A Bayesian Model of Surface Fill-in using Edge Statistics

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Abstract
Retinal defects cause gaps in visual information that are perceptually filled in by the brain. We hypothesize that statistics of natural scenes guide this process. The simplest statistic, two-point correlation, fails to explain even some basic psychophysical evidence about fill-in, so we must turn to more complex statistics. We use the Dead Leaves model to analytically derive joint probability distributions of edges and surfaces. These statistics can be used to infer missing surface properties from a collection of edges. Finally, this model offers testable psychophysical predictions about the relationship between the size of an object and the influence it has on fill-in.

Introduction
Retinal defects cause holes in visual information, but not in visual perception. The brain fills in missing information consistent with available visual signals. How?

Hypothesis: The brain uses natural image statistics to choose best fill-in

Can pairwise intensity statistics explain fill-in of blue in central fovea?

Joint Intensity Distribution

Three-point joint intensity distribution is solvable; reduces to odds that samples fall in same object.

\[
P(I_x, I_y, I_z) = P_{max}(I_x)P(I_y)P(I_z) + P_{odd}(I_x)P(I_y)P(I_z) + \text{permutation terms}
\]

Stationary image statistics \( \Rightarrow \) can use recursion to derive probability of being in same object (Ruderman 1997)

\[
P_{max} = P_{II} + P_{III}P_{aa}
\]

\[
= \frac{P_{II}}{1 - P_{III}}
\]

Analogous arguments give three-point probabilities

Geometric factors \( P_{III} \) etc., are straightforward in 1D

Three-point probabilities yield edge interactions

Combine multiple inferences na"ively

Theory of edge interactions reproduces simulated edge-conditional intensity distributions

Psychophysics Predictions

Theory predicts:
- Edges have strong local influence and weaker long-range influence;
- Edges contribute independently, giving exponential growth of prob with length of edges;
- Object circumference grows faster with distance than influence wanes, so bigger objects should have greater net effect on fill-in.

Extensions:
- Apply to colors
- Non-uniform objects (textures)
- Orientation: messy but tractable
- Higher-order statistics
- Test psychophysics!
- Neural plausible implementation?

Summary:
- Two-point stats can’t explain fill-in
- Dead Leaves Model offers higher-order stats, e.g. edges
- Intensity differences can be helpful for surface fill-in

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