

# MODELING THE DEVELOPMENT OF SIMPLE CELL RECEPTIVE FIELDS AND THEIR SPATIAL ORGANIZATION

By

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*Submitted  
In fulfillment of the requirements  
for the degree of*

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*to the*

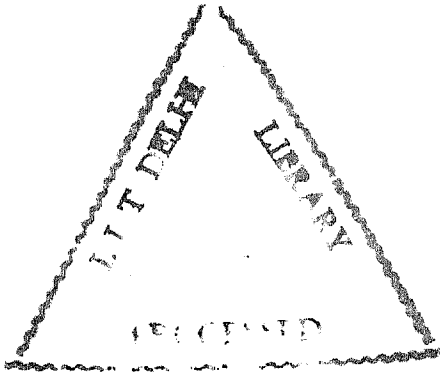


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## CERTIFICATE

This is to certify that the thesis entitled "Modeling the development of simple cell receptive fields and their spatial organization" being submitted by Ms. Mona Mathur 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 her under our joint supervision and guidance. The matter embodied in this thesis has not been submitted to any other institute or university for the award of any other degree or diploma.



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*Dedicated to my parents.....*

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## **Abstract**

Ever since the discovery of simple cells by Hubel and Wiesel, various research groups have been trying to understand the origin of orientation selectivity in the visual cortex. A number of factors have been observed to contribute to this property in cortical cells. It has generally been agreed that orientation selectivity is created by aligned thalamic inputs reaching a cortical cell and is amplified by local intracortical connections. Studies on cats and ferrets have shown that emergence of orientation selective responses does not require patterned vision, though its maturation is impaired in the absence of vision.

Many models have been proposed to capture cortical cell characteristics. The majority of these assume a thalamocortical origin of orientation selectivity. However, a few among these aim at understanding the possible developmental mechanisms that could lead to the desired arrangement of thalamic afferents. These models use a Mexican hat correlation function to model intra-cortical connectivity, and use synaptic normalization to bring in competition among afferent fibers. Experimental observations do not support the Mexican hat connectivity pattern and synaptic normalization has its own associated problems. These shortcomings have created the need to bring in models that are biologically more plausible and generate simple cells that have properties like those of the experimentally observed cells.

In this thesis, we propose a feedforward model for the development of orientation selectivity in the layer IV simple cells. Receptive field development in the model is

determined by diffusive cooperation among neighboring cells and resource limited competition among afferent fibers, and occurs in the presence of spontaneous activity in the LGN. The receptive fields obtained with the model show smooth transitions between subregions and fade off gradually at the boundaries, closely resembling experimentally observed receptive fields. The model successfully captures the spatial and spectral properties of the simple cells.

We examine the contribution of linear and non-linear excitatory inputs towards generating orientation selectivity in simulated cells. If only linear mechanisms are considered, cells show poor selectivity to orientation. Their tuning widths are seen to be dependent on the elongation of the ON and OFF subregions along the axis of orientation. Incorporating non-linearity in the form of spike threshold is observed to drastically improve the tuning properties of the cells. The spike threshold restricts the responses only to the highest cell potentials, creating a tip of the iceberg effect. The effect of spiking non-linearity varies considerably among cells. We show that besides the spike threshold voltage, the activity dependent scaling of synaptic strengths and the structure of receptive field (i.e. the type, size and number of subregions within a cell's receptive field), contribute substantially towards determining the amount of improvement seen in the cells.

The spiking non-linearity besides affecting the spatial tuning properties of the cells, also affects their spectral responses. Study of spectral properties of the cells reveals, that the iceberg effect sharpens the orientation selectivity of the cells at the cost of their spatial

tuning bandwidth. Further, our model suggests that sharpening of orientation tuning with spatial frequency as seen in a number of experiments could be accounted for by the distribution of synaptic strengths within the receptive fields of the cells.

The proposed model is also able to successfully capture the desired layout of orientation preferences on the cortical surface. The orientation map emerges in parallel with the formation of receptive fields. Once the maps appear they remain stable. The Fourier spectrum of obtained maps is half moon shaped resembling the spectrum of the orientation maps obtained in cats.

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