Contrast Statistics for Foveated Visual Systems: Contrast Constancy and Fixation Selection

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The human visual system combines of wide field of view with a high resolution fovea and uses high speed ballistic eye movements to direct the fovea to potentially relevant locations in the visual scene. This strategy is sensible for a visual system with limited neural resources. However, for this strategy to be effective, the visual system needs to employ sophisticated central mechanisms that exploit the varying spatial resolution of the retina. To gain insight into some of the design requirements of these central mechanisms, we have analyzed the effects of variable spatial resolution on local RMS contrast in 300 calibrated natural images. Specifically, for each retinal eccentricity ε (which produces a certain effective level of blur), and for each value of local RMS contrast c observed at that eccentricity, we measured the probability distribution of the local RMS contrast in the unblurred image. These conditional probability distributions can be regarded as posterior probability distributions for the "true" (unblurred) contrast, given an observed contrast at a given eccentricity. We find that the mode of the posterior probability distribution of the unblurred contrast (i.e., the MAP estimate c_{est}) is given by $c_{est} = kc\varepsilon + c$, the standard deviation by $\sigma = kc\varepsilon + \sigma_0$, and the differential entropy by $h = 0.5\log_2[2\pi e(kc\varepsilon + \sigma_0)^2]$, where k and σ_0 are constants. The formula for the MAP estimate of contrast suggests a simple rule the visual system could exploit to achieve approximate contrast constancy across eccentricity. Our results also suggest a potentially efficient algorithm/model for selecting fixation locations when the goal is to encode images as well as possible (maximally reduce uncertainty) with just a few fixations. We find that the algorithm works very well at reducing total contrast uncertainty, and also works well at reducing the mean squared error between the original image and the image reconstructed from the multiple fixations.

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