

Formulation and Performance-assessment of Linear Ideal Observers for Neural Spiketrain Decoding

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Introduction: We develop procedures to benchmark the performance of neural decoders which model the brain's extraction of real-world variables from sensory spiketrains. The problem of estimating a stimulus property can be posed as a Yes/No(Y/N) question about the stimuli, to which answers can be obtained by a linear decoder that assigns Y and N labels by a decision threshold operating on linearly filtered spiketrain inputs. Linear decoders, though popular, are not guaranteed to be optimal. To obtain upper-bounds of decoder performance without and with assumptions of linearity, we specify the Ideal Observer Decoder(IOD) as a maximum-a-posteriori (MAP) Y/N labeling of binary spiketrains represented as nodes in a Hamming Space, and apply on it a linearizing procedure to obtain the best-performing linear decoder i.e. the Linear Ideal Observer Decoder(LIOD). Applying both decoders to spiketrain recordings from retinal ganglion cells (RGCs) responding to natural images, we test whether linear decoders can yield optimal performance for some questions fundamental to early visual processing.

Materials and Methods: Extracellular recordings of RGC responses to natural images from Cao et al¹ are processed at a resolution where they can be treated as binary strings representable as unit-N-cube nodes. Ground-truth Y/N labels to be used for training and test sets, are obtained for the following questions by examining the stimulus images: **Q1:**Did the background-adjusted mean intensity of the current image at the receptive-field center increase by at least 20% with respect to the previous image? **Q2:**Did the same quantity as in Q1 change by at least 20% with respect to the previous image? The IOD is trained using Gaussian kernel density estimation applied to the training set instances in Hamming space, yielding predicted MAP Y/N labels for the unit-N-cube whose nodes represent the entire repertoire of spiketrains. This IOD is now in a form where a previously developed criterion for linear separability shown in Fig.1 can be applied. The IOD label predictions are used to initialize the Y/N predictions of the LIOD, which are updated iteratively till separability is achieved under the constraint that each update results in least loss of classification rate. Calculating how often the predicted labels of the IOD and LIOD match the ground-truth labels in the test set, yields their test classification rates.

Results and Discussion: The classification rates obtained by the IOD and LIOD for both questions for an ON and OFF cell example are shown in the table in Fig.1(c). For both the questions examined in the study, linear decoding yielded performance nearly identical to that of the Ideal Observer.

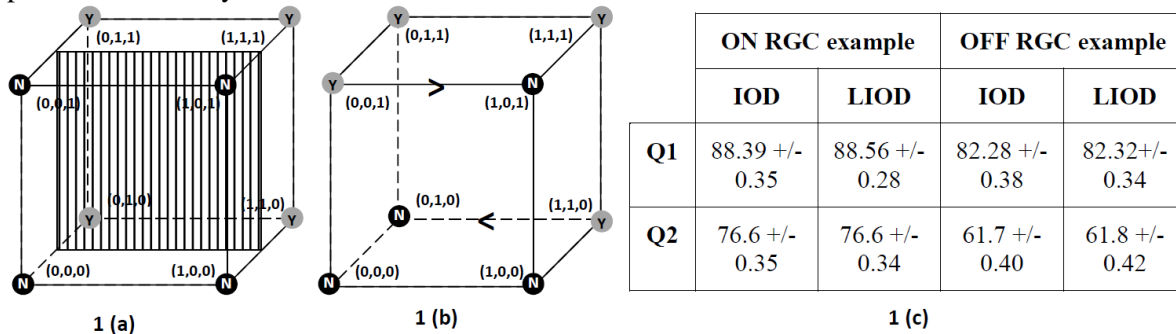


Figure 1: Example predictions of Y/N answers to questions are shown in panels 1(a) and 1(b), for a hypothetical neuron responding with spike sequences of 3 bits, represented here in the unit-cube i.e. the corresponding Hamming Space. If the IOD predictions are like those in 1(b), where the presence of the label arrangement shown by oppositely directed vectors precludes error-free linear separation classes, the LIOD must be obtained by optimally linearizing the label configuration into one that shares the property of 1(a) where the Y and N labels are linearly separable. The entries in the table in 1(c) are classification percentages achieved by the IOD and LIOD for the example questions defined in the Methods section, for two RGCs. Standard errors were obtained using bootstrap runs.

Conclusions: This study provides a principled non-parametric Ideal Observer approach to obtain the upper-bound of classifier performance and thus benchmark the performance of an arbitrary decoder. For the questions of interest in visual function considered so far, linear decoding appears to yield Ideal Observer performance.

References: [1] Cao, X., Merwine, D. K., & Grzywacz, N. M. (2011). Dependence of the retinal ganglion cell's responses on local textures of natural scenes. Journal of Vision, 11(6), 11.