Perceptual singularities in Smooth Orientation-Defined Textures
Segregation *without* feature gradient

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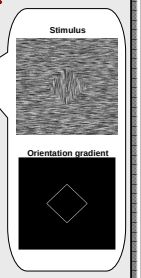
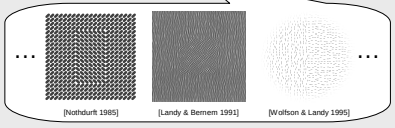
(i) Motivation and Background

Current state of affairs

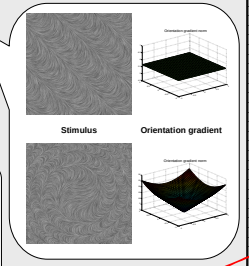
- A central notion in texture segregation is *feature gradient*.
- Existing results in orientation-based texture segregation (OBTS) link perceptual boundaries to orientation gradients: outstanding orientation gradients signal perceptual singularities and boundaries.
- Most OBTS research is based on piecewise-constant orientation-defined textures (ODTs).

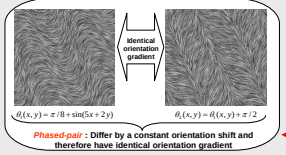




New observations: Perceptual singularities in smooth ODTs

- Smoothly varying ODTs almost always exhibit salient perceptual singularities.
- These perceptual singularities have no apparent relationship to the orientation gradient.
- Stimuli of identical orientation gradients can exhibit drastically different perceptual structure.



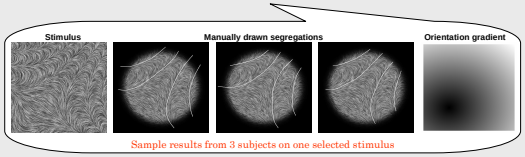


Research questions

- Are perceptual singularities without feature gradient significant visual events consistent across observers?
- Are perceptual singularities without feature gradient indeed dissociated from feature gradient?
- If orientation gradient is not the determinant factor, what theory would make correct predictions about the occurrence and spatial location of these perceptual singularities in smoothly varying ODTs?
- Would the derived model apply to classical cases of perceptual singularities due to feature gradients?
- What are the implications to theories of texture perception and segregation in general?

(ii) Experiment 1 - Free Viewing Segregations

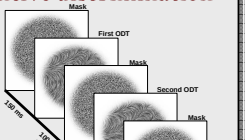
- *Stimuli*: 24 dense ODT stimuli (both piecewise-constant and smoothly varying), all intensity modulated as to create fading circular margins to minimize effect from image margins. Piecewise smooth ODTs were generated from random quadratic orientation functions.
- *Task*: tracing salient boundaries and curves. Free-viewing conditions with no time limit. Only piecewise-constant stimuli (i.e., no smoothly varying ones) were shown during instructions.
- 7 naïve subjects.
- Results compared qualitatively both for (i) between-subjects consistency and for (ii) correspondence with regions of high orientation gradients. All subjects traced multiple curves on the smoothly varying ODTs in a highly consistent manner and always independently of the orientation gradient.

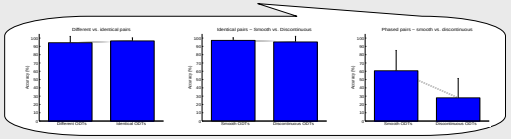


- A variation of this experiment with texel-based ODTs yielded the same results.

(iii) Experiment 2 - Preattentive discrimination

- *Stimuli*: 10 *phased pairs* with 90° phase shift
  - 7 smoothly varying pairs
  - 3 piecewise-constant pairs
- Each trial incorporated either
  - two identical ODTs
  - two different ODTs
  - two phased ODTs (*the critical trials*)
- 15 naïve subjects. 300 trials/exp.
- *Task*: 2AFC discrimination between the ODTs in the sequence.
- *Results*: while discrimination of different ODTs and identification of identical ODTs was equally accurate and nearly flawless (95%), regardless of stimulus type, discrimination accuracy for phased pairs was significantly better for smoothly-varying ODTs than piecewise-constant ones (32.□% difference, p<0.00005).





Conclusion: Salient structure and perceptual singularities in smoothly-varying ODTs are dissociated from the orientation gradient of the texture.

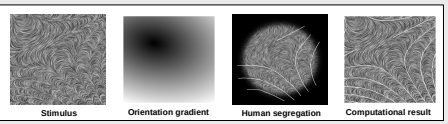
(iv) A novel saliency theory and a Perceptual Singularity Measure (PSM)

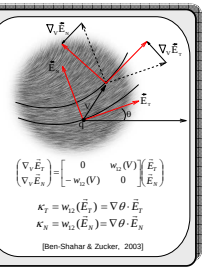
A different (differential) geometrical point of view

- A *moving (Frenet) frame* representation leads to two ODT curvatures, one *tangential* (κ_T) and one *normal* (κ_N). The pair $\{\kappa_T,\kappa_N\}$ fully generalizes and extends the orientation gradient..
- While neither curvature by itself predicts perceptual singularities and saliency in smoothly-varying ODTs, a measure combining them both does so very accurately [Ben-Shahar, 200□]:

$$PSM(x,y)=\prod_{\sqrt{\kappa_T^2+\kappa_N^2}>\tau}\left\{Ridges\left[\frac{\kappa_N(x,y)^2}{\kappa_T(x,y)^2+\kappa_N(x,y)^2}\right]\right\}$$

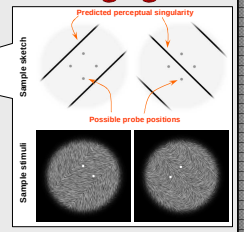
Rectification operator with perceptual threshold τ

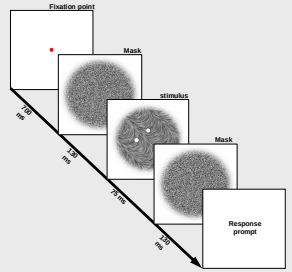




(v) Experiment 3 - Examination of proposed PSM via preattentive segregations

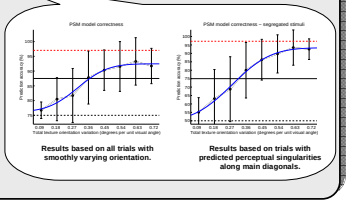
- *Stimuli*: Total of 72 stimuli with *predicted* straight singularities either along the image diagonal or offset from it
  - □4 smoothly-varying ODTs of the form $\theta(x,y)=\theta_0+g\cdot(x+d\cdot y)$ $\begin{cases}g\in\{\pm0.09,\pm0.18,\pm0.27,\pm0.36,\pm0.45,\pm0.54,\pm0.63,\pm0.72\}\\ d\in\{1,-1\}\\ \theta0\in\{\theta_{diag}(g,d),\theta_{offset}(g,d)\}\end{cases}$
  - 8 corresponding piecewise-constant pairs (control)
  - Two probes on two neighboring corners of a fixed diamond
- 10 naïve subjects. 57□ trials/exp.
- *Task*: Did the probes belong to the same perceptual segment or not?.





- *Results*: As soon as total orientation variation (g) exceeds some threshold ($\tau\approx20°$/visual angle), subjects' responses match the PSM-predicted perceptual singularities and become statistically indistinguishable from perceptual borders due to orientation discontinuities.

A byproduct of this experiment is the threshold value (τ) to be used in the computational PSM measure proposed theoretically.



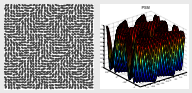
(vi) Summary

- Perceptual organization, saliency, and perceptual singularities in texture perception cannot be determined reliably from feature gradient: although outstanding feature gradient often do signal perceptual singularities, the lack of the former *does not* imply perceptual coherence.
- Salient structure and perceptual singularities in smoothly-varying ODTs are dissociated from the orientation gradient of the texture.
- Accurate localization of perceptual singularities in smoothly varying ODTs (extends to any ODT) emerges directly and solely from their curvature properties and can be modeled by the proposed PSM.

...and a solved mystery

The theory and results presented here also solve a decade long open question [Field, □ayes, and □ess 1993]: Why would there be perceptual inhomogeneities in line array textures with fixed orientation differences throughout?

The answer clearly relates to the perceptual singularities discussed here. The perceptual structure in [Field *etal* 1993] is accurately predicted by the presented theory!



Stimulus from [Field *et al* 1993] and corresponding PSM