Chapter 7

Conclusion and Future Directions

7.1 Conclusion

In this dissertation, the role of neuron morphology in type-specific function formation has been explored. Detailed neuron morphology has been constructed integrating active and passive membrane dynamics to form hierarchical linear & nonlinear structures. Active membrane dynamics have been studied and passive membrane properties have been modeled to mimic their respective behavior to integrate and design the morphologically detailed neuron. A morphologically detailed neuron architecture of neuron is designed to incorporate localized active ion channel dynamics in a dendritic arbor similar to a biological type-specific neuron. Several neurons with homogenous morphologies are arranged with mosaic-like patterns with single-cell precision to replicate orientation-selective RGC layers of the primate visual cortex. The orientation-selective RGC layer has successfully replicated orientation selectivity behavior in the primate visual cortex with spiking resonance toward preferred orientation and diminished or no activity corresponding to non-preferred orientation. The model has been further configured to replicate color and night vision in the human retina. Response from the model has successfully mimicked the intensity-dependent behavior in scotopic vision as well as frequency discriminating behavior in color vision. Responses of the edge-estimation model are compared against human vision edge-estimation performances., the designed model successfully compares against the human vision. The color vision model estimates a maximum OIS performance value of 0.815 whereas literature reported this accuracy to be about 0.825. Integrating the edge-estimation model with the cell field interaction model, bandwidth tuning capability due to cell-cell interaction has been observed. The coupled edge-estimation model, with a proper

coupling factor, can fine-tune the orientation selectivity behavior. Further, the cell-field interaction model also gives ample evidence of coupled networks capable of transmitting signals without interference between two neurons. Edge-estimation accuracy of the coupled edge-estimation model couldn't be computed owing to the computational complexity of the model but looking into the bandwidth tuning behavior or the model, performance was anticipated to go higher as compared to the uncoupled counterpart.

The importance of receptive field sizes of midget and ganglion RGCs has also been explored by incorporating different receptive field sizes, complex dendritic arbor morphology, and dendritic spread of neuron morphology. Midget and parasol cells have been designed to mimic their respective behavior in a similar network. Change in receptive field sides shapes the multi-resolution feature extraction behavior. In this work, the network with a small receptive field focuses on finer features with a broader bandwidth whereas the network bandwidth becomes precise with increasing receptive fields and focuses on the coarser counterparts. Connectivity dependence of such network has also been explored where the proposed framework shows the dependency of complement connectivity with bipolar cells for edge detection whereas connectivity with similar bipolar cells shapes segmentation type behavior. The proposed model has been extended to incorporate Hubel and Weisel type of neuronal networks consisting of layers of simple and complex cells to validate its validity in learning and recognition. Multiresolution features projected onto the parvocellular region successfully demonstrate the feasibility of such networks.

Thus the proposed framework signifies the role of type-specific neuron morphologies in shaping the global response of a layer. This work also suggests basic feature extraction in the visual cortex as inherent behavior of the neuron morphology coupled with its identical electrophysiology. The multi-resolution responses of analogous neuronal morphologies with similar class-specific electrophysiology but varying receptive field sizes extract inputs from the similar layers and project them onto different layers. Even though the functional specificity of the neurons are similar but due to their projection patterns and dendritic stratification, they might be misinterpreted as a sub-class. The proposed framework also suggests depends on a combination of localized active ion channels in a dendritic arbor in non-linear computations. The edge estimation model relies on the combination of the 'chattering' and 'bursting' membrane model whereas only the 'bursting' membrane model has been used to simulate non-linear dynamics due to localized active ion channels which is due to their current delivering capability at the successive

nodes.

7.2 Dissertation Contributions

A detailed survey on state-of-the-art *in-vitro* experiments and *in-silico* experiments on neurons has been conducted that helped us gain insight into the issues and challenges in the research along with some of the missing links between existing literature. The prime contribution of the dissertation can be divided into four sections. Subsections followed briefly summarizes the major dissertation contribution.

7.2.1 Mathematical Modeling and Simulation of Neuronal Assemblies

Neurons are composed of complex dendritic arbors enriched with unique blends of membrane dynamics corresponding to specific locations in the dendritic arbor and pertaining to a definite type of neuronal cells. Dynamics due to such neuronal morphology is yet to be explored and understood in detail. In this work, attempts have been made to mathematically model and simulate such dendritic structures. Active membrane and passive membrane fiber dynamics have been mathematically modeled and simulated with dendritic nodes/junctions modeled as summing points. Inter-fiber interference due to cell-field interaction has also been mathematically modeled using the cable equation and shades significant light on fiber coupling. Mathematically modeled structures are integrated to construct detailed morphology of neurons to simulate active dendritic integration behavior due to differential distribution of AIC in localized regions.

7.2.2 Single Layered Retinal Ganglion Cell Spiking Neural Network in Primate Visual Cortex and Edge Detection

In this proposed work, a single-layered edge detection type SNN has been designed to integrate morphologically detailed RGC cells. Designed morphologically detailed RGS's are connected to photoreceptor cells via ON and OFF bipolar cells (BC), organized in precise repetitive pattern with single-cell precision with connec-

tome specificity. The response generated by single layer RGC SNN has been compared against existing state-of-the-art models and ground truths from Berkley's BSD database. Simulated responses shows comparable edge detection precise in comparison to the existing state-of-the-art computer vision edge-detection models including those of the 'Sobel operator', 'Prewitt operator' and 'Laplacian edge detectors'. The model also suggests bandwidth tuning in such RGC's to be a dependent function of the combination of active membrane dynamics triggering spiking activity such as 'chattering', 'bursting', 'regular spiking' etc. The model also shows RF as a function of dendritic spread. The proposed model has been verified using the 'SIPI Image Database' and 'Berkley Segmentation Database' and compared against the ground truth provided with the 'Berkley Segmentation Database'.

7.3 Future Directions

The proposed framework has been modeled and analyzed considering the spiking rate-based encoding schemes of the neurons. But several unique spiking patterns have also been observed while analyzing the time series data of the spiking neuron. Exploration of spike time-dependent plasticity and its relation has not been explored in this work. Hence exploration of spike time-dependent plasticity opens up new unexplored knowledge in the field. Apart from spike timing, the proposed model is deterministic in nature, and dynamics due to stochastic synaptic connections remained unexplored. A detailed investigation of such connectivity might reshape single neuron dynamics as a network within neurons and remains a major interests for future works.