A THEORETICAL FRAMEWORK FOR TEXTURE PARAMETERIZATION

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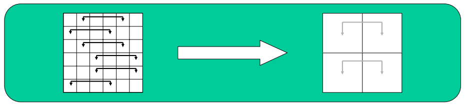
INTRODUCTION

Second-order and some higher-order image statistics support texture discrimination. However, a concise parameterization of the image statistics relevant to perception remains elusive. Here we suggest a minimal structure for the perceptual space of textures. The motivation for the present approach is that the visual system is likely to represent image statistics in a manner that is efficient, but perhaps not comprehensive.

A complete description of a generic texture requires specification of image statistics of all orders, and at all scales. We hypothesize that any texture is perceptually equivalent to a texture for which all statistics of all orders can be reconstructed from a small subset of image statistics. The maximum-entropy formalism (Zhu et al., 1998) is a natural way of performing this reconstruction, in a manner that adds the minimal amount of additional structure. For example, if pairwise correlations between pixels (A,B) and (B,C) are specified, maximum-entropy extension specifies the pairwise correlations (B,C) and the third-order correlations (A, B, C).

Maximum-entropy extension can always be carried out when only individual pixel statistics are specified. This leads to the "IID" (independent, identically-distributed) textures, studied extensively (Chubb et al. 1994, 2004).

Maximum-entropy extension can also be carried out when pixel-block statistics are specified for one-dimensional blocks. This leads to one-dimensional Markov textures (Julesz et al., 1973). Such textures are discriminable only when they contain second-order differences. Second-order correlations of distant pixels imply second-order correlations of adjacent "pixels" on a larger scale.



We hypothesize that two-dimensional statistics are visually salient only if they correspond to 2x2 block probabilities at some spatial scale. **Maximum-entropy extension of 2x2 blocks is possible only if the probabilities satisfy certain conditions (Pickard 1980):**

A	B
C	D

Conditional independence of B and C, given A, denoted B⊥C|A:
p(BC|A) = p(B|A)p(C|A)
Pickard's conditions:
{B⊥C|A *and* B⊥C|D} *or* {A⊥D|B *and* A⊥D|C}

The Pickard conditions result in a 7-parameter set of textures. Within this, a 3-parameter set (upper panel) has no second-order correlations. The middle panel shows the extreme textures within the full 7-parameter set. ***These textures all have salient visual structure. Conversely, the "2x2" hypothesis accounts (GLIDERS panel) for the lack of salience of other maximum-entropy textures.***

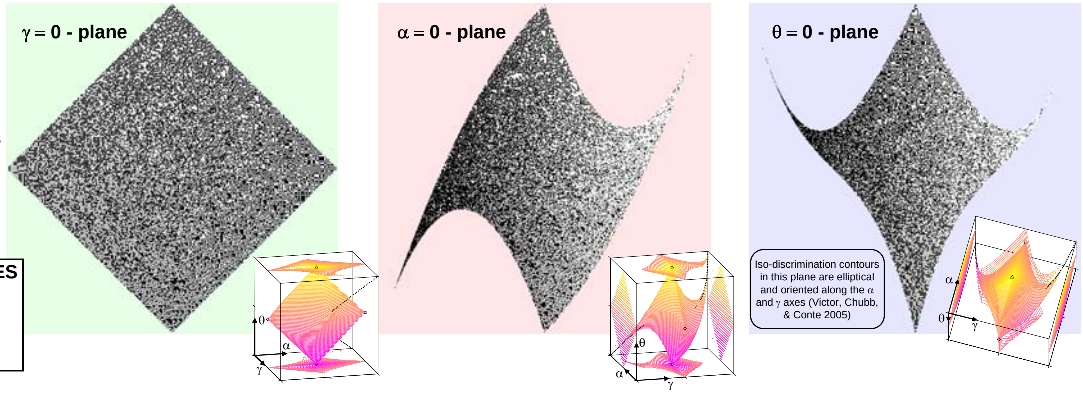
ISODIPOLE TEXTURES

There is only a three-parameter family of binary 2x2 block probabilities that (a) are compatible with maximum-entropy extension and (b) contain no second-order correlations. The parameters of this family are γ, the luminance bias; θ, the third-order bias, and α, the fourth-order bias. Only some triplets (γ, θ, α) can be realized.

VALUES OF (γ, θ, α) FOR SPECIAL CASES

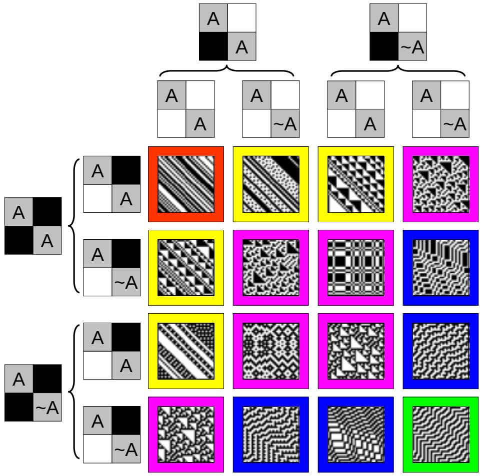
- Independent (IID): $(\gamma, \gamma^3, \gamma^4)$

△ white triangles: (0,1,0) ▽ black triangles: (0,-1,0)
□ even: (0,0,1) ◇ odd: (0,0,-1)



EXTREME TEXTURES

There are 16 extremes of the binary 2x2 block probabilities that allow for maximum-entropy extension. The textures that have zero second-order correlation (purple background) are extreme examples of the textures shown above. Textures with nonzero second-order correlations can be grouped into isodipole families (each background color), within which local second-order statistics are identical. Within each of these families, discrimination is strong.



THE RULES

A	B
C	D

The pair (B,C) can be colored in four ways. For each coloring of B and C, the rule specifies either D=A or D=~A. This yields 2^4=16 different rules. For each rule,

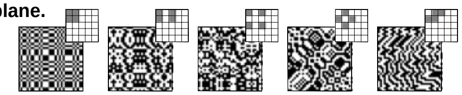
All 8 fillings of A B / C have probability 1/8.

All 8 fillings of B / C D have probability 1/8.

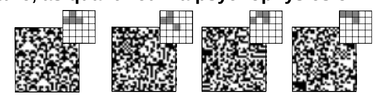
So the Pickard conditions are satisfied.

GLIDERS

Parity rules within a generic "glider" generate maximum-entropy textures (Gilbert, 1980). Only some gliders yield salient visual structure (Victor and Conte, 1991). These include the 2x2 block glider that defines the even texture and gliders that induce the same correlation structure at a different scale, or after linear transformation in the plane.



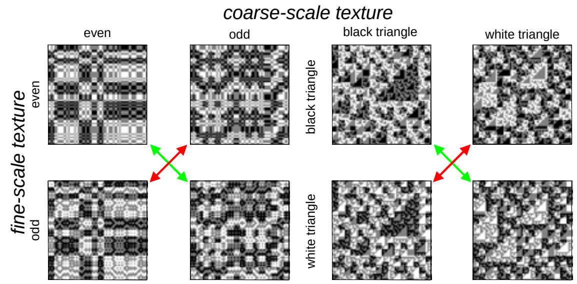
Four-element gliders that cannot be transformed to 2x2 blocks yield textures with at most minimal visual structure, as quantified via psychophysics or VEP's.



Textures are constructed by specifying one or more rows and columns, and completing the interior recursively so that the number of white squares within each glider template is even.

MIXING SCALES

The critical area for analysis of isodipole textures grows proportionally with check size (Victor & Conte, 1989). But is scale information lost? If so, a superposition of a coarse-scale even texture and a fine-scale odd texture should be indistinguishable from the superposition of a fine-scale even texture and a coarse-scale odd texture, and vice-versa (red arrows). But if scale information is preserved, these textures should be as distinguishable as the superposition of even textures at two scales, from the superposition of odd textures at two scales (green arrows). This demo suggests the latter.



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