Orientation selectivity in goggle-reared kittens: An overcomplete unsupervised learning model

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Unsupervised learning models applied to natural scene statistics almost ubiquitously generate V1-like receptive fields. To assess further how well these models describe the functional goals of its neural representation, we applied such a model to the V1 responses of animals raised in environments with unnatural statistics, namely the recent sustained goggle-rearing experiments of Tanaka [2]. We show that an over-complete product-of-experts model (POE) [1] captures well many characteristics of V1 simple cells observed under both normal and goggle-reared input.

Tanaka [2] used optical imaging and electrophysiological methods to show that severely restrictive striped goggle rearing for many months post-eye opening has extreme effects on neural development. The percentage of neurons in goggle-reared kittens preferring the orientation permitted by the goggles was over five times that of neurons in normal kittens along with other more subtle changes.

We simulated the effects of goggle-rearing by training POE, an over-complete extension of independent components analysis, with inputs consisting of unadulterated natural scenes and/or natural scenes that had been filtered with (software-defined) goggles. Different proportions of the two inputs were used in order to model innate mechanisms favoring the statistics of natural scene-like input or incomplete striped rearing. We applied POE models with differing degrees of over-completeness, the other variable that is known to exert significant influence over the nature of receptive fields in functional models.

Our results show that there is a significant regime in which model filters at the goggle-filtered orientation (GO) are over-represented, together with a relatively even distribution of filters for other orientations, as is seen in the experimental data. The degree of orientations selectivity can be quantified by an over-representation index, ORI=(n oriented at GO)/(n oriented elsewhere) where n is the number of neurons. In experiment, ORI values ranged from 3.74-12.7 [2] and the results of our modeling spanned a similar range, with ORI values that scaled with the percentage of GO stimuli present in the input. Also like goggle-reared neurons, our model neurons exhibit; a lower proportion of oriented-localized neural RFs relative to normally-reared kittens; narrower tuning widths for RFs at GO (characterized by the full width half max (FWHM) of the tuning curve; and larger and more elongated shape of RFs at GO ([2]; and Tanaka personal communication).

Figure: Sample of model (a) and experiment (b; reprinted from [2]) results showing an orientation histogram and average FWHM values (white lines) as a function of preferred orientation. Experimental FWHM is overlaid on a 2D plot of all imaged pixels, color-coded for preferred orientation.

References: