

MODELING DISPARITY AND SURFACE SLANT SELECTIVITY IN PRIMARY VISUAL CORTEX

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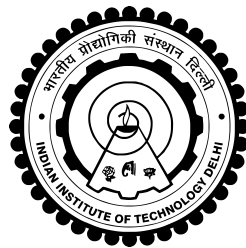
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Submitted in fulfillment of the requirements
of the degree of

Doctor of Philosophy

to the



Indian Institute of Technology Delhi

December, 2012

To my parents and family members

Certificate

This is to certify that the thesis entitled “**Modeling Disparity and Surface Slant Selectivity in Primary Visual Cortex**”, being submitted by **Mr. M Sultan M Siddiqui** for the award of the degree of **Doctor of Philosophy** to the Department of Electrical Engineering, Indian Institute of Technology Delhi, is a record of bonafide work done by him under my 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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Acknowledgement

I would like to express my greatest gratitude to my supervisor Professor Basabi Bhaumik for her guidance, interest, advice, support, for her understanding of the subject and help throughout the course of present work. I am indebted to her for introducing me to the area of computational neuroscience. I am very grateful for having the opportunity to work with her and hope that I shall continue to have her blessings in the future.

I would also like to thank Professor G. S. Visweswaran for helping and motivating me throughout the course of this work. He was always concerned about my progress and whenever I went to him he was very kind to extend me the helping hand.

My special thanks to Professor Dinesh Mohan, Professor R. K. Patney and Professor G. S. Visweswaran members of my “Student research committee” for all the constructive ideas and criticism throughout my research work.

I remember with great pleasure the time I spent with my colleagues at IIT Delhi. It was great fun to work together in a close and fruitful collaboration with Anoop C. Nair, Girish V. and Hitesh Shrimali. I also thank other present lab members Dhanaraj K. J., Kinde, Mamata Jain, Roohie Khaushik, Nagarjuna Nallam, and Gajendranath.

I am grateful to the Department of Electrical Engineering at the Indian Institute of Technology Delhi for providing me the excellent work environment during the past years. I would specially like to mention the help which Mr. Rakesh Kumar

and Mr. Jiley Singh have provided me during my research work.

I would like to thank my parents, uncles and brothers for their individual support throughout my course. I could not have finished this work without their love and support.

Finally, I acknowledge all other who have helped me and whose names could not be accommodated in this brief acknowledgment.

M SULTAN M SIDDIQUI

Abstract

Visual information processing for Stereopsis from binocular disparity begins in the primary visual cortex. Decades of experimental studies are available on disparity selective cells in primary visual cortex of macaque and cat. Recently local disparity map for iso-orientation sites for near-vertical edge preference is reported in area 18 of cat visual cortex. No experiment is yet reported on complete disparity map in V1. Disparity map for layer IV in V1 can provide insight into how disparity selective complex cell receptive field is organized from simple cell sub-units. Though substantial amount of experimental data is available for binocular disparity selectivity in V1, no model on receptive field development of such cells or disparity map development exists in literature.

In this thesis, we have presented a three-layer visual pathway model to capture binocular disparity selectivity in layer IV of cat V1. The first layer models left and right retinæ. The second layer models left and right eye specific Lateral geniculate nucleus (LGN) layers. The third layer models cortical layer IV of cat V1. We have proposed a reaction-diffusion two-eye model to develop thalamo-cortical connections between LGN and cortical cells. The model develops realistic left and right eye receptive field (RF) profiles of simple cells. Developed left and right eye RF profiles possess spatial offsets: RF positional and phase disparities. We have used a modified SRM (spike response model) for obtaining cortical cell response.

The modeled cortical cells are classified into three classes. (i) Disparity Selec-

tive cells for vertical or fronto-parallel surfaces. (ii) Horizontal surface slant selective cells and (iii) Dif-frequency selective cells. Our modeled cells that are disparity selective for vertical surfaces capture the following experimentally observed results. (1) Matched Orientation (OR) preference with interocular OR difference $< \pm 18^\circ$ in both eyes. (2) Matched Spatial frequency (SF) preference with interocular SF difference $\leq \pm 0.05$ cycles/deg. in both eyes. (3) Range of Ocular dominance (OD) from left eye preference to binocular to right eye preference. (4) Lack of correlation between disparity selectivity and OD at cell population level as observed experimentally. (5) Cells with vertical OR preference show wider range of RF phase disparity as compared to cells with horizontal OR preference. This is referred as OR anisotropy of RF phase disparity. (6) Slight positive correlation between RF position and phase disparities.

Our modeled cortical simple cells that are horizontal surface slant selective capture horizontal surface slant in the range of 0° to 80° as observed in real visual scenes using their Inter-ocular difference in their preferred OR (IDPO) values. However, wide OR tuning widths in binocular responses of these modeled cortical cells indicate poor specialization for signaling horizontal surface slant encoded by IDPO. Our results agree with the reported experimental observations.

Our modeled cells that are Dif-frequency selective show disparity gradient range of ± 0.95 which represents vertical surface slants in the range $\pm 85^\circ$ from the fronto-parallel plane at 50 cm fixation distance in real three-dimensional (3D) visual

space. Most of the Dif-frequency cells have wide tuning width and show poor vertical slant selectivity. A small fraction of modeled cells have vertical slant tuning characteristics similar to ones reported in V4.

At cortical map level, we have jointly developed OR, OD and disparity maps. OD peak points are located on/near the pinwheel singularities of OR map as observed experimentally. Disparity selectivity topography in our model V1 is not random but weakly clustered for similar preferred disparities. The disparity map consists of disparity selective simple cells. The details of weakly clustered disparity selectivity map can provide insight into how disparity selective complex cell receptive field is organized from simple cell subunits. From the weakly clustered spatial organization of the disparity selective simple cells in our model cortex, we find two types of complex cell receptive fields. Complex cell RF consisting of simple cell subunits with (i) same/almost same disparity selectivity and (ii) different disparity selectivity.

Cells with significant IDPO and cells with Dif-frequency selectivity are poor in slant selectivity and they respond equally well for a wide range of surface slant including vertical surfaces. Individual cells in V1 are not effective in detecting surface slant but appropriate pooling of inputs from such cells in V1 by higher visual area neurons make them detect a surface slant or a curve in real visual space. We have obtained complete disparity map for our model cortex and estimated the depth that would be detected by disparity selective cells in V1. Using disparity map and estimated depth detection, in this thesis, for the first time we have shown how pooling

of inputs from V1 may take place so that higher visual areas can encode depth for 3D objects.

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