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Optimal processing and the statistics of visual input signals

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Sensory information processing can be seen as a statistical estimation problem, where relevant features are extracted from a raw stream of sensory input containing an imperfect representation of those features. Broadly speaking, the optimal solution to the feature extraction problem depends on the statistical structure of those input signals. Here we study the statistics of natural visual input signals, and the optimal solution to the problem of visual motion detection. Motion detection is a biologically important feature estimation problem, as many animals use vision to estimate their motion through space. Many years ago, Reichardt and Poggio drew attention to two important aspects of this problem: First, computing motion from an array of photosensors is an irreducibly nonlinear operation, and second, biological versions of this operation seem mathematically tractable. To paraphrase, the problem is interesting but not hopelessly complicated. In this spirit I will discuss motion estimation in the visual system of the blowfly, with an emphasis on performance under natural conditions. As noted above, the array of photoreceptors in the retina implicitly contains data on self motion, but this relation is noisy, indirect and ambiguous due to photon shot noise and optical blurring, and also as a result of the structure of the natural environment. Further, natural variations in the visual signal to noise ratio are enormous, and nonlinear operations are especially susceptible to noise. One can therefore reasonably hope that animals have evolved interesting optimization strategies to deal with large variations in signal quality. I will present experimental data, both from sampling natural probability distributions, and from motion sensitive neurons in the fly brain, that illustrate some of these solutions and that suggest that the fly indeed approaches optimality. The implications of these findings and their possible generalizations will be discussed.