Simple combination rules for sensitivities to image statistics

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Motivation

Segmenting natural images into objects and characterizing their surface properties depends on visual processing of image statistics. However, analyzing the underlying computations is hindered by the interdependencies of these statistics and their high dimensionality. To address these issues, we previously studied a dimensionally-reduced stimulus domain: a 10-dimensional space of black-and-white textures in which contrast, edge, and corner could be varied independently. We found that (a) first-, second-, third- and fourth-order image statistics were visually salient, (b) sensitivity to positive and negative variations of a statistic were similar, and (c) a simple combination rule governed how image statistics combine.

Here we ask whether these results apply to images with multiple gray levels.

Stimulus Domain

The stimulus domain is parameterized by the probabilities of all configurations of black, gray, and white checks in 2x2 patches. For ternary textures, there are 66 dimensions (2 first-order, 16 second-order, 32 third-order, and 16 fourth-order). We study a subset of these dimensions.

To parameterize the domain, the four checks in a 2x2 patch are designated A, B, C, and D. The parameters AB_{XY}, for example, describe how the luminance values L(A) and L(B) are correlated. Specifically, the parameter AB_{XY} indicates the distribution of values of q=X*L(A)+Y*L(B) (mod 3), where black = 0, gray = 1, and white = 2.

Each parameter spans a triangular gamut (right) that specifies the distribution of q. The vertices are the textures for which q is maximally biased, i.e., always 0, always 1, or always 2. The centroid is the random texture, where q is equally likely to be 0, 1, or 2.

Methods

SUBJECTS
5 subjects
VA: 20/20

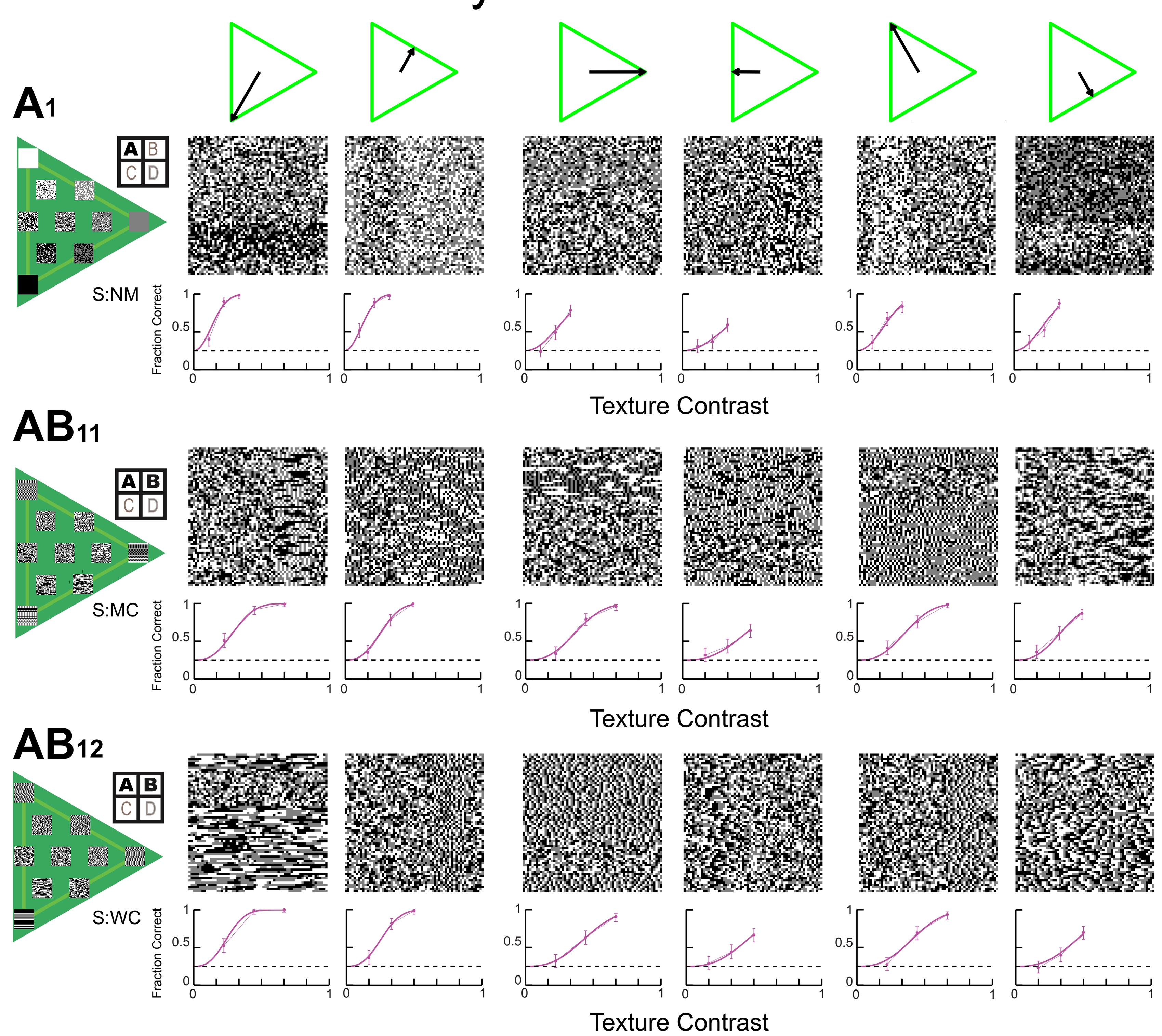
CONDITIONS
4-AFC design
288 trials per block
4-15 blocks per condition
4,320 trials per plane
224,640 total trials

STIMULI
Contrast: 1.0
Check size: 14 min
Display size: 14.8 deg^2
Binocular viewing at 1m
Duration: 120 ms, followed by a 300 ms mask
Target: 16 x 64 pixels on a 64 x 64 array

Practice: approx. 50 trials per condition
Feedback during practice only

Support: EY7977

Results: Psychometric Functions



Fraction correct in the first-order plane (A_1) and two second-order planes (AB_{11}, AB_{12}) for subjects NM, MC, and WC. In each plane, 6 directions are shown (the directions towards and away from each vertex, as indicated by the arrows). The maximum on the abscissa is a texture contrast of 1: the distance from the random texture to a texture of maximum structure.

Stimulus examples are shown above each curve. Error bars are 95% confidence limits. Smooth curves are fits to Weibull functions, and the texture contrast yielding a fraction correct of 0.625 was taken as threshold. Note that performance is similar for positive variations of an image statistic (towards a vertex) and negative variations (away from a vertex).

Conclusions

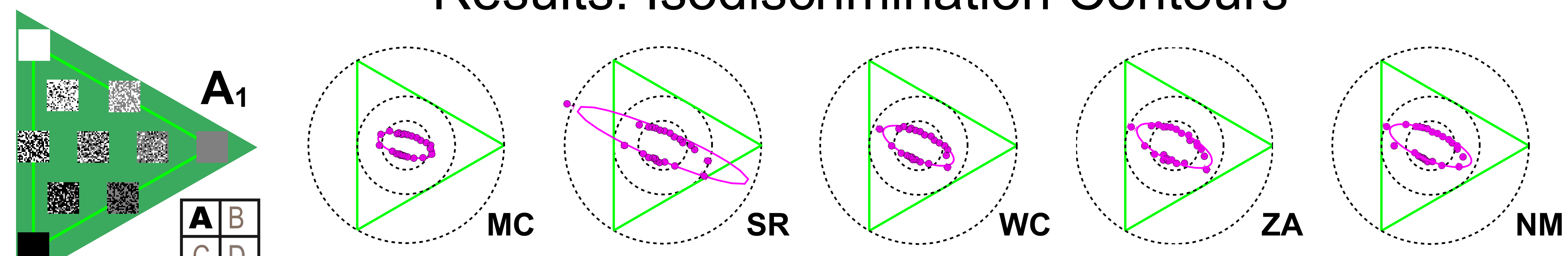
As in the binary (black-and-white) case,

- all first- and second-order statistics are visually salient
- sensitivities to positive and negative variations of an image statistic are nearly equal
- image statistics combine in an approximately quadratic fashion, yielding elliptical isodiscrimination contours

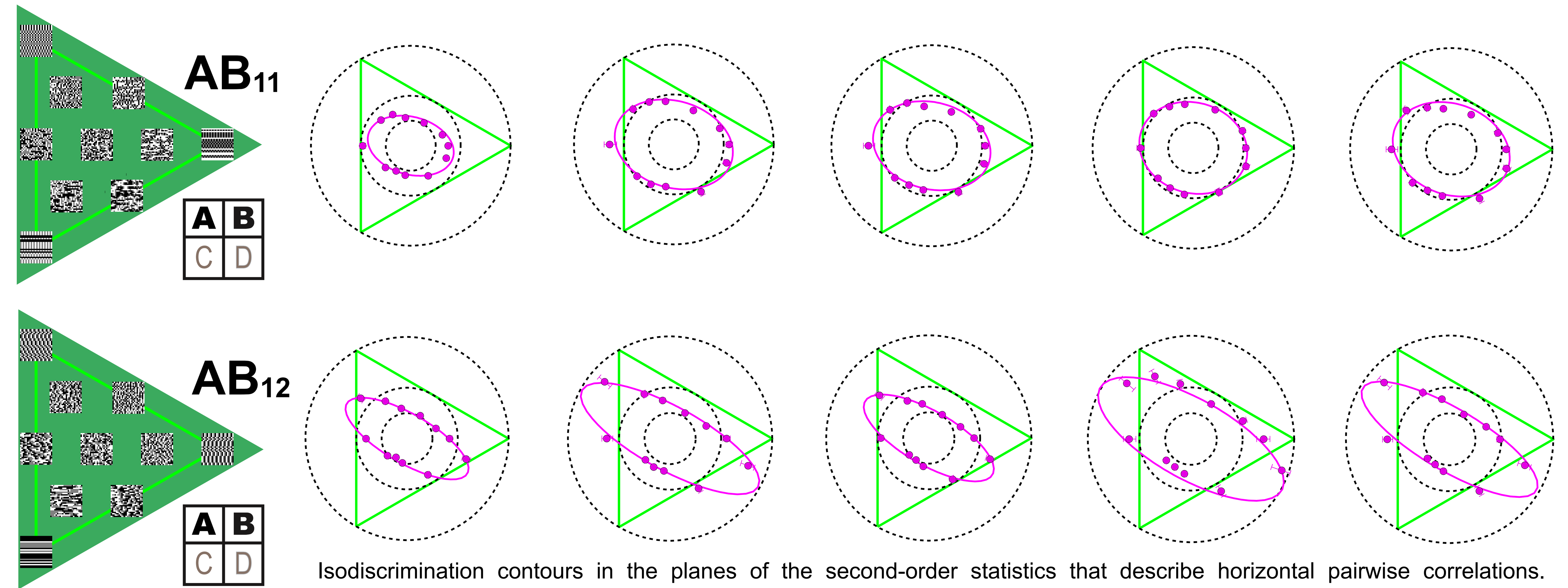
In contrast to the binary case,

- only some third- and fourth-order image statistics are visually salient

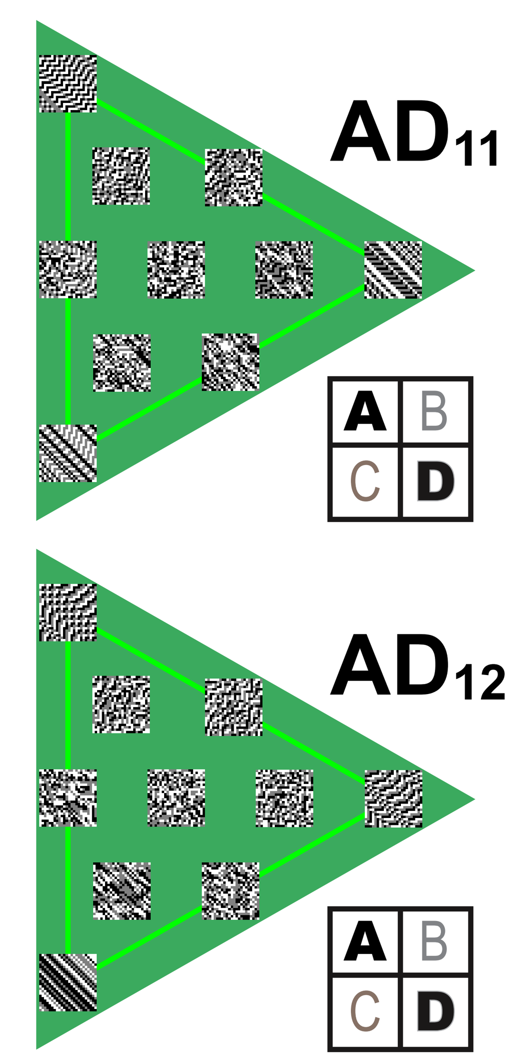
Results: Isodiscrimination Contours

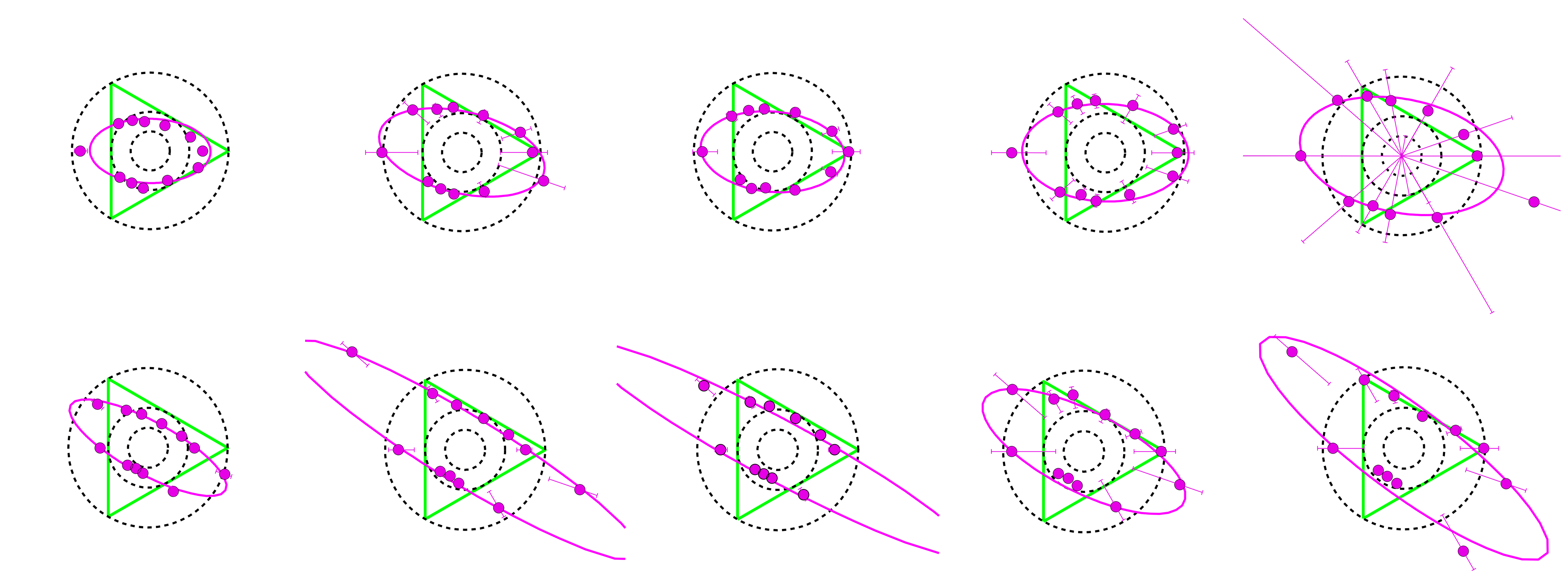


Isodiscrimination contours in the plane of the first-order statistic. The isodiscrimination contours are approximately elliptical and centered around the origin, indicating similar sensitivities for positive and negative deviations of the image statistics.

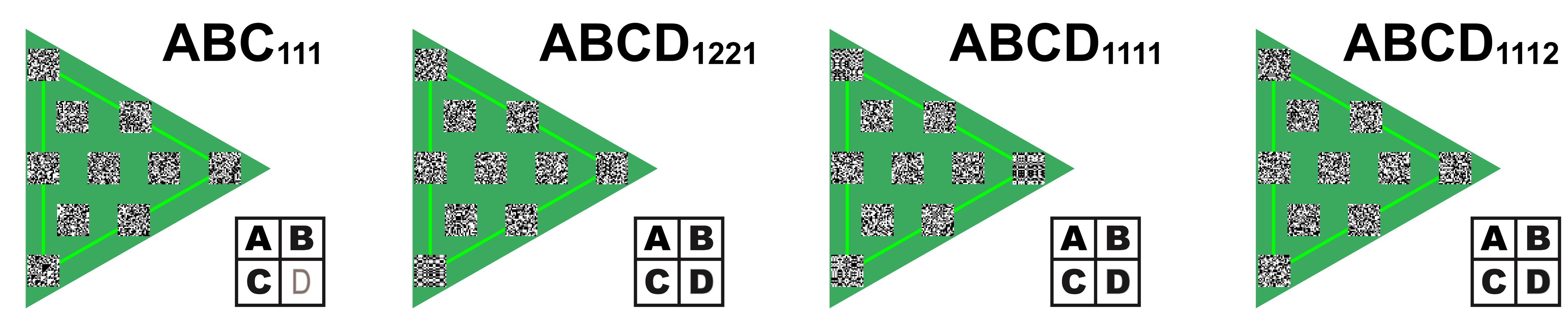


Isodiscrimination contours in the planes of the second-order statistics that describe horizontal pairwise correlations. Contours are approximately elliptical and centered around the origin. In the AB_{12}-plane, the ellipse is more eccentric than in the AB_{11}-plane, indicating a lower threshold for statistics that produce horizontal stripes.





Isodiscrimination contours in the planes of the second-order statistics that describe pairwise correlations in a diagonal direction. Contours are elliptical, but larger than in the horizontal second-order planes AB_{11} and AB_{12}. Note the difference in scale: the outer circle corresponds to the same texture contrast in all panels.



For third- and fourth-order statistics, segmentation thresholds were only measurable in directions that produced homogeneous patches: towards the lower left in the third-order plane ABC_{111} and the fourth-order plane $ABCD_{1221}$, and towards all three vertices in the fourth-order plane $ABCD_{1111}$.

In the $ABCD_{1112}$ plane, no directions reached threshold.