Everyone will be famous for 15 minutes.

Andy Warhol

Abstract

Vision is the dominant human sensory modality. Due to the relative ease with which both visual input and visual brain areas can be studied and manipulated, vision has become an important window for enlarging our understanding of the biological sensory processing. Whether artificial or biological, visual processing systems must quickly and efficiently make sense of a large volume of noisy, high-dimensional input. To do this they construct statistical models of the input and utilise these models to efficiently encode visual scenes, detect features and construct a model of the world. In this thesis, we combine the study of natural scene statistics with mathematical models, experimental analysis and visual psychophysics to glean a deeper understanding of the development and function of the mammalian primary visual cortex.

We start by considering functional models of receptive field development. We find, in agreement with previous work, that unsupervised learning models trained on natural scenes consistently learn that oriented “edges” (Gabor-like filters) are the basic features of natural scenes. The similarity between these filters and primary visual cortex receptive fields is strong evidence that primary visual cortex receptive fields are optimal encoders of visual input. We then significantly extend this work by comparing the prediction of unsupervised learning models with the receptive fields of animals reared in unusual visual environments. We find good agreement, which is evidence that aspects of receptive fields are learned during development, rather than innate. We also show that applying such unsupervised learning models to binocular visual input is not a simple extension of monocular visual input. Interoocular correlations change the optimal encoding strategy of binocular input so that it depends...
on edge orientation. Such functional models intriguingly predict an over-representation of vertically oriented receptive fields.

After establishing that oriented edges are the basic feature of natural scenes and the unit of primary visual cortex receptive fields, we consider the statistics of edge arrangements in natural scenes. Sigman et al. (2001) showed that edges in natural scenes over short distances tend to be tangent to a common circle, or co-circular. Edge arrangements which contain a dependence between edge position and orientation may be said to have “reduced symmetry” as they lack a symmetry in that the edge position and orientation cannot be rotated independently without modifying the statistics of the arrangement. Co-circularity is one specific type of reduced symmetry. We extend previous work on natural scene co-circularity using a noise-resistant measure of co-circularity we develop and show that natural scenes contain significant co-circularity over extremely large angular distances (> 14°). We also discuss preliminary work into variations in co-circularity statistics by scene type.

After establishing that co-circularity is found pervasively in natural scenes, even over large distances, we then return to the structure of the primary visual cortex, but this time at the network level. Previous work has shown that, like edges in natural scenes, V1 orientation preferences maps also have reduced symmetry. However, the details of this dependence between orientation and position have not been examined in detail. We examine cat orientation preference maps from normal, stripe and blind-reared animals and find that, although orientation preference maps do contain reduced symmetry, it is not co-circularity. Moreover, the statistics of reduced symmetry in the maps are not affected by changes to visual input during development.

Continuing our examination of V1 network structure, we consider the statistics of lateral connectivity in tree shrew V1. Previous work demonstrated that long-range V1 lateral connections are more common between regions with similar orientation preferences (Bosking et al. 1997). We re-examine this connectivity data using our noise-resistance measure of co-circularity. We find evidence that lateral connections between cells in the primary visual cortex may use two opposite wiring strategies which simultaneously facilitate quick processing of co-circular visual input while increasing the salience of the less expected deviations from co-circularity.
Finally, we use the psychophysics of binocular rivalry to test whether co-circularity statistics can affect the functional processing of visual input in humans. We show, using binocular rivalry dominance as an objective measure of salience, that randomly arranged edges are more salient than edge arrangements which contain co-circularity. This is evidence that early visual processing may be functionally utilising edge arrangement statistics. In concurrence with our findings about lateral connections, this may indicate a general strategy of increasing the salience of unexpected visual input.

Overall, we demonstrate that early visual coding uses natural scene statistics extensively. We show that oriented edges are a key currency in early visual processing. We find that the arrangement of edges in natural scenes contain rich statistical structure which influences wiring in the primary visual cortex during development and produces measurable changes in the salience of visual stimuli.

**Keywords**

Primary Visual Cortex, Receptive field development, Lateral connections, Neural Coding, Natural scene statistics, Co-circularity

**Australian and New Zealand Standard Research Classification (ANZSRC)**

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