Ongoing activity in a spiking network of visual cortical columns representing local optimal inference modules

- Federica Capparelli
- David Rotermund
- Udo A. Ernst
- Klaus R. Pawelzik

Spontaneous activity in visual cortex has been found to resemble the spatially organized responses to oriented stimuli [1]. We wondered if and how this finding can be reconciled with the hypothesis that cortex mainly performs optimal inference [2-4]. The latter is based on the idea that the brain organizes sensory information into an efficient representation of the outside world: neurons receive noisy and unreliable inputs, accumulate evidence over time and compete with each other to build sparse representations of the stimuli.

This would be equivalent to inferring the most probable features of the stimulus that may cause an input from sensory neurons, while minimizing a sparsity measure. Models of visual cortex developed within this framework [3, 4] use features that are localized in space. As a consequence, they are not able to account for the spatial correlations and high-order statistics of natural images.

We propose a spiking network that extends the architecture of these models, by combining it with a term that links different locations of the visual space in an associative manner. In our model each hyper-column implements a sparse coding module [2] that alone would produce an optimal local representation of the stimulus. These representations are then interacting with all other hyper-columns via long range connections. In particular, similar orientations are positively coupled so that evidence of a cause in one location provides evidence of the same cause in others. The model maintains its optimal inference property, building robust representations of visual scenes from the information contained in localized image patches, thereby exploiting prior knowledge about spatial correlations in natural scenes.

Without external input and driven only with noise, the system exhibits a spontaneous dynamics highly structured in space and time. Activity patterns that closely resemble orientation maps emerge, as observed in [1]: when a cortical state occurs, it spans different hyper-columns and switching between states is continuous, i.e. activity patterns close in time correspond to similar orientations. While reproducing the experimental findings, the network maintains low firing rates and large variability typical of spontaneous activity.

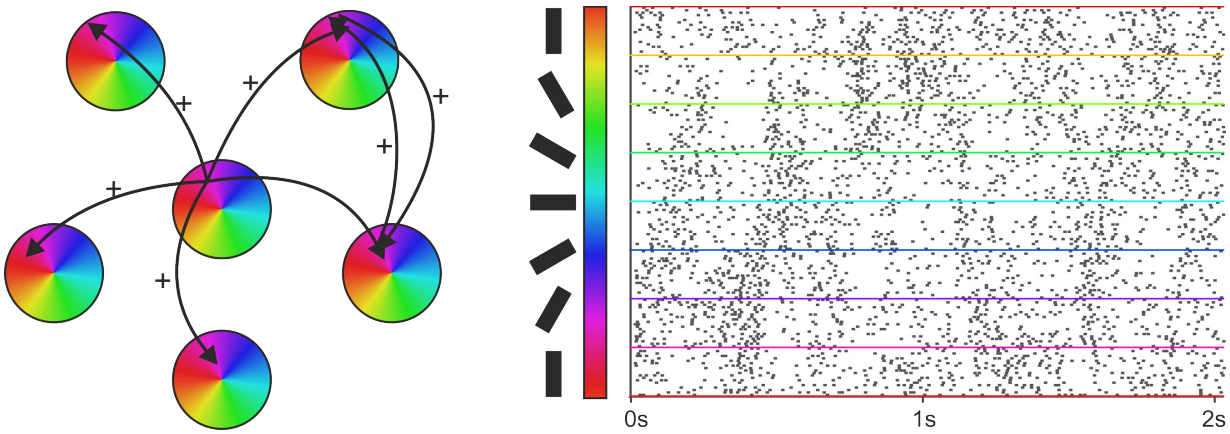
In the future, this will allows us to explore and quantify the impact of electrical stimulation (e.g. for visual cortex prosthesis) on a cortical network and to investigate its interaction with information processing.

Acknowledgements

This work has been supported by the Creative Unit I-See of the University of Bremen and the BMBF, Bernstein Award Udo Ernst, Grant No. 01GQ1106.

References

1. Kenet, T., Bibitchkov, D., Tsodyks, M., Grinvald, A., & Arieli, A. (2003). Spontaneously emerging cortical representations of visual attributes. Nature, 425(6961), 954-956., doi:10.1038/nature02078
2. Moreno-Bote, R. and Drugowitsch, J. Causal Inference and Explaining Away in a Spiking Network. Sci. Rep. 5, 17531, doi: 10.1038/srep17531
3. Olshausen, B. A., & Field, D. J. (1997). Sparse coding with an overcomplete basis set: A strategy employed by V1?. Vision research, 37(23), 3311-3325., doi:10.1016/S0042-6989(97)00169-7
4. Zhu, M., & Rozell, C. J. (2013). Visual nonclassical receptive field effects emerge from sparse coding in a dynamical system. PLoS Comput Biol, 9(8), e1003191., http://dx.doi.org/10.1371/journal.pcbi.1003191



a) Network architecture; arrows linking hyper-columns indicate positive connections between cells with a similar orientation preference ('associative term')
b) Patterns of spiking activity emerging during spont. activity; neurons from all modules are ordered according to their orientation preference