A Computational Model for Perception of Two-dimensional Pattern Velocities

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Outline

• Computational model: Bayesian velocity estimator

• Simple two-stage model implementation

• Model response to plaid stimuli

• Comparison to psychophysical data:
  - Ferrera & Wilson, 1990, 1991
  - Stone, Watson, Mulligan, 1990
Bayesian Velocity Estimator

• Gradient measurement equation, with noise model:
  \[ I_x (v - n_1) + I_t + n_2 = 0 \]

• Prior probability distribution on velocity:
  \[ P(v) \sim N(0, \sigma_v^2) \]

• Bayes’ rule gives probability distribution on velocity:
  \[ \log P(v \mid I) \propto - \frac{(I_x v + I_t)^2}{(\sigma_e^2 + I_x^2)} - \frac{v^2}{\sigma_v^2} \]
Implementation: Stage 1

- Linear filtering, using spatio-temporally oriented operators
- Energy computation (squaring)
- Divisive normalization, with semi-saturation parameter, $\sigma_e$
- Outputs are spatio-temporally tuned

Input: image intensities
Output: normalized "energy"
Implementation: Stage 2

- Weighted summation of stage 1 energies over space, frequency bands

- Some of the summations include prior variance parameter, $\sigma_v$

- Outputs are velocity tuned
Grating Examples

stimulus

idealization

model
Plaids: Effect of Relative Contrast

stimulus  |  idealization  |  model

- Stimulus:
  - Circular pattern with arrows indicating directions.

- Idealization:
  - Diagram showing vectors $V_x$ and $V_y$.
  - Arrow indicating vector $\hat{V}_x$.

- Model:
  - GRF images with arrows and spotted circles.
  - Graph showing vectors $V_x$ and $V_y$. 

Simoncelli & Heeger, ARVO-92
Stone et al. 1990

**Total Contrast**
- 5%
- 10%
- 20%
- 40%

**Subject**

**Model**

- Perceived Direction Bias (degrees)
- Log Contrast Ratio

Log Contrast Ratio: 0 to 4

Perceived Direction Bias: -5 to 20
Plaid: Effect of Grating Angles

stimulus

idealization

model
Ferrera & Wilson, 1990

Perceived Direction Bias (degrees)

Plaid Type

Symmetric I  Asymmetric I  Type II

subject  model

Simoncelli & Heeger, ARVO-92
Ferrera & Wilson, 1991

Perceived Speed (relative to IOC)

Plaid angle (degrees)

- black line: subject2
- red line with circles: model
- blue dashed line: cosine
Summary of Model

• Derived as a Bayesian estimator

• Starting from image intensities, computes response of a population of velocity-tuned units

• Implemented in two simple stages of computation

• Velocity estimates are consistent with psychophysics of plaid perception
Example Receptive Field