The tilt illusion, population decoding, and natural scene statistics

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Context exerts a dramatic influence on neural processing and sensory experience. Perceptually, the presence of contextual information at a given point can elicit striking misjudgements of local features, such as orientation and motion. This is manifest in illusions and aftereffects, which have been a topic of intensive study for decades. Perceptual illusions are most puzzling when contexts induce distortions that appear inconsistent with their statistically normative implications, as their functional role then is quite mysterious.

Here we focus on one of the best studied contextual effects, namely the influence of spatial surround on local orientation misjudgements, i.e., the tilt illusion. We build computational models that treat populations of orientation-tuned neurons in primary visual cortex in statistical terms, and link the outputs of such populations with the perceptual phenomena they appear to underpin.

Specifically, we consider neural-level models of divisive gain control. This idea has a rich mechanistic and functional pedigree. We formulate a generative version of divisive gain control as part of a well-found model of natural image statistics (so-called Gaussian Scale Mixture Models). We then ask how this model leads to changes in tuning curves, and consequently, through population decoding, to misjudgements in the tilt illusion.

Previous work has shown that in natural scenes, filters with similar orientation preferences that represent nearby locations in the image have strong statistical dependencies, and so are, correctly, members of the same divisive gain control pool. We demonstrate that through population decoding, this contextual normalization leads to tilt repulsion. However, an interesting consequence of contextual effects, as in the tilt illusion, is that the nature of the misjudgements can be either repulsive or attractive, depending on factors such as the relative angle between the center target and surrounding context stimuli. Although the repulsive effect has been most widely modeled, the (weaker but consistently present) attractive effect is also diagnostic of the system behavior. We formulate a variant of the model that obtains both attraction and repulsion. The modified model assumes a more sophisticated scheme, in which the target and spatial context filters have a probability of belonging to the same gain control pool.

Although tilt and spatial context is a particularly convenient example for which there are many diverse data, most of the underlying issues extend to other visual attributes and contextual phenomena.

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