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Pinwheel crystallization in a dimension reduction model of visual cortical development

Wolfgang Keil*[1,2,3,4] and Fred Wolf[1,2]

Address: [1]Department of Nonlinear Dynamics, Max-Planck-Institute for Dynamics and Self-Organization, D37073 Göttingen, Germany, [2]Bernstein Center for Computational Neuroscience, D37073 Göttingen, Germany, [3]Faculty of Physics, University of Göttingen, D37073 Göttingen, Germany and [4]IMPRS, Physics of Biological and Complex Systems, D37077 Göttingen, Germany

Email: Wolfgang Keil* - wolfgang@nld.ds.mpg.de

* Corresponding author

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The primary visual cortex (V1) of higher mammals contains a topographic representation of visual space in which neighborhood-preserving maps of several variables describing visual features such as position in visual space, line orientation, movement direction, and ocularity are embedded [1]. It has been hypothesized that the complex spatial layouts of these representations can be interpreted as ground states of a smooth mapping of a high-dimensional space of visual stimulus features to an effectively two dimensional array of neurons [2,3]. Competitive Hebbian models of cortical development have been widely used to numerically study the properties of such mappings [2-5], but no analytical results about their ground states have been obtained so far. A classical example of such dimension reducing mappings is the Elastic Network Model (EN), which was proposed in [2].

Here we use a perturbative approach to compute the ground states of the EN for the joint mapping of two visual features: (i) position in visual space, represented in a retinotopic map and (ii) line orientation, represented in an orientation preference map (OPM). In this framework, the EN incooporates a mapping from a four-dimensional feature space to the twodimensional cortical sheet of neurons. We show that the dynamics of both feature representations can be treated within a general theory for the stability of OPMs [6]. We find various ground states as a function of the lateral intracortical interactions and external stimulus distribution properties. However, in all parameter regimes, the grounds states of the Elastic Network Model are either stripe-like, or crystalline representation of the two visual features. We present a complete phase diagram of the model, summarizing pattern selection. Analytical predictions are confirmed by direct numerical simulations. Our results question previous studies (see [5] and references therein) concluding that the EN correctly reproduces the spatially aperiodic arrangement of visual cortical processing modules.

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