

On the Temporal and Phasic Response of Activity Profiles in the Bresslof-Cowan Sphere Model of a Hypercolumn

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Summary

A mechanism for the response of simple and complex cells to phase dependent stimuli is presented. This mechanism is built upon the Bresslof-Cowan spherical model of a cortical hypercolumn. We first show that the single hypercolumn model is sufficient to produce simple and complex activity profiles; that is, activity profiles which produce phase dependent behavior in response to a phase dependent stimulus (in the case of simple cells) or phase independent behavior in response to the same (in the case of complex cells). Furthermore, we extend the model to account for populations of simple and complex cells within a single hypercolumn.

Preliminary results suggest that simple behavior arises because the intracortical connections are sufficiently weak that the network acts as a simple linear filter, thereby preserving phase dependence of the stimulus. In the case of complex cells, intracortical connections are of sufficient strength to provide for spontaneous pattern formation in the absence of a stimulus. This mechanism of pattern formation is a spontaneous breaking of the $O(3)$ symmetry expressed by the topology of cortical connections. In this case, when the network is exposed to a stimulus which itself breaks the $O(3)$ symmetry, the dominance of the recurrent interactions drives the selection of one of the spontaneously broken states. More precisely, the Bresslof-Cowan model hypothesizes that the dynamics of V1 serves to amplify those components of the activity profile which correspond to the zeroth and first order spherical harmonics. This results in a unimodal activity profile centered at a particular orientation and spatial frequency. A spontaneously broken state in the case of dominant intracortical interactions is then one with a “randomly” chosen orientation and spatial frequency which the activity profile reflects. When a stimulus is presented, the shape of the activity profile is dominated by the intracortical interactions, although the presence of the stimulus perturbs it sufficiently to select the location of the profile’s peak to be at the orientation and spatial frequency of the stimulus. Thus, *to lowest order*, the activity profile of a “complex cell” is independent of other features of the stimulus. In particular, the activity profile is independent of phase. This leads to the prediction that at higher orders the activity profile should have phase dependent corrections. We will provide the explicit form of these corrections.

The above discussion applies in particular to stimuli presented over long time scales relative to the time scale of neural dynamics in visual cortex. A key result

of the Bresslof-Cowan analysis is that a feedforward input to the visual cortex from the lateral geniculate will not faithfully encode the orientation and spatial frequency of the stimulus. They hypothesize several mechanisms to account for this mismatch, the most intriguing of which is the suggestion that feedback from V1 to the LGN renormalizes the input to cortex. This has the consequence that the visual system will have a time scale on which stimuli will not be faithfully represented, i.e. before the cortex has an opportunity to “correct” the LGN. If we wish to consider the effects of experiments in which the visual system is exposed to moving gratings, for example, this time scale cannot be ignored if the grating is moving sufficiently rapidly. We perform an analysis of the time-dependence of solutions in the Bresslof-Cowan model and attempt to extract a prediction of this time scale in order to determine the applicability of the solutions described above for “long” time scales.

References

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