Natural scene statistics relate to perceptual salience of second-, third-, and fourth-order spatial correlations

Ann M. Hermundstad[1*], John Briguglio[1*], Mary M. Conte[2], Jonathan D. Victor[2=], Gašper Tkačik[3=], Vijay Balasubramanian[1=]

[1]Department of Physics and Astronomy, University of Pennsylvania; [2] Weill Cornell Medical College; [3]Institute of Science and Technology Austria, [*,=]Equal Contributions

ABSTRACT

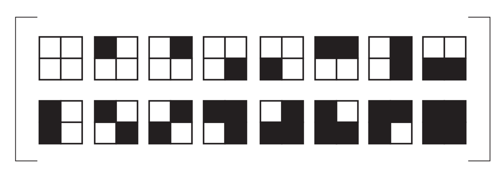
The statistical regularities of natural signals provide insight into characteristics of early visual processing (e.g. the center-surround receptive fields of retinal ganglion cells). Can the match between natural signal statistics and neural processing mechanisms be extended beyond the sensory periphery?

Recent work, which revealed that human sensitivity to isodipole synthetic textures is closely related to the structure of fourth-order spatial correlations in natural scenes [1], leads us to propose the following organizing principle:

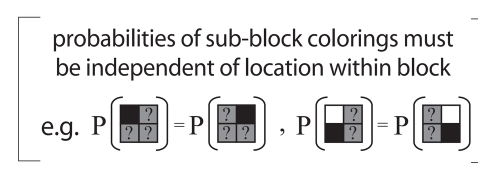
The perceptual salience of visual textures increases with the variance, or unpredictability, of the corresponding correlations over the ensemble of natural scenes.

BINARY TEXTURE SPACE

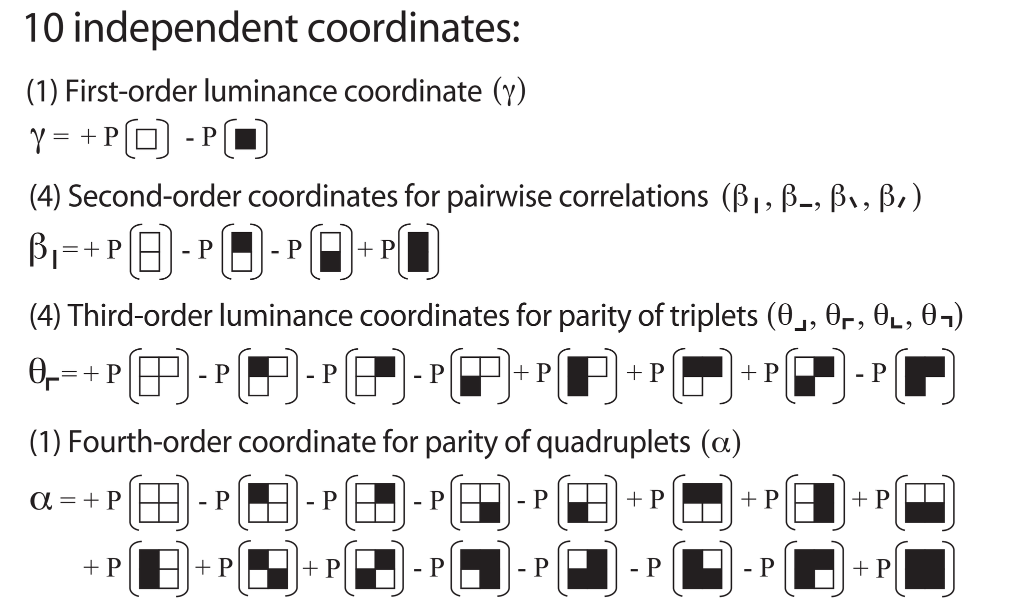
16 binary colorings



6 independent constraints

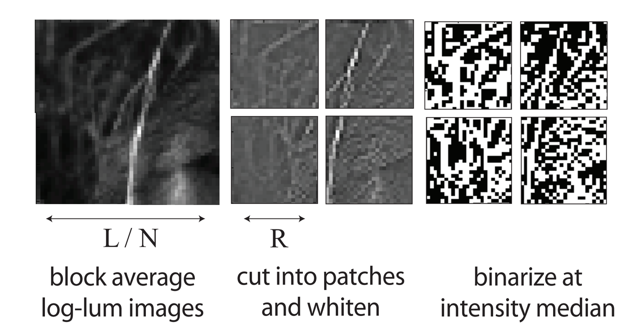


10 independent coordinates:

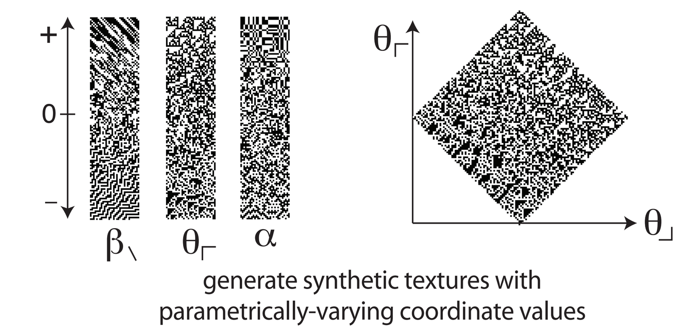


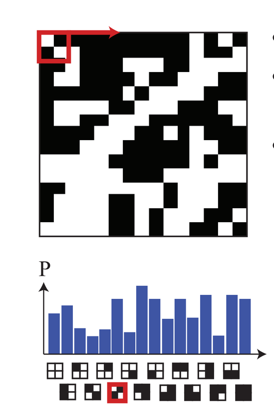
ANALYSIS METHODS

Natural Image Analysis



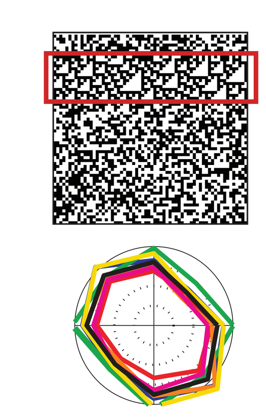
Human Psychophysics [2]





- collect histogram of colorings
- compute coordinate values β, θ, α
- measure coordinate variances across ensemble of patches

[note that mean luminance is subtracted out, leaving 9 coordinates for comparison with psychophysics]



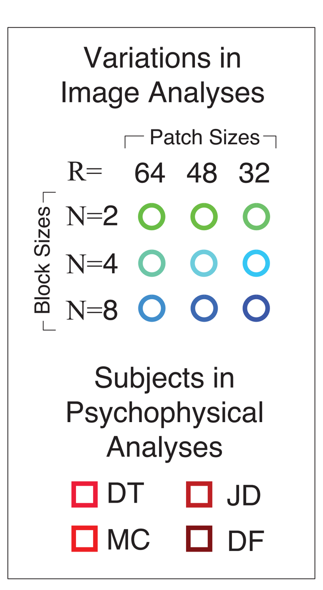
- brief (120ms) stimulus presentation: structured target/noisy background or noisy target/structured background
- detect target location (top, bottom left, right)
- measure sensitivity across variations in coordinates

[measure 15 coordinate planes in 4 subjects, 4320 judgements per plane, 64800 judgements per subject]

GENERAL APPROACH

We compare the following between natural image and psychophysical data:

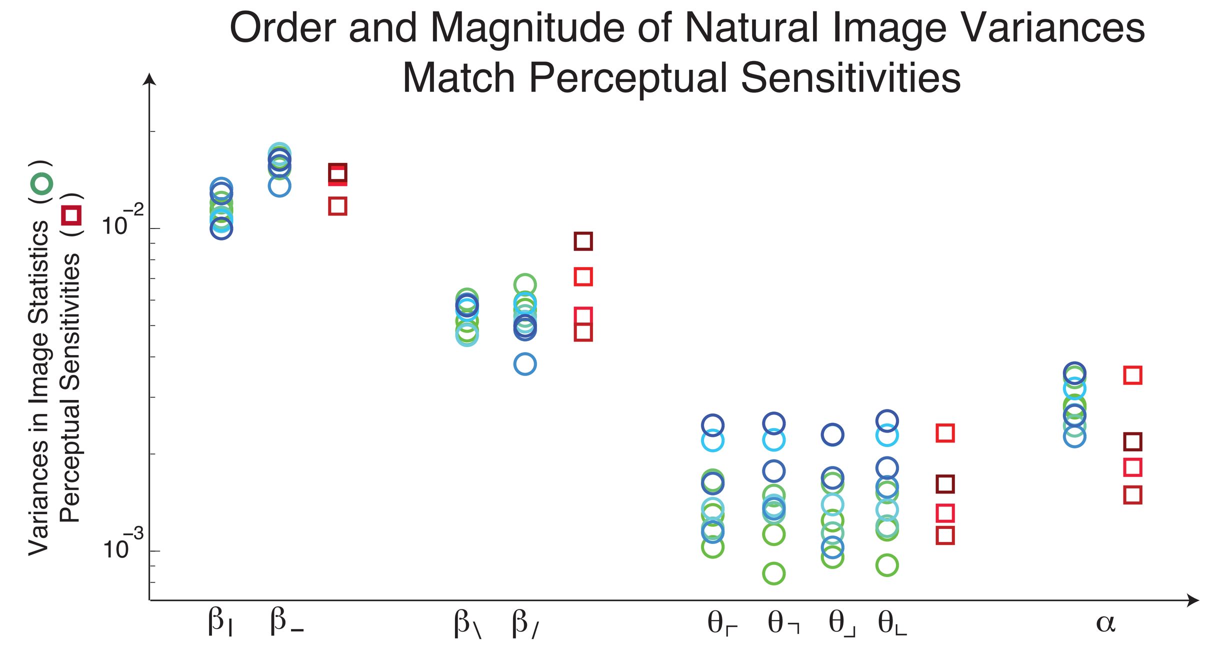
- Single statistics (upper right): Variances in image statistics versus perceptual sensitivities
- Pairwise statistic planes (lower left): inverse covariances in image statistics versus perceptual thresholds
- Full 9D space of statistics (lower right): principal components of image statistic variances versus principal components inferred from psychophysical isodiscrimination contours



Note that there is an overall scale difference between image and psychophysical analyses. Each image analysis was rescaled by a single factor chosen to minimize the least squared error (summed over all 9 statistics) between image variances and perceptual sensitivities.

SINGLE STATISTICS

Order and Magnitude of Natural Image Variances Match Perceptual Sensitivities



CONCLUSIONS

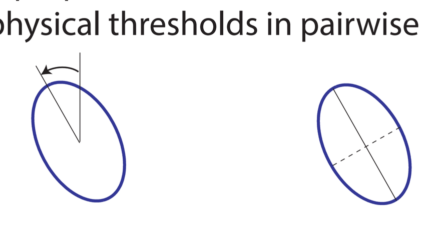
Variances in natural image statistics match perceptual sensitivities:

- Order and magnitude of variances match order and magnitude of perceptual sensitivities
- Features of 9D space of covariances (including pairwise plane projections and principal components) match the features of 9D space of sensitivities

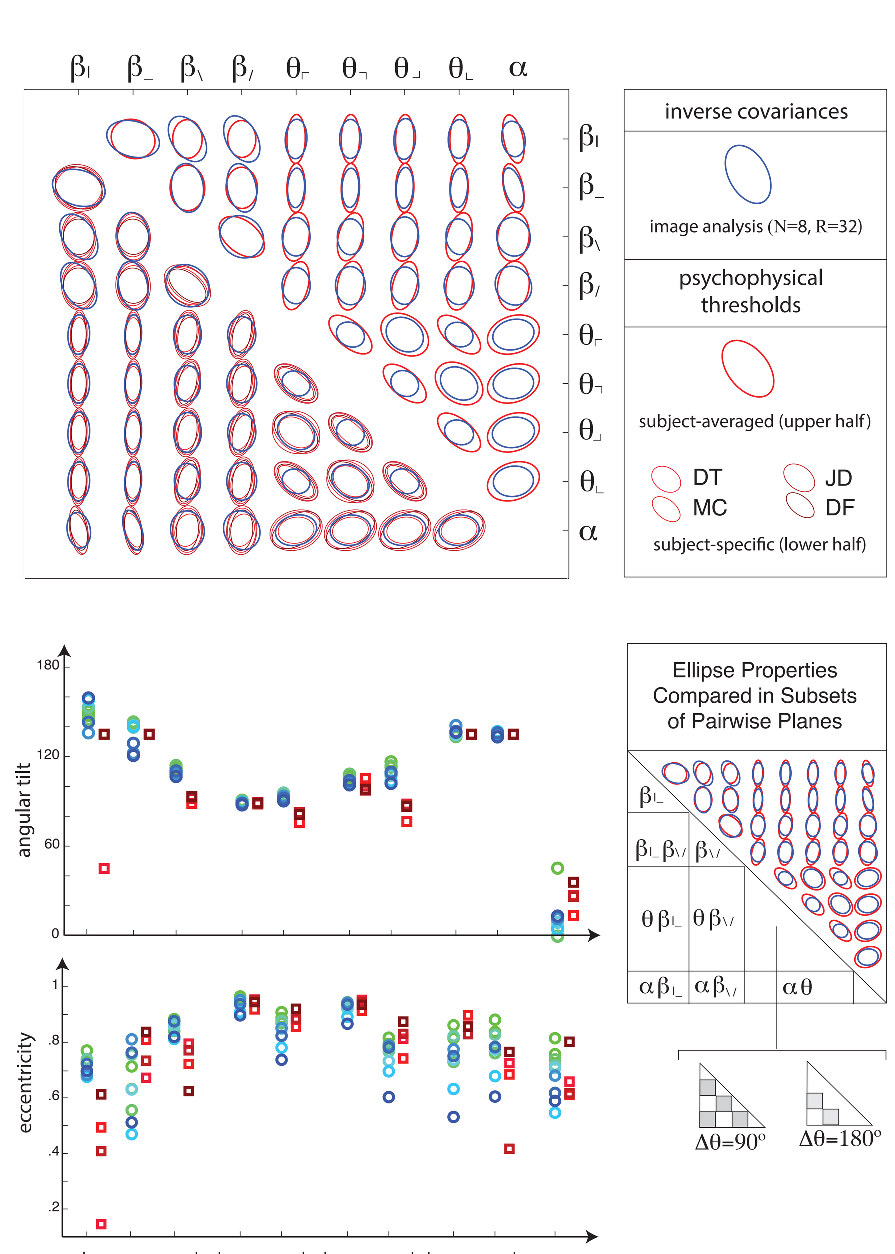
These results suggest that central neural mechanisms are efficiently tuned to higher-order statistics of natural scenes.

PAIRS OF STATISTICS

compare properties of inverse covariance ellipses and psychophysical thresholds in pairwise statistic planes

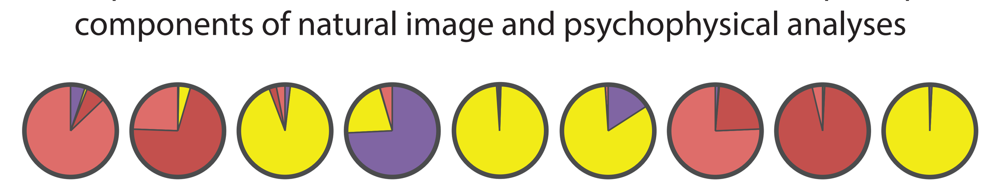


Inverse Pair Covariances in Image Statstics Match Perceptual Thresholds

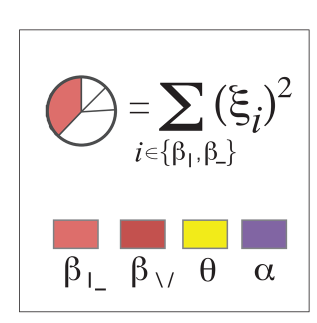


FULL 9D SPACE OF STATISTICS

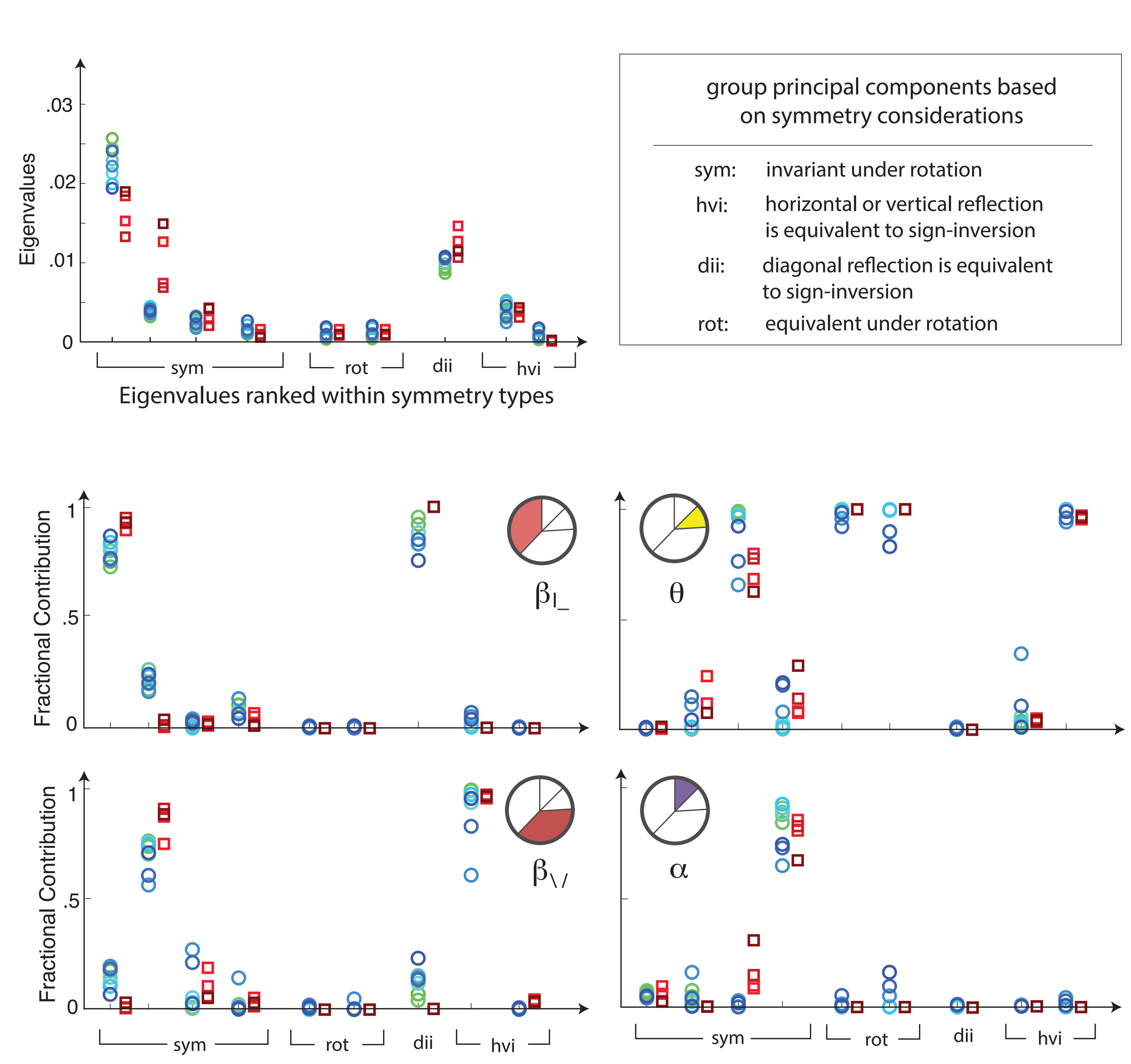
compare relative contributions of different statistics to principal components of natural image and psychophysical analyses



fractional contribution of statistics to principal components ξ [N=8, R=32]



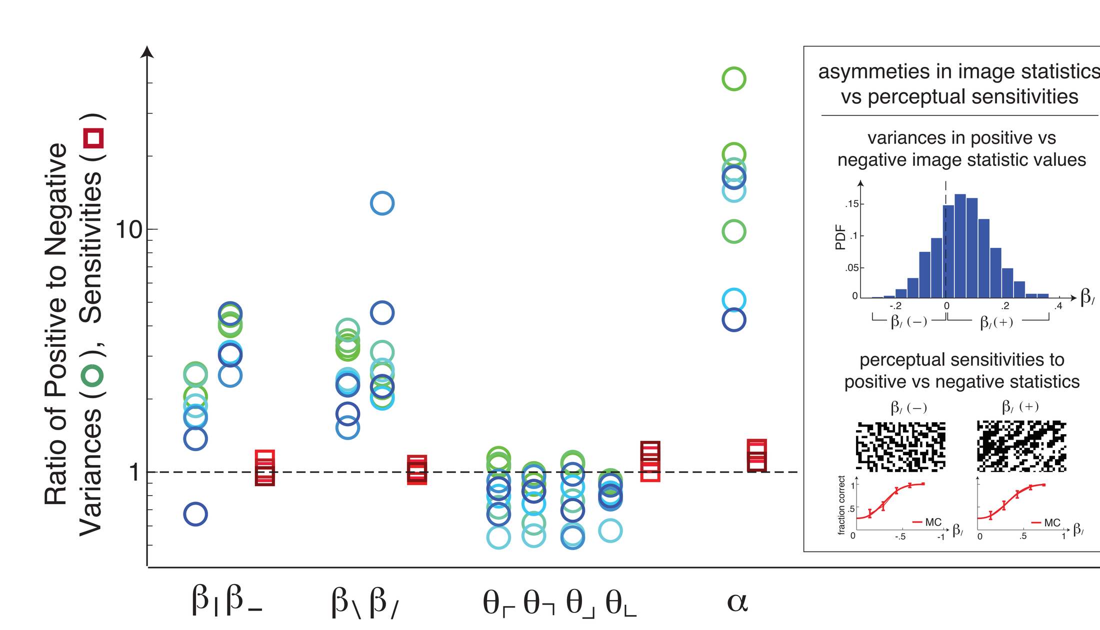
Principal Components of Image Statistics Match Principal Components Inferred from Psychophysical Isodiscrimination Contours



FURTHER QUESTIONS

Systematic differences (mostly small) between natural image statistics and perceptual sensitivities:

- Natural images show systematic asymmetries in β| versus β_ variances (upper left)
- Natural images deviate in third-order covariance plane projections (lower left)
- Natural images show asymmetries in the variances of positive versus negative image statistics, but psychophysical sensitivity does not mirror this:



ACKNOWLEDGEMENTS

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[1] Tkacik G, Prentice JS, Victor JD and Balasubramanian, V (2010), PNAS,107(42):18149-18154.
[2] Victor JD, Conte MM, Local image statistics (2012), J. Opt. Soc. Am. A, 29:1313-1345.