Reaction-Diffusion Processes as Computational Model for Image Segmentation

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In this paper, we present a model of perceptual processes occurring in visual cortex during segmentation, in which the dynamics of such processes can be interpreted in terms of *reaction-diffusion* mechanisms governed by nonlinear partial derivative equations. This direct mapping from physics to computation appears to provide an efficient solution to the problem of feature binding in image segmentation.

In machine vision, scene segmentation can be obtained when different features are bound in a global unifying percept. After recent observations that synchronous oscillations in different regions of visual cortex reflect global properties of the stimulus [**?**], several cooperative neural networks have been proposed in which global properties of the image can be read in the correlated activity of neural populations [**?**] [**?**]. At macroscopic level, the modeling of neural activity is drastically simplified on the basis of the following assumptions: (i) all nervous processes of any complexity are dependent upon isolated pairs of interactive excitatory and inhibitory populations; (ii) the flow of information across the neural mass is mediated by diffusion processes that spread activation across the cortical surface. These processes are analogous to the diffusion of reacting chemical species and can be modeled by the following *reaction-diffusion* equation:

$$\frac{\partial \mathbf{v}}{\partial t} = \nabla \cdot (\mathbf{D} \nabla \mathbf{v}) + \mathbf{f}(\mathbf{v}) + \iint \mathbf{k}(\mathbf{x};\mathbf{x}')\mathbf{v}(\mathbf{x}')\ d\mathbf{x}' + \kappa,$$

where $\mathbf{v}(\mathbf{x},t)$, $\mathbf{x}\in\Re^2$, is the vector which represents the spatio-temporal distribution of excitatory and inhibitory variables, $\mathbf{f}(\mathbf{v})$ is the reaction term which describes pair interactions, $\mathbf{k}$ is the vector kernel of the integral operator responsible for lateral recurrent inhibition, and the vector function $\kappa(\mathbf{x},t)$ is the external stimulus which modulates the interactions between neural populations. The diffusion term is given by the product of the diffusion matrix $\mathbf{D}$ with the Laplacian on $\mathbf{v}$. Anisotropic diffusion allows for a weighted averaging on the input signal κ over a region of a certain extent (the receptive field) oriented along the principal axis of diffusion, thus extracting oriented featural elements from the image. Through space-variant diffusion coefficients, we obtain continuous distributions of oriented receptive fields similar to biological orientation maps. The nonlinear competition between the two populations leads to a macroscopic organized dynamic behavior that, under appropriate input conditions, results in oscillations.

Superimposed excitatory and inhibitory couplings between localized portions of the orientation map impose a long-range coherence and the whole system evolves through different configurations of coherent states. Averaging the pattern of activity over a window comparable in size with those of a complete set of orientations, we gain instantaneous global perception supporting scene segmentation. Experiments on texture segmentation, conducted with artificial and natural textures, validates the approach.