SEQUENTIAL DEVELOPMENT OF ORIENTATION AND OCULAR DOMINANCE MAPS: A REACTION-DIFFUSION APPROACH

by

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CERTIFICATE

This is to certify that the thesis titled **"Sequential Development of Orientation and Ocular Dominance Maps: A Reaction-Diffusion Approach"**, being submitted by C. M. Markan, for the award of Doctor of Philosophy to the Indian Institute of Technology, Delhi, is a record of bonafide research work he has carried out under our supervision. The results contained in this thesis have not been submitted to any other University or Institute for the award of degree or diploma

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Dedicated to Him,

the Teacher,

who taught me the meaning

of Work and Worship

of Success and Failure,

of Life and Existence,

of Creater and Creation ..

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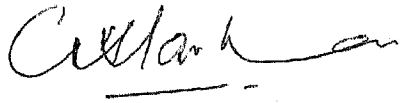

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ABSTRACT

In this thesis we present a reaction diffusion model for development of maps in the visual cortex. Recently, using optical imaging technique, orientation map (i.e. the layout of iso-orientation domains), ocular dominance map (i.e. zebra-stripe like eye-specific neuron response pattern in the cortical layer IV) and the relationship between the two maps have been extensively studied. A model based on reaction diffusion has so far not been applied explicitly for modelling the development of orientation and ocular dominance maps. Very early in development, it is unlikely that long range intracortical connections exist in the cortex and the only way cortico-cortical interaction may take place is through near neighbour short range interaction, namely, diffusion. A developmental model where diffusion plays an important role assumes further significance in the light that recent experimental results show that long term potentiation (LTP) can spread to synapses on neighbouring neurons by diffusible signal. In our model development of orientation map is followed by ocular dominance map. Our modelling is based on the observations that orientation selective cells are present at birth and linear maps of orientation appear long before the segregated bands of afferents in layer 4C.

A two morphogen reaction diffusion model is developed for formation of orientation map. This model captures all the features of adult orientation maps in monkey, cat and ferret. Ours is the first model that gives an insight into the variations observed in the orientation maps of various species and correlates the width of orientation columns and development of orientation tuning as a function of developmental time in different species. The development of orientation tuning in our model resemble experimental results available for ferrets and cats.

Heightened activity at pinwheels centers and orientation fractures has been observed in the experimental maps. This heightened activity may be understood from the fact that as pinwheel centers could either consist of (i) cells having poor orientation tuning or (ii) a mixture of well tuned cells having different orientation tuning. Time averaged activity i.e response to all orientations, at these locations will be high. Since ocular dominance is essentially a visual activity based map, according to Hebbian learning principles, competition between eye-specific afferents should be intense at locations where the time averaged activity is high as compared to other locations of low activity. The visual activity modulated segregation process starting at the pinwheel centers form the basis of our single morphogen ocular dominance model. Our model captures the details of both orientation and ocular dominance maps and the inter relationship between these two feature maps in adult animals.

We also modelled monocular deprivation experiment wherein either one eye is completely closed or has reduced activity as compared to the eye. We found the ocular dominance stripes corresponding to the deprived eye to shrink in width while stripes corresponding to non-deprived eye to become wider.

Origin of orientation selectivity has intrigued researchers ever since Hubel and Wiesel first demonstrated that visual cortical cells selectively respond to oriented bars shown within their receptive fields. Two hypotheses have been used in literature to explain the origin of simple cell orientation selectivity. According to the first hypothesis proposed by Hubel & Wiesel, orientation selectivity is chiefly determined by feedforward connections from the LGN to cortex. The second hypothesis lays emphasis on role of corticocortical interaction in the generation of orientation selectivity. It has been argued that cortical cells receive only a weak orientation bias from feedforward connections from the LGN and the orientation preference of cortical neurons is largely determined by intracortical connections. Whether it is cortical mechanisms that amplify the weak orientation bias in the feedforward

connections from LGN to cortex or not, a question, which is still open, is how the complex organization of geniculate inputs develop during the prenatal period. Also how this development will then lead to global order in the form of orientation maps, as observed experimentally. Through our diffusive-LTP model we have studied this aspect of feature map formation. In our diffusive-LTP model during development of orientation selectivity, corticocortical interaction are essential. During development diffusive corticocortical interaction not only guides the development of the orientation map but also guides the topographic organization and strengthening of the thalamocortical arbors. Strengthening of thalamocortical arbors in turn increase the input to the cortical cells. As the orientation map matures the thalamocortical connections also reach their matured values. At this stage thalamocortical input itself can account for a cortical cell's orientation selectivity. This explains why recent experiments on adult animals support Hubel & Wiesel's hypothesis on orientation selectivity being chiefly determined by feedforward connections from the LGN to cortex.

The diffusive-LTP model produces all the features of experimental orientation map and captures the development of orientation tuning in cats and ferrets. As diffusive interaction guides the development of orientation map, we conjectured that it has the potential to fill-in or reorganize scotoma affected cortex in adult animals and used diffusive-LTP interaction for reorganize of scotoma affected cortex. We studied the role played by thalamocortical and long range iso- orientation cortical connections in reorganization. We found that in neonatal animal reorganization of orientation map takes place even in absence of long range connections. However, for an adult animals afflicted with large size scotoma long range horizontal connections are necessary to recover pre-lesion orientation map structure.

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