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Reconciling models of surround modulation and V1 feature map development

Judith S Law* and James A Bednar

Address: Institute for Adaptive and Neural Computation, School of Informatics, University of Edinburgh, Edinburgh, UK

Email: Judith S Law* - j.s.law-1@sms.ed.ac.uk

* Corresponding author

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The cerebral cortex of mammals is organized as a set of topographic maps, forming sensory and motor areas such as those in the visual, auditory, and somatosensory systems. Understanding how these maps develop and whether they have any functional significance is critical for understanding cortical processing.

The prototypical example of topographic feature maps is the map of orientation preference in primary visual cortex (V1). Models of V1 orientation map development have been very successful in reproducing the features of biological maps. The majority of these models are based on a principle of "Mexican-hat" connectivity i.e. short-range excitatory and long-range inhibitory connections between neurons (e.g. [1]).

However, experimental data is in striking disagreement with this principle. There is a consensus that long-range connections between V1 neurons are excitatory [2]. Moreover, models with long-range excitatory connections are able to account for a wide range of experimental data from adult V1, such as surround modulation (e.g. [3]). Models of orientation map development are thus based on a connectivity which is precisely opposite to that suggested by a mounting body of experimental and computational evidence.

It is not yet clear if the circuits used in surround modulation models are consistent with the development of orientation maps. It is also important to consider how the topographic organization of orientation preference may affect surround modulation. Since cortical circuitry is intimately tied to topographic organization, it is likely that surround modulation properties differ depending on the position of a cell within the orientation map.

In order to address the above issues, we have developed the first model that is consistent with current models of surround modulation, yet also reproduces the features of successful developmental models of topographic map formation. The model consists of sheets of firing-rate-based units that represent the retina, LGN, excitatory, and inhibitory neurons in V1. An activity-driven Hebbian learning mechanism results in the adjustment of afferent (retina to V1) and long-range lateral connection weights (within V1), leading to the development of orientation selectivity organized smoothly in a realistic orientation map.

References

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