

Sparse codes of V1 simple-cells and the emergence of globular receptive fields – a comparative study

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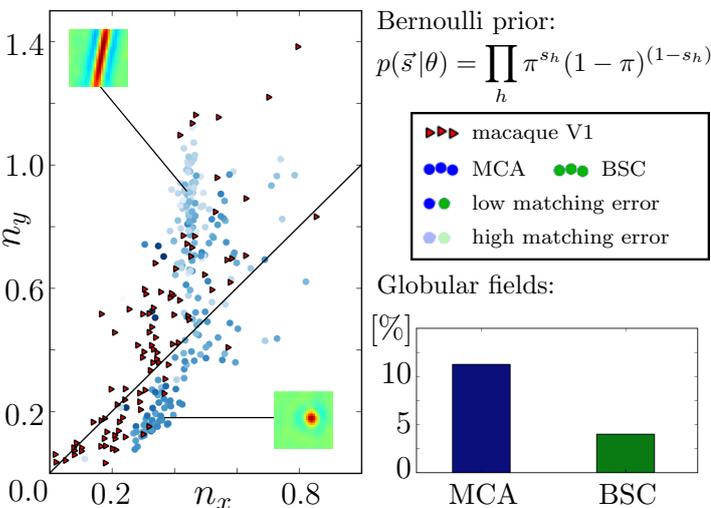
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The presumably most influential models to describe the response properties of simple-cells in primary visual cortex are independent component analysis (ICA; [1]) and sparse coding (SC; [2]). Since they were first introduced, many studies have critically investigated the different assumptions made by these models (e.g., [3]). However, an assumption that has been so far studied very little is the assumption of linearly superimposing basis functions. While this is a plausible assumption, e.g., for sound waveforms, it is more difficult to justify for visual data. In this comparative study we systematically investigate the implications of different superposition assumptions using two generative models for image patches. Both models use the same prior (Bernoulli) and noise model (Gaussian). However, while the one model assumes standard linear superposition of basis functions (BSC; [4,5]), the other assumes a point-wise maximum instead of a sum (MCA; [6,7]). The inferred basis functions of both models resemble Gabor-like functions but we find the shapes of these functions to be markedly different. In comparison with *in vivo* recordings [8] the distribution of shapes obtained by the non-linear model may be interpreted as more closely resembling the measured shapes than the one obtained by the linear model. The basis functions of the linear model thus contain many more Gabor-like fields elongated orthogonal to the wavefront direction than the non-linear fields and the measurements. Additionally, and more saliently, we find that the fields of the non-linear model and of the measurements contain many globular fields while only a very small number of such fields are obtained in the linear case. Our results demonstrate a strong influence of the superposition type on the obtained basis functions, and could suggest an important role of non-linear models for primary visual processing.

Methods: The results in the figure were obtained using the same 200 000 image patches (26×26) for both models (preprocessed and channel-split as in [7]). Both models were trained with 400 hidden units and for each model all parameters were inferred (basis functions W , data noise σ , and level of sparseness π) using the same training scheme [5] (120 variational EM steps each). Gabors were matched on the convoluted generative fields which approximate predicted receptive fields (see [7]). The percentages of globular fields were automatically determined using matching with DoG functions. We found the

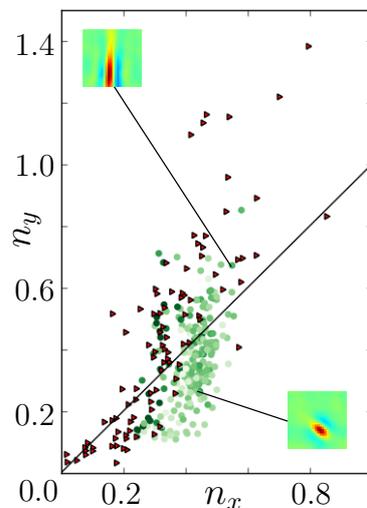
Maximal Component Analysis (MCA)

$$p(\vec{y}|\vec{s}, \theta) = \mathcal{N}(\vec{y}; \max_h \{s_h \vec{W}_h\}, \sigma^2 \mathbb{1})$$



Binary Sparse Coding (BSC)

$$p(\vec{y}|\vec{s}, \theta) = \mathcal{N}(\vec{y}; \sum_h s_h \vec{W}_h, \sigma^2 \mathbb{1})$$



globular fields of the non-linear model to explicitly represent globular structures in the data, while the linear model usually explained such patterns by linearly combining Gabor functions.

[1] Bell, Sejnowski, *Vis Res* 37:3327-38 (1997)
 [2] Olshausen, Field, *Nature*, 381:607-609 (1996)
 [3] Rehn, Sommer, *J Comp Neurosci* 22:135-146 (2007)
 [4] Henniges et al., *Proc LVA/ICA*, 21-30 (2010)

[5] Lücke, Eggert, *JMLR* 11:2855-2900 (2010)
 [6] Lücke, Sahani, *JMLR* 9:1227-67 (2008)
 [7] Puertas et al., *NIPS* 23 (2010)
 [8] Ringach, *J Neurophysiol* 87:1018-27 (2002)