MODELING SHORT AND LONG RANGE CORTICOCORTICAL CONNECTIONS IN THE VISUAL CORTEX AND STUDY OF ORIENTATION SELECTIVITY

By

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CERTIFICATE

This is to certify that the thesis entitled "Modeling Short and Long Range Corticocortical Connections in the Visual Cortex and Study of Orientation Selectivity" being submitted by Mr Atanendu Sekhar Mandal for the award of the degree of Doctor of Philosophy in the Department of Electrical Engineering, the Indian Institute of Technology, Delhi, is a record of bonafide work done by him under our joint supervision and guidance. The matter embodied in this thesis has not been submitted to any other University or Institute for the award of any other degree or diploma.

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To succeed, you must have
tremendous perseverance,
tremendous will:
'I will drink the ocean',
says the persevering soul,
'at my will',
'mountains will crumble up'.
Have that sort of energy,
that sort of will, work hard,
and you will reach the goal.

-Swami Vivekananda

This Work is Dedicated

To the People of

Sundarbans,

My Teachers,

My Parents, and

My Elder Brother

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My mother left for her heavenly abode when I just started my PhD. Today she would have been the happiest person to see her son achieving this distinction in his life!

ASmandal

Atanendu Sekhar Mandal

ABSTRACT

In this thesis we study the development of lateral corticocortical connections in the visual cortex, layer 4, area 1 (V1). We present two models for short and medium range lateral connections and one model for long-range horizontal connections.

The first category of models are based on the following biologically plausible assumptions:

(a) There are competitions for pre-synaptic resources. A pre-synaptic cell has a fixed amount of resource to distribute among its branches. This constrains the number of axonal branches a cortical neuron can maintain.

(b) There are competition among axons for target space. The axons compete for neurotrophic factors, growth or survival promoting factors, released by the postsynaptic cells which the axons innervate.

(c) There exists Hebbian cooperation between cells with similar orientation preference.

In the first model for short and medium range lateral connections, the cooperation between cortical cells is determined by the orientation preference of the cells. As this model is basically a single layer model representing the cortex, the effect of receptive field could not be incorporated in this model. In the second model the initial orientation selectivity is determined by thalamocortical connections. During the development of lateral connections, the cooperation between cortical cells depends on the orientation selectivity as well as on the location of the receptive fields of the cells. We have used a three-layer model consisting of the retina, LGN and the cortex. Our simulation results

resemble the experimentally observed results in layer 4 in the visual cortex. We have observed that the connection strength between two cells increases if their orientation preferences are similar and their receptive fields overlap. Due to computational constraints, we have used a cortex of size 50x50 in our simulations. A cortex of this size can have at most 4 to 5 hypercolumns. Therefore the lateral connections developed by our model can be tested for only short and medium range connections.

The effect of (i) LGN, (ii) cortical excitatory connections and (iii) cortical inhibitory connections on tuning of cortical cells is studied using the lateral connections developed in this second model. Contributions from each of three factors on tuning depend on the location of the cell in the orientation map. Iso-orientation neighbours mainly determine tuning of cells located in the iso-orientation region. The effects of inhibitory lateral connections are observed more in cells in the boundary between iso-orientation regions and near pinwheels. Improvement in tuning is more if cross orientation inhibition is present. To understand the cortical organization and the interactions among cells we have done the contextual effect experiment in the simulation environment. Both facilitatory as well as inhibitory effects were observed in our cortex under simulation. These effects are location dependent.

Finally, we have presented an optimization based neural network model for the axon growth. This model can be used for modeling long distance horizontal connections. We have used a simple force directed mechanism for the movement of the tip of the axon i.e. the growth-cone. In this work we have shown that our axon growth model can innervate various zones lying at distant places. It could sprout axonal branches at appropriate locations and make connections with the cells in its neighbourhood. We have used an optimization technique to obtain an optimal axonal network.

In summary, in the thesis we have tried to verify the following hypotheses:

1. Competition and Hebbian cooperation are the most natural ways for the development of corticocortical connectivity patterns.
2. The orientation selectivity and orientation tuning of cortical cells are due to various mechanisms such as the feed-forward inputs from the LGN, cortical inhibition, and cortical excitation. Feed-forward connections contribute to the emergence of orientation selectivity of cortical cells. The initial seed of orientation selectivity provided by the feed-forward connections are further refined by cortical excitatory and inhibitory inputs.
3. These mechanisms are location dependent.
4. The phenomena of Contextual Effects are also location dependent.
5. Force directed mechanism can be a natural way for the growth of axons

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