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.

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 \(O(r)\).
Let the probability that a point \(r\) on the image is generated by lightness \(L_k\) be
\[P_k(r) = \frac{1}{|G_k(r)|}\]
The posterior probability of \(k\) = \(L_k\), and \(G_k(r)\) be expressed as a Gibbs distribution
\[P_k(r) = \exp \left( \frac{E}{T} \right) \]
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:
\[E = w_I E_I(\Theta, \Gamma, O) + w_C E_C(\Theta, \Gamma, O) + w_H E_H(\Theta, \Gamma, O) + w_Q E_Q(\Theta, \Gamma, O) + T \sum_{k,r} g_k(r) \log g_k(r)\]

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:
\[E_I = \sum_{k,r} g_k(r) V_k\]
\[V_k = (L_k(r) - O(r))^2\]

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
\[E_D = \sum_{k,r} g_k(r) (r + 1) V_D\]
\[V_D = \left\{ \begin{array}{ll} (L_k(r) - L(r + 1) - O(r))^2 & \text{if } O(r) > T_D \\ 0 & \text{otherwise} \end{array} \right.\]

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
\[E_H = \sum_{r \in N_k} g_k(r) V_N \]
\[V_N = \exp \left( \frac{\delta_H |L_k(r) - L(r)|}{} \right) \]

Grouping term
To facilitate grouping, we include the following term in the model
\[E_G = \sum_{r \in N_k} g_k(r) g_N V_G\]
where the neighborhood \(N_k\) is specified as a fixed symmetrical interval around the point \(r\), as long as no luminance discontinuity is met, and
\[V_G = |L_k(r) - L(r)| \]

Results
To find a solution we minimized the effective energy using a mixture estimation procedure (expectation maximization (EM)) [2]. Weiter we computed first \(g_k\) and then \(L_k\), assuming \(L_k(r) = a + b r^2\).

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