Abstract

Biological neural networks are highly dynamic and play an important role in cognitive and learning intelligence. A plethora of neuronal layers with complex morphology, electrophysiology, connection, and projection specificity drive these biological neural networks. However, the compute capability and dedicated functionality of these computing elements remain unknown. There is insufficient evidence to conclude a connection between type-specific neuronal morphology, non-linear integration, and complex cognitive functionality. The current study attempted to investigate the role of relatively homogeneous morphology and electrophysiology in type-specific neurons in achieving type-specific functionality. Active membrane dynamics have been studied and passive membrane dynamics have been modeled to simulate action potential generation, propagation, and cell-field interaction to design a morphologically detailed neuron. To replicate class-specific neurons with analogous electrophysiology, a dedicated neuron morphology with a hierarchical linear-nonlinear structure has been designed. To emulate an orientation-selective ganglion cell network and investigate their interplay in edge estimation, morphologically detailed neurons are clustered together with connectome specificity to form layers of neuronal network. The modeled orientation-selective network has been configured to simulate scotopic and color vision edge estimation in the human visual cortex. The visual cortex model's performance estimation approaches the score of actual human vision reported in the literature. The proposed framework also provides insight into bandwidth tuning capability due to proper coupling between fibers within a neighborhood by integrating the orientation-selective ganglion cell layer model with the cell-field interaction model. In primates' visual cortex, the effects of receptive field sizes on similar networks and the type of information transmitted to parvocellular and magnocellular regions have also been modeled and investigated. Orientation selective ganglion cell network with multiple receptive field sizes corresponding to midget and parasol cells shows multi-resolution behavior in the visual cortex. Midget cells have a preference for fine features, whereas parasol cells with larger receptive fields prefer coarser features. Restructuring the proposed ganglion cell with a larger receptive field, greater dendritic spread, and connectivity solely with ON or OFF bipolar cell gives scene segmentation type behavior that is being projected onto the magnocellular layer. The proposed model shows these signals in the magnocellular layer are capable of shaping boundary estimation and contour detection type behavior exclusive to the region. Similarly, a Hubel and Weisel type network has been modeled and simulated in order to verify its viability in learning and recognition.

Keywords: Neuron morphology, type-specificity, dendritic arbor, structure-function relation, non-linear integration, visual cortex, primate vision