Design of a Field Model for Early Vision: A Case Study of Evolutionary Algorithms in Neuroscience
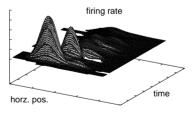
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Natural evolution has composed complex nervous systems, so it appears obvious to employ evolutionary algorithms (EAs) for modeling in computational neuroscience. Evolution creates the projection from the data space onto the solution space. Presuming a *structure*, this structure can either include a set of elements and rules for their cooperation or a model of the entire projection of which the parameters have to be estimated. This methodology is demonstrated by means of an example in the field of early vision.

Recently we have discussed evolutionary and hybrid methods for parameter adaptation of dynamic neural field models (Igel *et al.*, Neurocomputing 36, 2001). However, parameter adaptation is just the starting point for the design of complex neural structures; we propose that evolutionary "analysis by synthesis" guided by neurobiological knowledge can offer answers to more difficult questions in neuroscience (Hoffmann *et al.*, "Evolutionäre Neurobiologie", Ministerium f. Wissenschaft u. Forschung NRW, 2001). The challenge is to force artificial evolution to favor solutions that are sensible from the biological point of view. Such solutions are only likely to evolve if as much neurobiological knowledge as possible is incorporated into the design process. This can be achieved by providing sufficient experimental data to evaluate the evolved (sub-)systems. Additional knowledge can be coded in the fitness function and in constraints that ensure biological plausibility.

We consider a neural population representation for the horizontal position of a stimulus in visual space, which is based on single cell activity recorded in the primary visual cortex of cat (Jancke *et al.*, J Neurosci 19; 1999, Erlhagen *et al.*, J Neurosci Methods 94, 1999). Two stimuli—flashed small spots of light—have been presented. We focus on the prominent effect that the response to the second stimulus is reduced depending on temporal and spatial distance of the stimuli, see figure. We choose a homogeneous, non-linear field model with linear spatio-temporal interactions (von Seelen *et al.*, Biol Cybern 56, 1987). These inhibitory and excitatory interactions combine effects of pre-cortical and early cortical neural coding, particularly in the retina.

The fitness function consists of two parts. One measures the differences between evolved model and population representation, the other stresses the important aspects of the neural data, i.e., those characteristics of the spatio-temporal pattern that cannot be side-effects of the data preprocessing. An elaborated evolution strategy, the CMA-ES (Hansen *et al.*, EUFIT'97, 1997), is used for optimization leading to qualitatively and quantitatively accurate results.