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Perceptual grouping and lightness

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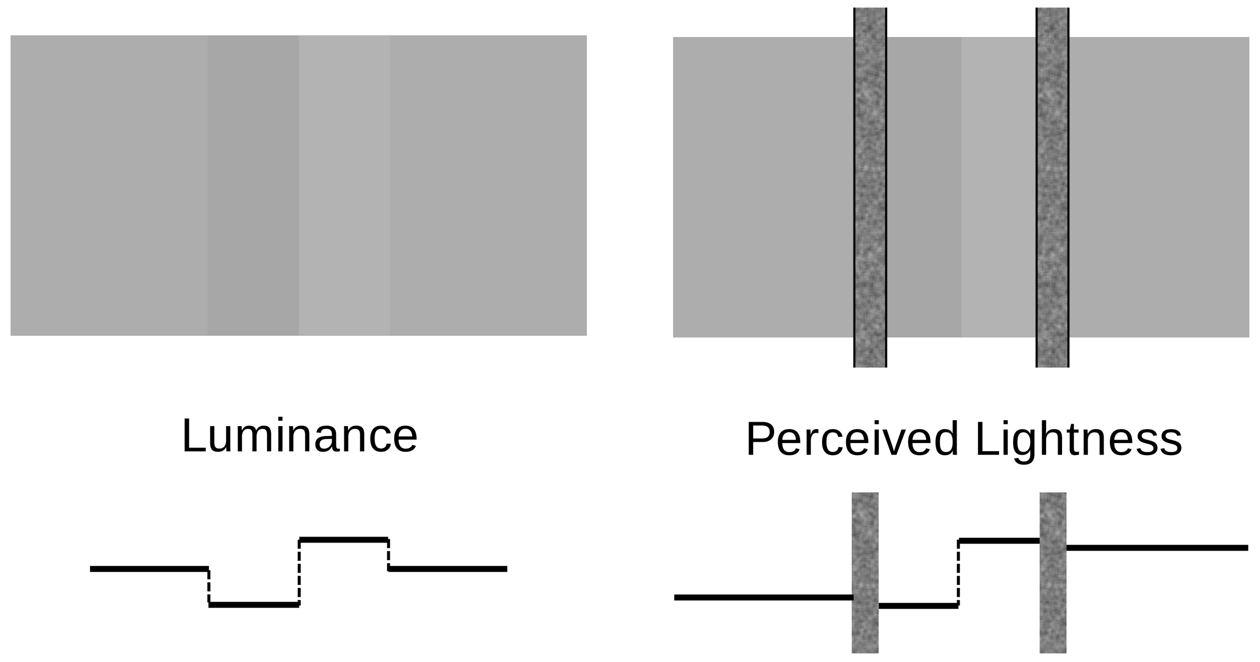
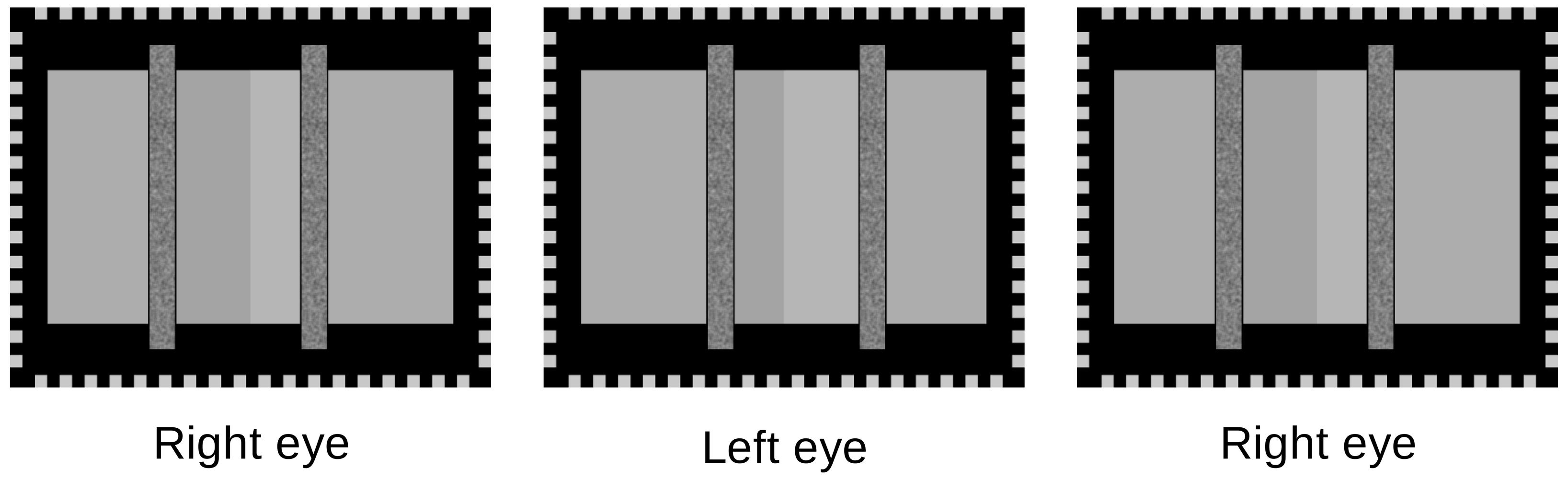
Introduction

Amodal completion - when two spatially separated surfaces appear to be grouped together behind an occluder - is one of the mechanisms which can facilitate perceptual grouping and may influence surface lightness.

In the stimulus shown below-right the two flanking regions are identical, but they appear to have different lightnesses. Because the surface is amodally completed behind the occluder bars and the luminance profile of the central region affects the lightness of the flanks. We refer to this illusory percept as the *Lightness Effect*.



3D view



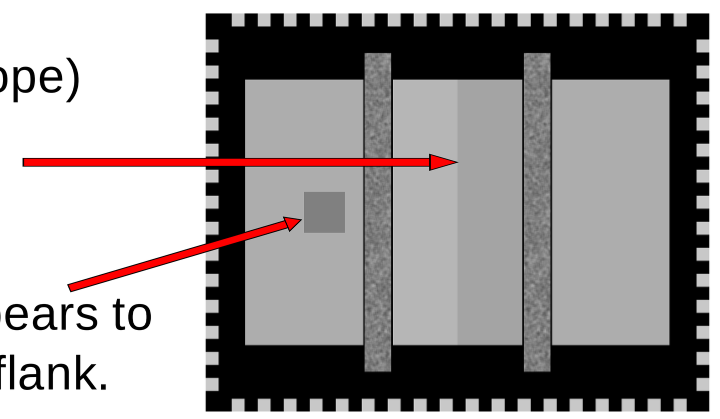
However, the effect vanishes if the contrast of the central border increases. Below a strong lightness effect is observed in the left stimulus but not in the right one. This is presumably because of the break down of perceptual grouping due to the large differences between the flanks and the central regions.

Behavioral measurement of the lightness effect

3 observers participated in a behavioral experiment (3D presentation in a stereoscope)

11 border contrast levels tested, 5 trials for each level, unlimited time

Task: Adjust the matching patch untill it appears to have the same luminance as the opposite flank.



$$contrast = \frac{L_{max} - L_{min}}{L_{mean}}$$

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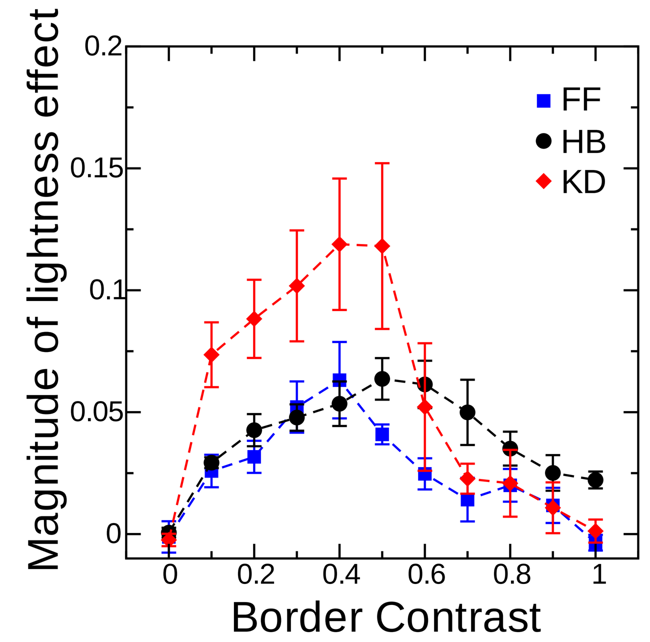
Results



Magnitude of the lightness effect is defined as the contrast between the matching patch and its background

For all three observers, the lightness effect first increased with the contrast of the central border, but then started to decrease around 0.5 level and largely diminished at the level of 1

Modeling the lightness effect

We would like to implement a computational algorithm that estimates the perceived lightness at any location r in the image given the intensity data $\mathcal{O}(r)$.

Let the probability that a point r on the image is generated by lightness L_k be

$$g_k(r) \equiv P(G_k(r) = 1 | \mathcal{O}(r), L_k).$$

The posterior probability of $\Lambda = \{L_k\}$, and $\Gamma = \{g_k(r)\}$, given the observed data can be expressed as a Gibbs distribution

$$p(\Lambda, \Gamma | \mathcal{O}) \sim \exp\left(-\frac{E}{T}\right),$$

where E is an effective energy function, and T controls the variance [1].

Effective energy function

The effective energy is composed of intensity matching, discontinuity preserving, homogeneity, grouping and entropy terms:

$$E = w_I E_I(\Theta, \Gamma, \mathcal{O}) + w_D E_D(\Theta, \Gamma, \mathcal{O}) + w_H E_H(\Theta, \Gamma) + w_G E_G(\Theta, \Gamma, \mathcal{O})$$
$$+ T \sum_{k,r} g_k(r) \log g_k(r)$$

Intensity matching term

In the absence of any illumination and geometry effects, *i.e.* in a "diffuse 2D world," the best that the visual system can do is measuring the luminance and performing a monotonic transformation from luminance to lightness. This is the $0th$ order approximation to lightness:

$$E_I = \sum_{k,r} g_k(r) V_I$$
$$V_I = (L_k(r) - \mathcal{O}(r))^2 .$$

Discontinuity preserving term

Sharp contrast boundaries usually indicate changes in reflectance. Therefore we include in the algorithm the following term to preserve discontinuities that are likely to represent a surface reflectance change

$$E_D = \sum_{k,r,l} g_k(r) g_l(r+1) V_D$$

$$V_D = \begin{cases} (L_k(r) - L_l(r+1) - \mathcal{O}'(r))^2 & \text{if } \mathcal{O}'(r) > T_D \\ 0 & \text{otherwise} \end{cases}$$

Homogeneity term

As opposed to sharp intensity boundaries, smooth luminance variations can be attributed to illumination and geometry, and discounted for estimating lightness. In order to incorporate these observations, we introduce the following term in the effective energy to bias the outcome for homogenous solutions

$$E_H = \sum_{k,r} g_k(r) V_H,$$
$$V_H = \exp\left(\beta_H |L'_k(r)|\right).$$

Grouping term

To facilitate grouping, we include the following term in the model

$$E_G = \sum_{\substack{k,l,\\ r,s \in N_r}} g_k(r) g_l(s) V_G.$$

where the neighborhood N_r is specified as a fixed symmetrical interval around the point r, as long as no luminance discontinuity is met, and

$$V_G = |L_k(r) - L_l(s)| \times \begin{cases} 1 & \text{if } |\mathcal{O}(r) - \mathcal{O}(s)| < \beta_G/2 \\ 1 - \frac{|\mathcal{O}(r) - \mathcal{O}(s)| - \beta_G/2}{\beta_G} & \text{if } \beta_G/2 < |\mathcal{O}(r) - \mathcal{O}(s)| < 3\beta_G/2 \\ 0 & \text{if } |\mathcal{O}(r) - \mathcal{O}(s)| > 3\beta_G/2 \end{cases}$$

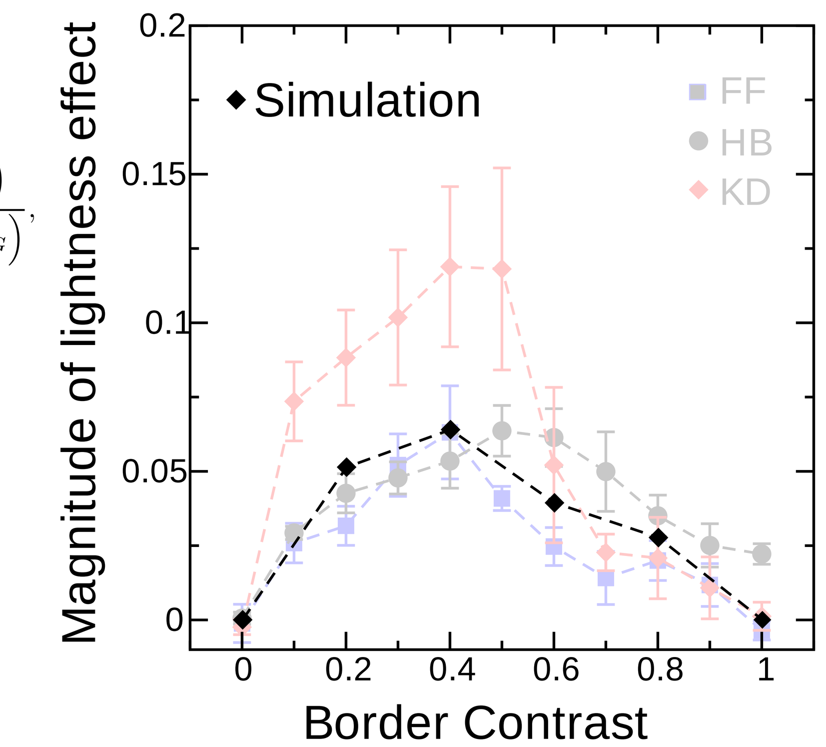
Results

To find a solution we minimized the effective energy using a mixture estimation procedure (expectation maximization (EM)) [2]. We iteratively computed first g_ks and then L_ks, assuming $L_k(r) = a_k r + b_k$:

$$g_k(r) = \frac{\exp\left(-\frac{w_I}{T} V_I - \frac{w_H}{T} V_H - \frac{w_D}{T} \sum_l g_l(r+1) V_D - \frac{w_G}{T} \sum_{l,s} g_l(s) V_G)\right)}{\sum_j \exp\left(-\frac{w_I}{T} V_I - \frac{w_H}{T} V_H - \frac{w_D}{T} \sum_l g_l(r+1) V_D - \frac{w_G}{T} \sum_{l,s} g_l(s) V_G\right)},$$

$$L_k = \arg\min_{\Lambda} \left\{ \sum_r w_I g_k(r) V_I + w_D \sum_l g_k(r) g_l(r+1) V_D + w_H g_k(r) V_H + w_G \sum_{l,s} g_k(r) g_l(s) V_G \right\}.$$

$w_I = 1.0$ $w_D = 1.0$ $w_H = 5.0$ $w_G = 4.0$ $T = 10$
$T_D = 10.0$ $\beta_H = 100$ $\beta_G = 10$ $N_r = 20$



Discussions

* Perceptual grouping, through amodal completion affects lightness;
* Human performance can be predicted by a model which puts together a few intuitive perceptual rules;
* The framework presented here can be used with any other set of rules;
* The rules should in the future be extended to include light field and geometry.

References

[1] Kersten, D., Madarasmi, S. "The visual perception of surfaces, their properties, and relationships," DIMACS Series in Discrete Mathematics and Theoretical Computer Science,19 373-389 (1995).

[2] Weiss, Y., Adelson, E.H. "Perceptually organized EM: A framework for motion segmentation that combines information about form and motion," M.I.T. Media Laboratory Perceptual Computing Section Technical