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The Optimal Estimator of Objects' Lightness

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ABSTRACT
We have recently shown that eye movements have an effect on lightness estimation of real objects. Observers tended to fixate points with above-average luminance and they overestimated the objects' lightness. The matched lightness was higher when observers were forced to fixate a bright region of the object than when they fixated a darker region. In the present work we performed a simulation with a physically based rendering system, showing that this is an efficient and simple heuristic for the visual system to arrive at accurate and invariant judgments of lightness.

Categories and Subject Descriptors
J.4 [**Social and Behavioral Sciences**] –*psychology*.

General Terms
Experimentation, Human Factors

Keywords
Lightness perception, albedo, estimator reliability, physically based rendering.

1. INTRODUCTION
When observers matched the color of natural objects they based their judgments on the brightest parts of the objects [1,2], and at the same time they tended to fixate points with above-average luminance [2]. To investigate a possible causal link between fixations and lightness matches, we forced participants to fixate a specific point on the object using a gaze-contingent display setup [2]. The matched lightness was higher when observers fixated bright regions.

Assuming that the visual system estimates objects' lightness based on local reflected light, different parts of the objects' luminance distributions might provide differently reliable cues.

We test whether the participants' visual scanning behavior is an effective strategy for lightness estimation.

The luminance of diffusely reflecting surfaces is proportional to the cosine of the angle between the surface normal and the direction of the incident light. However, at the same time variations in surface orientation also have the biggest effect on luminance when the surface normal is almost perpendicular to the light. Predicting how these two opposing tendencies interact in the case of complex objects in a realistic light field is not a trivial task.

2. METHODS

2.1 Physically based rendering
We resorted to a physical-based rendering simulation to find the portion of the objects' luminance histogram which yields the most robust estimate of the objects' reflectance. Using the software RADIANCE [2] interfaced with a MATLAB toolbox [3], we rendered a set of tridimensional models of objects under several different viewing and illumination conditions using simulated natural light fields [e.g. 4]. Each view was rendered with different values of reflectance (Figure 1).

Figure 1. Tridimensional models.

2.2 Analysis
For each rendered object, we calculated the percentiles of the radiance distribution as potential lightness estimates. We performed an ROC-analysis in order to indicate to what degree an ideal observer can identify a change in reflectance in the presence of variations in scene geometry. The reflectance values have been chosen to have partially overlapping distributions for each couple. Areas under ROC curve are a measure of criterion independent diagnosticity. We computed the cumulative AUC as an aggregated index of discriminability for each percentile.

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3. RESULTS

We found that the distribution of the standard deviations for each estimate has approximately an inverted U-shape with minima for the darkest and the brightest object regions (Figure 2A). Given that the dependency of the luminance on the incident light direction has to be maximal for the most illuminated parts of the objects, the sharp drop in variability for the extremely bright portions of the objects can only be due to a reduction in the variability of their orientation within the light field. Intuitively, this means that for most natural objects there is nearly al ways a region that is close to perpendicular to the direction of the light source.

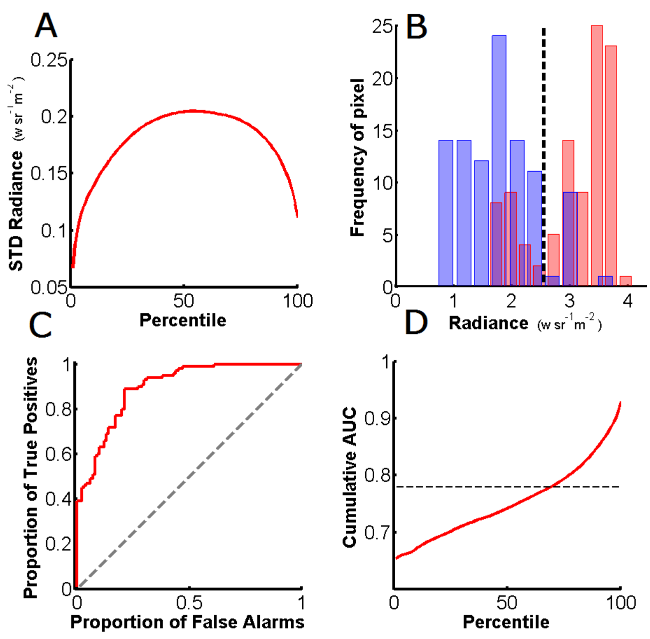

Figure 2. Physically Based Rendering Simulation.

ROC-analysis indicates to what degree an ideal observer can identify a change in reflectance in the presence of variations in scene geometry. The reflectance values have been chosen to have partially overlapping distributions for each pair (Figure 2B). The area under ROC curve is a measure of criterion independent diagnosticity (Figure 2C). We computed the cumulative AUC [6] as an aggregated index of discriminability for each percentile (Figure 2D). ROC analysis clearly shows that the discriminability monotonically increases with the luminance of the object region which is compared. Performing the same analysis on the average luminance yields worse discrimination performance as compared to the higher percentiles (black dashed line, Figure 2D).

Taken together the results of both analyses indicate that the luminances of both the dark and the bright regions of objects are comparatively invariant under different views, but only the most illuminated regions are also diagnostic of the object´s reflectance.

Our results illustrate that the visual system sometimes uses very simple and unexpected strategies to obtain good solutions to perceptual problems. In our case, the lightness of the object is better estimated by the brighter regions of the object and sampling the brighter parts thus is a good heuristic to estimate the lightness of the object. The advantage of this solution is that no knowledge about any high level visual aspects such as geometry or shape is required.

4. ACKNOWLEDGMENTS

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