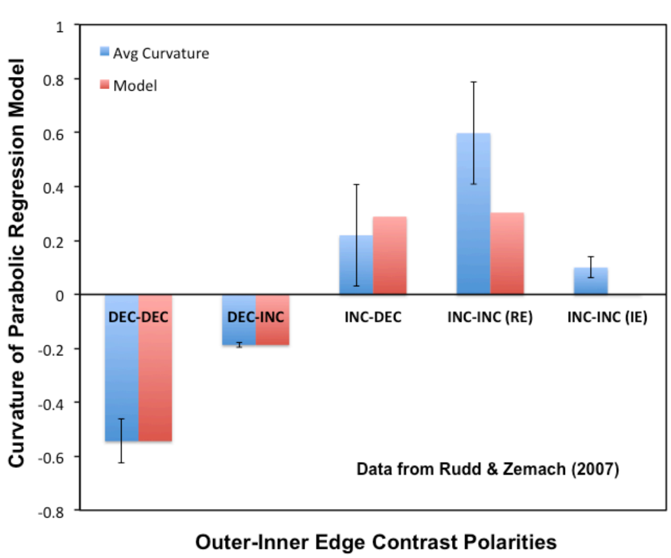
Parametrically Constrained Lightness Model Incorporating Edge Classification and Increment-Decrement Neural Response Asymmetries

Lightness matches from disk-annulus displays take the form of 2nd-order polynomial (parabolic) functions when plotted in log-log coordinates (Rudd & Zemach, 2007). Rudd (2010) proposed a cortical lightness computation model that explains this fact and later extended the model (Rudd, 2013, 2014, 2015) to account for lightness in other display types, including staircase-Gelb and a gradient lightness illusion in which luminance decrements appear as increments, and luminance increments as decrements, when surrounded by steep gradients (Galmonte, Soranzo, Rudd, & Agostini, 2015). The cortical model includes neural stages involving: encoding by oriented contrast detectors in areas V1; contrast gain control between the outputs of nearby contrast detectors; and directed spatial integration of oriented contrast neuron output to compute lightness in area V4 or beyond.

Here, I re-examine the disk-annulus lightness data of Rudd and Zemach, and Rudd (2010) with an eye to further nailing down the model parameters. The 2010 data was collected with a fixed stimulus, presented on a computer monitor, in which the luminance step from the background to the annulus was always positive and the luminance step from the annulus to the disk was also positive (INC-INC). Matches were made under different instructions, including: no special instructions; instructions to assume the disk and annulus depicted illuminated surfaces and changes in annulus luminance denoted changes in reflectance; and instructions to assume the disk and annulus were surfaces, but the annulus change represented an illumination change on that side of the display only. (The other side contained the matching disk and its annulus). The 2007 data comprised naïve matches made to displays having all possible combinations of the annulus-background, and disk-annulus, edge contrast polarities: INC-INC, INC-DEC, DEC-INC, and DEC-DEC.

The current version of the cortical model (Rudd, 2013, 2014, 2015) postulates: 1) neural responses to incremental and decremental steps in log luminance have different inherent neural gains, with incremental steps making contributions to disk lightness 1/3 the size of those made by decremental steps; 2) edge contrast polarity is defined directionally from the background to the target; and 3) top-down feedback filters out neural responses to edges interpreted as changes in illumination rather than reflectance. The present question is how to combine the high-level (edge classification) and sensory (increment-decrement asymmetries) in the lightness model to explain quantitative data. To this end, I used the formula of Rudd (2010) for the lightness of a disk surrounded by an annulus:

$$\Phi_D = w_1(D-A)g_1\left[1+\kappa_{21}(r_A)g_2\left|A-B\right|\right]^+ + w_2(A-B)g_2\left[1+\kappa_{12}(r_A)g_1\left|D-A\right|\right]^+ \qquad (1)$$



where Φ_D is the disk lightness; *D*, *A*, and *B*, are the disk, annulus, and background luminances in log units; [ ]+ denotes half-wave rectification; r_A is the annulus width; w_1, w_2, g_1, g_2, κ_{12}, and κ_{21} are model parameters. I used Eq. (1) to model the 2nd-order regression coefficient (informally, the “curvature”) of the least-squares polynomial lightness plot models, under the following parametric constraints: a) w_1 and w_2 = 1 or 1/3 when the luminance steps from the annulus to disk and background to annulus are either negative to positive; b) g_1, g_2 = 0 (when the observer is implicitly instructed to interpret the disk/annulus or annulus/background edge as an illumination edge) or 1 (when the edge is interpreted as a reflectance edge). Once the 2nd-order term (plot curvature) is modeled, the 1st-order term (plot slope) is also known because the two coefficients are related by a constant when g_2 = 1 (Rudd, 2010).

The results (shown above) strongly confirm the *computational* lightness model with constrained parameters, but it raises questions about the *neural* interpretation, which I will discuss.