A contrast-based model of achromatic transparency

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One of the most compelling examples of image segmentation is the perception of transparency: the visual system decomposes the 2D pattern of image intensities into the surfaces in the background and the transparent medium that partially obscures the background (see Fig. 1). How the visual system accomplishes the decomposition is not clear but it has been suggested that the link between perceived transparency and image intensities might be contrast [1], [2].

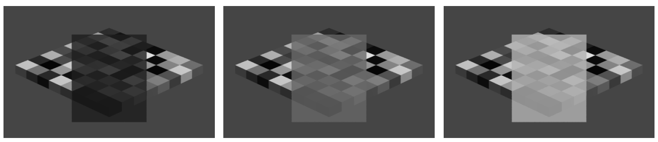

Fig. 1. Checkerboard stimuli with superimposed transparent surfaces. Stimuli are rendered using α compositing (Metelli model) with identical transmittance ($\alpha = 20\%$). Reflectance of the transparent surface increases from left to right and so does the mean luminance of regions seen through the transparency.

For simpler stimuli, consisting of only two luminances, perceived transmittance is reasonably predicted by Michelson contrast, defined as the ratio of contrasts in the region of transparency and in plain view $\alpha_c = \frac{c_{TRANSP}}{c_{PLAIN}}$ [2], [3]. Each contrast is defined as $c = \frac{l_{max} - l_{min}}{l_{max} + l_{min}}$ with l_{max} and l_{min} being the minimum and maximum luminances in each region, respectively. A so-defined contrast is invariant to changes in illumination [4], because luminances l are proportional to the reflected light $I * R$, and hence Michelson contrast can be rewritten as $\frac{I*R_{MAX} - I*R_{MIN}}{I*R_{MAX} + I*R_{MIN}}$, where I cancels out.

We apply a similar logic to test whether a version of α_c carries information about perceived transparency in stimuli that consist of more than two luminances. Following one physical model (Metelli), luminances under transparency l' and in plain view l are related by the equation $l' = \alpha * l + (1 - \alpha) * l_T$, where l_T is the luminance produced by the transparent medium of reflectance τ, when α, its transmittance, is 0. Assuming that the lightest and darkest regions are seen through the same transparent medium, then inserting the previous equation for l_{min} and l_{max} yields $c_{TRANSP} = \frac{\alpha*(max - min)}{(\alpha*(max+min) + 2*(1-\alpha)*\tau)}$. For $\tau > 0$ (and thus $l_T > 0$), the contrast under transparency is a decreasing function of τ. For most observers the dark transparency in Figure 1 looks indeed more transmittant than the light one of equal physical transmittance. Here we test to what extent observers' perception of transmittance follows quantitative predictions of different contrast metrics.

Stimuli were checkerboards (Fig. 1), otherwise we closely followed the protocol in [2]. A reference stimulus had a transparent medium with fixed τ and α, and a test stimulus had varying values of τ. Observers adjusted α in the test stimulus (corresponding to the luminance range in the image) so as to match perceived transmittance. Figure 2A shows the mapping between check reflectances and luminances for fixed α and our stimulus variations of τ. Figure 2B shows c_{TRANSP} from above as a function of τ. Figure 2C shows the luminance range (α) that observers should adjust if they tried to keep c_{TRANSP} constant, together with empirical data obtained from one observer. The model based on the mean of all contrasts performed slightly better than the one based on the extreme contrasts, but neither of them fully captures the data. We also measured perceptual scales of perceived transmittance in order to get closer to the representation which is underlying transmittance matches [3]. We tested various contrast metrics [1], [2] but none of them accounted well for the data.

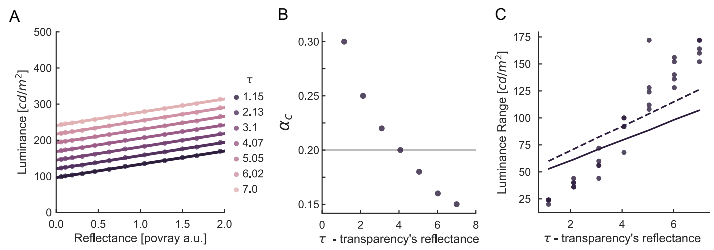

Fig. 2. Prediction of perceived transparency A. Atmospheric transfer functions (ATFs) relating luminance to check reflectance (x-axis) [5]. B. Contrast ratio α_c as a function of τ, the reflectance of the transparent medium (dots), for a fixed physical transmittance ($\alpha = 20\%$, line). C. Matching data from one observer (dots) and predicted matches (lines) derived from the type of function shown in B but computed for a number over the full range of contrast (dashed) or only between l_{min} and l_{max} (continuous line).

So, although it seems beyond question that the visual system uses contrast to determine the visibility of image structure, it is less clear which contrast metric it uses to do that. Part of the discrepancies between models and data might be due to methodological problems, because we noticed that the psychophysical task of judging perceived transparency might evoke different strategies.

References

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