Medial Axes Neuronal Codification in Topographical Maps

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Abstract. A simple neuronal model for medial axes codification in biological vision systems is presented which is based on the concept of the propagation of wavefronts along topographically organized cortical structures.

1. Introduction

Although one of the most ubiquitous features exhibited by cortical modules in mammals corresponds to their accurate topographical organization, in which the spatial adjacencies are preserved, relatively few models of neuronal processing have explicitly taken into account the potential for representation and codification of visual stimuli allowed by the intrinsical geometrical properties of such structures [1]. At the same time, by allowing particularly comprehensive and useful representations of the visual stimuli, the interrelated concepts of medial axes and curvature (medial axes terminations correspond to curvature peaks) stand out as primary principles for both biological and computational vision. The current work presents a simple model for biological codification and analysis of visual information in terms of medial axes involving a neuronal processing mechanism defined by a biologically realistic scheme of synaptical connections.

2. The Model

Let the activity of the neurons in the topographical module be represented as \( a(x,y) \), where \((x,y)\) is the Cartesian coordinate of the neuron with respect to an arbitrarily placed reference origin \((0,0)\). Although the orthogonal lattice is assumed here for simplicity’s sake, good coding results can also be obtained by the proposed model even when noise with intensity proportional to the spatial resolution is added to the coordinates. Each neuron is assumed to be radially connected to its more immediate neighbors up to a maximum distance \( R_M \), as it is often the case with biological neuronal structures. As the visual stimulus sent to the cortical cells is first processed by the retinal circuitry, the signal received by each neuron in the model is assumed to correspond to the outlines of the original objects. The cells directly receiving such a signal are induced into activity, which is duly propagated along the neighboring cells through the synaptical connections.

As the thus initiated waves propagate, the inactive neighboring cells are reached and surrounded. Given the differential schemes normally characterizing neuronal cell operation, every time a neighboring cell is surrounded, it produces spikes as a response. Since this condition corresponds precisely to the shocks between different portions of the traveling waves, the differential spikes become associated to the medial axis transform of the outline of the original object [2]. It should be observed that the type of obtained medial axis transform depends on the distance scheme induced by the synaptic connection scheme. For instance, a simple 4- or 8-neighborhood connection scheme will produce medial-axes which are less invariant to rotation than those obtained for Euclidean distances. Indeed, in case a plausible neuronal scheme assigning different properties to the waves initiated at each point along the object contour can be identified, the scheme described in [2] would be enough to produce a graded version of the medial axes of the object, where the intensities along the obtained axes are directly proportional to the significance of the related detail in the original object. This intensity can be shown to be proportional to the arc-length between the two contour elements producing the shock at that position along the skeleton. It is argued here that this multiscale representation scheme could naturally provide the basis to the selective attention mechanisms known to operate at the cortical level.

References