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ISODISCRIMINATION CONTOURS IN A THREE-PARAMETER TEXTURE SPACE

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http://www-users.med.cornell.edu/~jdvicto/vps.html

INTRODUCTION

Image statistics are often classified as first-order (e.g., luminance histogram), second-order (e.g., contrast, autocorrelation, power spectrum) and high-order (e.g., fourth-order isodipole). Many studies of visual texture processing have considered texture discrimination based on one kind of image statistic, but few have examined how these statistics interact. We recently (VSS 2005) described a framework for study of visual textures that combines luminance histogram and spatial statistics across orders, based on maximum-entropy extension (Zhu et al., 1998) of statistics defined on small blocks. When applied to statistics of binary 2x2 blocks, this approach yields a three-dimensional space of textures, in which mean luminance (γ), third-order spatial correlations (θ), and fourth-order spatial correlations (α) can be independently manipulated, and second-order correlations are absent.

For the ideal observer, isodiscrimination contours around the origin of this space are circular. We measure human performance two ways: in a forced-choice texture segregation paradigm with brief exposures, and in a continuous-response, minimally-distinct border paradigm with free viewing. Results are concordant and show that isodiscrimination contours have several deviations from circularity. Elongation of the isodiscrimination contours into ellipses indicates intrinsic differences in the efficiency of processing statistics of various orders, and tilting or distortion of the ellipses indicates interactions between them.

METHODS

TASK: Identify the location of the target stripe (4-AFC, top, right, bottom, left)

SUBJECTS:
N=5, VA corrected to 20/20
Practice: 2 - 3 hrs

STIMULI:
Size: 11.6 deg square, viewed binocularly at 57 cm
Contrast 1.0, Luminance 50 cd/m², Duration 120 ms
Monitor: Sony GDM F520 at 100 Hz, driven by VSG 2/5

CONDITIONS:

In the (γ,α)-plane: 8 repeats of 20 on-axis points, 16 repeats of 8 diagonal points

In the (γ,θ)- and (θ,α)-planes: 8 repeats of 12 on-axis points, 8 repeats of 24 oblique points

288 trials per block, condition order randomized
15 blocks per plane per subject
(12960 = 4320 x 3 trials per subject)

Feedback on error during practice only

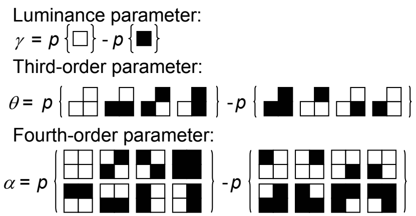
STIMULUS EXAMPLES

RED: structured target on random background

BLUE: random target on structured background

(γ,α) = (0.125, 0.583)

PARAMETER SPACE



Specification of the textures is completed by requiring that they are maximum entropy, subject to the constraints specified by the parameters γ, θ, and α. Such maximum-entropy textures may be constructed by a two-dimensional Markov process, provided that γ, θ, and α are within a 3-dimensional domain, illustrated to the right. In the coordinate planes, the equations that bound the domain are:
$\gamma^4-(1-|\gamma|)^4 \le \alpha \le \gamma^4+(1-|\gamma|)^4$, $|\alpha|+|\theta|\le 1$, $|\theta+3\gamma|\le 1+3\gamma^2$, and $|\theta-\gamma|\le 1-\gamma^2$.

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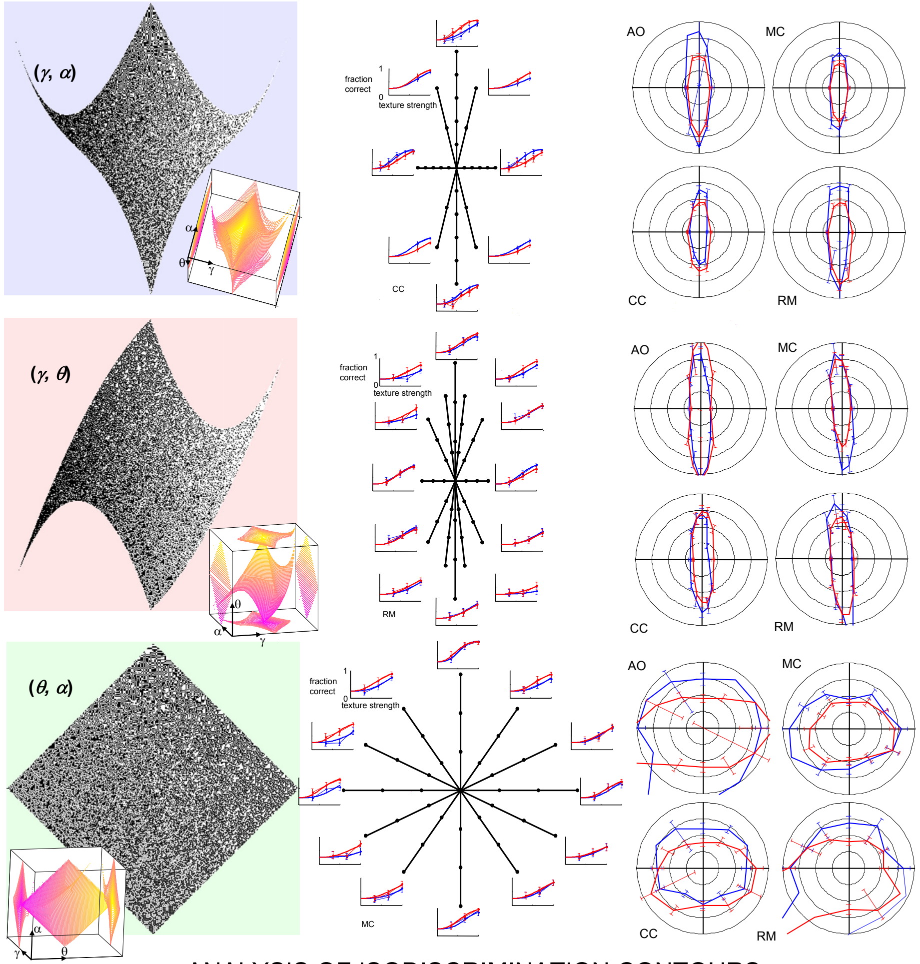
Victor, J.D., Chubb, C., and Conte, M.M. (2005) Interaction of luminance and higher-order statistics in texture discrimination. Vision Research 45, 311-325.

Zhu, S. C., Wu, Y. & Mumford, D. (1998). Filters, random fields and maximum entropy (FRAME): Towards a unified theory for texture modeling. International Journal of Computer Vision 27, 107-126

RESULTS: TEXTURE SEGREGATION

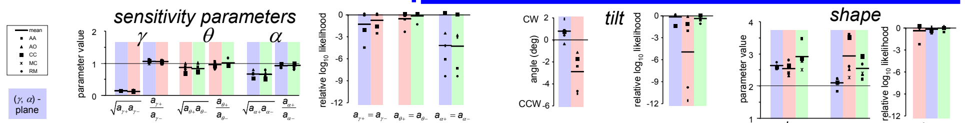


ANALYSIS OF ISODISCRIMINATION CONTOURS

Psychophysical performance was fit by a Weibull function along each direction in texture space. Isodiscrimination contours were determined by reading off the Weibull function halfway between chance and ceiling. Initially, we used a Minkowski rule to fit how sensitivity in the oblique directions depended on sensitivity in the cardinal directions. For example, in the (γ, α)-plane, the observed fraction correct data $p_{obs}(\gamma, \alpha)$ were fit to:

$$p_{model}(\gamma,\alpha) = 1-\frac{3}{4}\exp\left(-\left(\left|\gamma/a_\gamma\right|^m+\left|\alpha/a_\alpha\right|^m\right)^{\frac{b}{m}}\right)$$

This model predicts that isodiscrimination contours are symmetric about the origin, and their axes are parallel to the coordinate axes. However, we found consistent deviations from this prediction, and therefore used a more general model in which (i) the Weibull threshold parameters, a_γ a_θ, and a_α could depend on the signs of the projections onto the coordinate axes, and (ii) the axes of the isodiscrimination contours could be tilted with respect to the coordinate axes.



Thresholds are lowest for γ, highest for θ, and intermediate for α, in ratio approximating 1:5:4. Sensitivities along positive and negative directions are asymmetric for γ and α but not θ. This asymmetry is highly significant: forcing symmetry results in a 10-fold decrease (γ) or a 10^4-fold decrease (α) in the likelihood of the fit. These findings do not depend on the plane in which the measurement is made. In the (θ,α)-plane, discrimination contours are elongated into the (θ<0, α<0)-quadrant.

Isodiscrimination contours were tilted with respect to the cardinal axes by about 3 deg in the (γ,θ)-plane. Eliminating tilt decreased the likelihood of the fit by 10^5. One subject showed a tilt in the (γ,α)-plane. Tilt is not meaningful in the (γ,θ)-plane, since contours are close to circular.

Isodiscrimination contours were slightly more squared-off than ellipses (m>2). Contours were consistent with probability summation (forcing $b=m$ did not change the likelihood of the fit significantly).

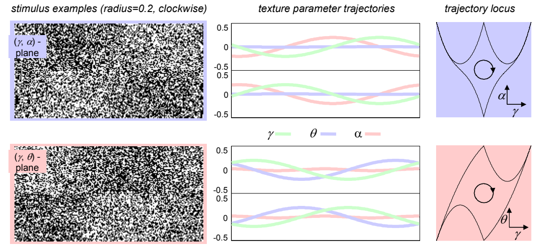
SUMMARY

- Texture discrimination can be reliably measured in a principled 3-parameter space, and performance characteristics are strikingly similar across N=5 normal subjects.
- In each direction of this texture space, psychometric functions have similar shapes, well-fit by a Weibull function with shape parameter *b* of approximately 2.5.
- Thresholds for first-, third, and fourth-order statistics (γ, θ, α) are in approximate ratio 1:5:4.
- Thresholds are asymmetric along the first- and fourth-order axes: lower for dark than light ($a_{\gamma-}<a_{\gamma+}$) and lower for even than odd ($a_{\alpha+}<a_{\alpha-}$).
- First- and third-order statistics interact, as manifest by a tilt of the isodiscrimination contours in the (γ, θ)-plane. Thresholds are lowest when first- and third-order statistics have the same sign. The direction of tilt is consistent with the "blackshot" (Chubb et al., 2004) mechanism.
- In the (θ,α)-plane, discrimination contours are elongated into the (θ<0, α<0)-quadrant, implying an interaction between the extraction of these statistics.
- A minimally-distinct-border paradigm rapidly identifies the long axis of the isodiscrimination contour.

MINIMALLY DISTINCT BORDER PARADIGM

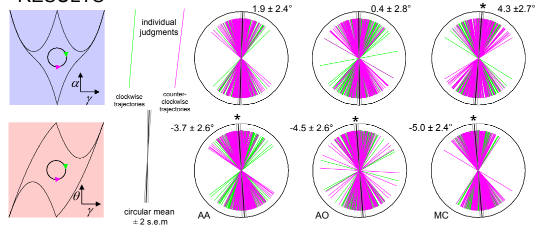
STIMULI: Bipartite field. In each field, texture parameters follow a circular trajectory in the (γ, α)- or (γ,θ)-plane . Textures parameters are in antiphase across the partition.

TASK: Identify the horizontal location of the least distinct border between the upper and lower halves of the display. Indicate this location with the mouse pointer.



CONDITIONS: Free binocular viewing without time limit, new stimulus every 4 sec until decision. 8 blocks of 180 trials, (γ, α) and (γ,θ), clockwise vs. counterclockwise, and 3 radii (0.1, 0.2, 0.25) randomly intermixed.

RESULTS



For all subjects, the minimally-distinct direction in the (γ,θ)-plane was tilted counterclockwise, as in the segmentation experiment. MC, who showed the largest clockwise tilt in the (γ,α)-plane in the segmentation experiments, also showed a significant clockwise tilt in this paradigm.