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Task-dependent geometry of a perceptual space

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Motivation

There are two general approaches for defining the geometry of a perceptual space.

- One uses thresholds (just-noticeable differences) to infer distances.
- The other uses relative similarities to infer distances.

How do the results compare?

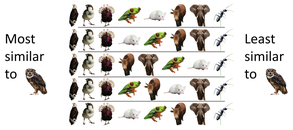
To address this question, we used a high-dimensional domain of visual textures with well-characterized psychophysical thresholds. We applied a new, efficient method for collecting and analyzing similarity judgments and compared the results.

Methods

Task: *Rank stimuli in order of their similarity to the central stimulus*

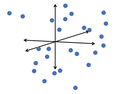
Previous work

Responses for a trial repeated 5 times

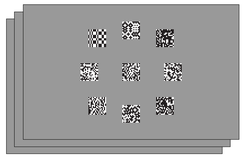


Observed choice probabilities

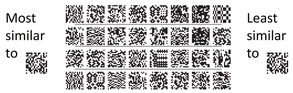
Geometric model of the perceptual space



Current study



Ranking responses, one for each trial



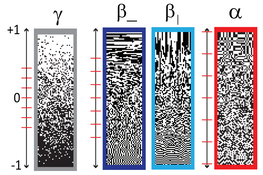
Observed, aggregated choice probabilities

Details

Subjects: 2F, 1M, VA: 20/20
Viewing Distance: 57 cm
Texture Size: 4 deg (16 x 16 checks)
Display: Dell monitor; 24 deg diam.; 1680 x 1050 pxls
3 conditions (25 stimuli per condition)
1000 trials (100 trials x 10 sessions) per condition
28,000 pairwise comparisons:
(1000 trials x 28 comparisons/trial) per condition
Data were fit to models of 1 to 7 dimensions

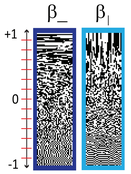
Results

We compared the geometry of the perceptual space inferred from threshold measurements, with the geometry inferred from experimentally-measured similarity judgments. As shown here, these differed substantially in several respects.

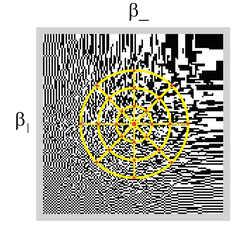


red tickmarks indicate stimulus values used in each experiment

When inferred from similarity judgments, sensitivities along the axes are approximately equalized, rather than the 4:2:1 ratio predicted by threshold experiments. Rays map to rays but axes are not orthogonal. Even along a single axis, positive and negative rays do not run in opposite directions.



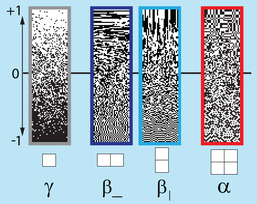
While there were major deviations from threshold predictions of the lengths and angles between coordinate axes, there was no evidence for range compression. Here, two coordinate axes (β_- , $\beta_|$) were explored in 6 equal steps. While the axes are not orthogonal, there is no evidence of range compression, in line with previous threshold psychophysics (Victor et al., 2017)



A city-block distance could also lead to distortions, but there was no evidence for this. Here, the coordinate plane spanned by β_- and $\beta_|$ was explored along 8 rays (4 directions). A city-block distance would predict that steps along the diagonals are perceived as longer than equally steps along the axes. Instead, we found equal lengths, consistent with the threshold psychophysics

Previous Work: Threshold Measurements

Texture Space Coordinates



First-order statistics (γ): fraction of black vs. white checks

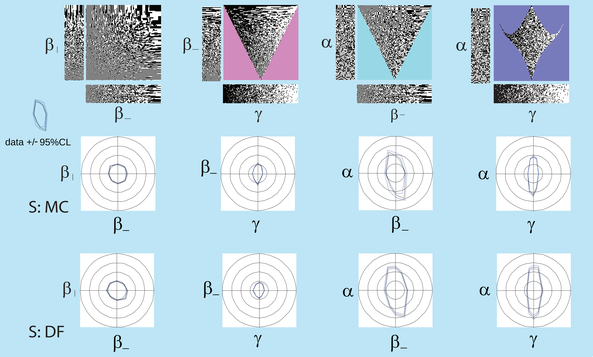
Second-order statistics (β): correlations between pairs of adjacent checks (here horizontal and vertical)

Fourth-order statistics (α): parity of checks in a 2x2 neighborhood

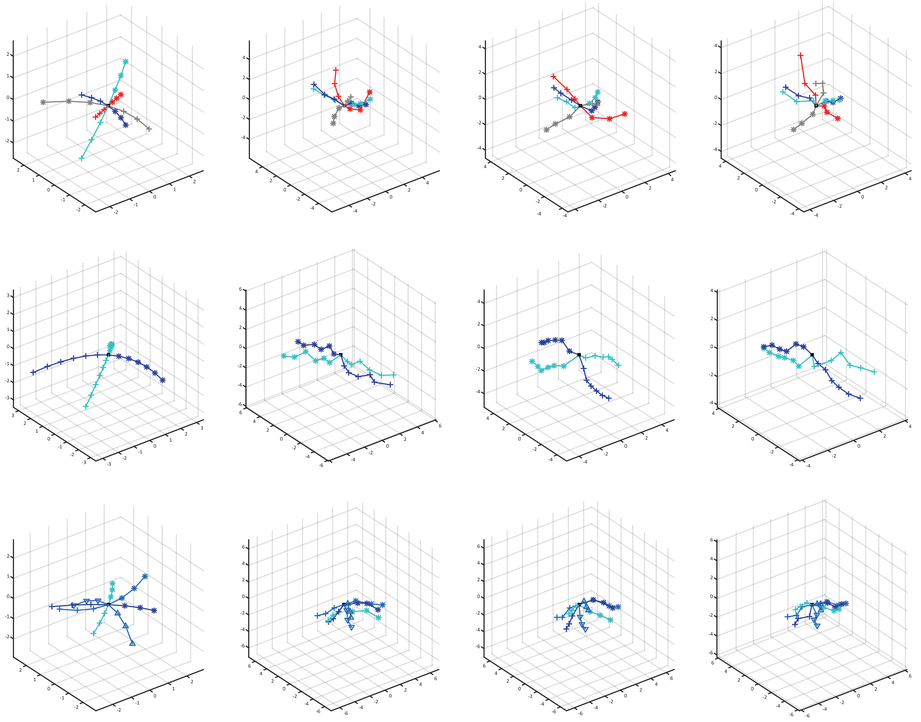
Thresholds for distinguishing structured and random textures in a segmentation task

Each plot explores a coordinate plane. Threshold contours are elliptical and the axes of the ellipses indicate relative sensitivities (4:2:1 for γ: β: α).

The orientations of the ellipses, approximately aligned with the texture coordinate axes, indicate that texture coordinate axes are approximately orthogonal. The elliptical shape indicates that subthreshold signals are combined in a Euclidean fashion.



Predictions



1 unit corresponds to d'=1 for judgments of dis-similarity.

Conclusions

While both approaches reveal an approximately Euclidean space, there were major differences in the inferred geometries.

Commonalities:

- Rays map to rays
- No range compression
- Coordinates combine in a Euclidean fashion

Differences:

- Lengths are not maintained
- Angles are not maintained

We speculate that similarity judgments are driven by representation of features at a more abstract level.

References

Victor, J. D., Thengone, D. J., Rizvi, S. M., and Conte, M. M. (2015) A perceptual space of local image statistics. Vision Research, 117, 117-135.

Victor, J.D., Rizvi, S.M., and Conte, M.M. (2017) Two representations of a high-dimensional perceptual space. Vision Research 137, 1-23.

Waraich, S.A., and Victor, J.D. (2022) A psychophysics paradigm for the collection and analysis of similarity judgments. J. Vis. Exp. (181), e63461, doi:10.3791/63461.

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