several methods have been proposed to characterize the tuning properties of auditory neurons from responses to natural stimuli that reduce the impact of stimulus-correlation biases on the estimated STRFs [2, 3]. These algorithms differ in their functional models, cost functions, and regularization methods. Here we describe the stimulus-response relationship with a generalized linear model (GLM). In this model, each cell's input is described by: 1) a stimulus filter (STRF); and 2) a post-spike filter, which captures dependencies on spike history. As opposed to most previous models, this model provides precise spike timing information that allows accurate predictions of neural spike trains to novel stimuli.

Using maximum likelihood techniques, we fit the model to the spiking activity of zebra finch auditory midbrain neurons in response to conspecific vocalizations (songs) and modulation-limited (ML) noise for which the maximum spectral and temporal modulation boundaries matched zebra finch song. In order to obtain accurate fits, we add the L1 regularizer to the likelihood function, yielding a sparse solution.

Comparison of GLM and NRC methods shows that a GLM has better predictive power for songbird auditory midbrain neurons. We compare GLM and NRC STRFs in terms of their basic tuning properties and show that GLM STRFs are more consistent between stimulus ensembles. With ML noise stimuli, STRFs computed with the NRC and GLM methods were similar, as would be predicted theoretically. With song stimuli, STRFs from the two models can differ profoundly. These results suggest that the L1-penalized GLM method provides a more accurate characterization of spectrotemporal tuning than does the NRC method when responses to natural sounds are studied in these neurons.

[1] F.E. Theunissen et al. (2001) Network: Comput. Neural Sys. 12: 289-316.

[2] T.O. Sharpee et al. (2004) Neural Comput. 16(2): 223-250.

[3] S.V. David et al. (2007) Network: Comput. Neural Sys. 18(3): 191-212.