A Probabilistic Model Predicting Retinal Ganglion Cell Responses to Natural Images
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Introduction: Computational models predicting retinal responses to natural images are needed for both reverse-engineering the retina and building good retinal prostheses. Models predicting the response of retinal ganglion cells (RGCs) to artificial stimuli (e.g., flashes, gratings, and white noise) have been successfully developed1. However, the same models fail to predict responses to natural images, mainly because under natural conditions, RGCs spike weakly, sparsely, and probabilistically. To overcome the failure of current models to predict the RGCs’ response to natural images, we have developed a computational model that determines the neurons’ response to images probabilistically.

Materials and Methods: Sets of natural and artificial images2 (between 7020 to 10530 images in each set) were presented four times to an in vitro retinal preparation (Long Evans Rat), alternating at 30Hz. The RGCs’ responses were recorded using a multi-electrode array (Cerebus, Blackrock Microsystems, Salt Lake City, Utah).

To estimate the receptive field (RFs) of the RGCs, the spike-triggered average (STA) was calculated with 16 image delays. Next, the STA projection was obtained by calculating the dot product of every 16 image sequence and the RF filters. We then binned those projections yielding a spiking response into equal count bins and calculated their probability to elicit a response. By looking at the probabilities of the individual firing magnitudes we obtained a three dimensional probability histogram estimating the conditional probability to fire increasing number of spikes (F) given an STA projection (S). We developed a probability distribution composed of a normal distribution and a spike limiting function to model our data. The function has two free parameters K controlling the sensitivity of the RGC to spike saturation and A arising from the RGC’s maximal firing rate.

Results and Discussion: Figure 1 presents an example RGC data (histogram bars) and our model fit to it (black lines). Because this RGC is sensitive to spiking saturation the probability doesn’t decay monotonically for increasing number of spikes but is higher for intermediate firing magnitude and high projection values (example: P(F=2|S=10)=0.5). In general the probability rises for increasing STA projection values, which is expected. Our model fit follows the histogram bars closely resulting in a two dimensional correlation value of $R^2=0.99$. Moreover, considering a stringent multinomial statistical test with randomization the model fit is significant at a 5% significance level (P value=0.16).

![Figure 1](image_url)

Considering the 108 RGCs we recorded from, the mean correlation of the model fits to the data sets for natural image stimuli is $R^2=0.970$ with a standard error of 0.006. For artificial image stimuli our model resulted in an $R^2=0.89$ with standard error of 0.02. Examining our predictions with the randomized multinomial test 31 of the RGCs stimulated with natural images and 35 RGCs stimulated with artificial images yielded statistical significance values above 5% level.

Conclusions: Neuronal responses are noisy and tend to vary between trials. Aiming to predict the response probability instead of the average or absolute response is preferable, yielding a more accurate and realistic prediction. We have found an accurate probabilistic model consistent with known retinal mechanisms for the distribution of RGC responses to all types of images. Our approach managed to reduce the problem into a
two-parameter optimization problem, namely K and A, and is thus simple, elegant, and efficient. This probabilistic approach suggests a new venue in the field of neural engineering with implications to prosthetic devices.

Acknowledgements: Supported by NEI grants EY11170 and EY016093, and NSF grant EEC-0310723
