BMC Neuroscience

BioMed Central

Poster presentation

Theoretical analysis of the information carried by the contrast response functions of M-cells, P-cells and V1 neurons

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P131 doi:10.1186/1471-2202-10-S1-P131

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P131

Many types of contrast sensitive neurons have been shown to maximize the mutual information between their response and the distribution of contrasts in natural images: The contrast response functions (CRF) of the fly large monopolar cell [1], cat X- and Y-retinal ganglion cells (RGC) and LGN neurons, cat V1 neurons, and macaque retinal and LGN M-cells [2,3] can be predicted from the respective contrast distributions using histogram equalization/infomax principles. However, macaque P-RGC, -LGN and V1 neurons are less sensitive to contrast than optimal information transmission would predict.

We determine the contrast distribution encountered by RGC, LGN neurons and V1 neurons in natural images using biologically plausible Difference-of-Gaussian (DoG) and Gabor contrast operators representative of the range of macaque neurons in LGN and V1 by sampling a set of calibrated grey-scale natural images [4]. The full contrast distribution (each position sampled by all contrast operators) reconfirms the above-cited results regarding histogram equalization. However, sampling each location only with the contrast operator that shows the strongest response at this location (for each, DoG and Gabor operators separately) produces a contrast distribution that predicts the CRF of both, macaque P- and V1 neurons.

We then compare the performance of the histogram equalization-based (referred to as "M-like") encoding strategy with that of a top-response-based ("P-like") strategy, for the stages of LGN contrast coding and of V1 contrast coding. We find that for each individual neuron, M-like encoding outperforms P-like encoding with respect to the information conveyed about natural image contrast. However, considering the mutual information between neurons with similar receptive field characteristics (e.g., neighboring preferred spatial frequencies) shows that P-like encoding is accompanied by a pronounced decrease in the mutual information between different output channels.

Together, these findings suggests that macaque P- and V1 neurons employ a contrast coding strategy intrinsically different from M-cells and cat visual neurons. The latter maximize mutual information between contrast and response for each neuron individually. On the other hand, P and V1 contrast responses are not optimized for maximizing the contrast information transmitted by individual cells, but also reduce the redundancy between different transmission channels, thus providing a trade-off between the desire of maximizing the transmitted information and reducing the redundancy at the population level. In doing so, their CRF is in fact optimized for encoding the contrast of spatially optimal features. Such a strategy would imply the operation of a winner-takes-all-like encoding at the readout stage.

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