DiCE: Dichoptic Contrast Enhancement for VR and Stereo Displays

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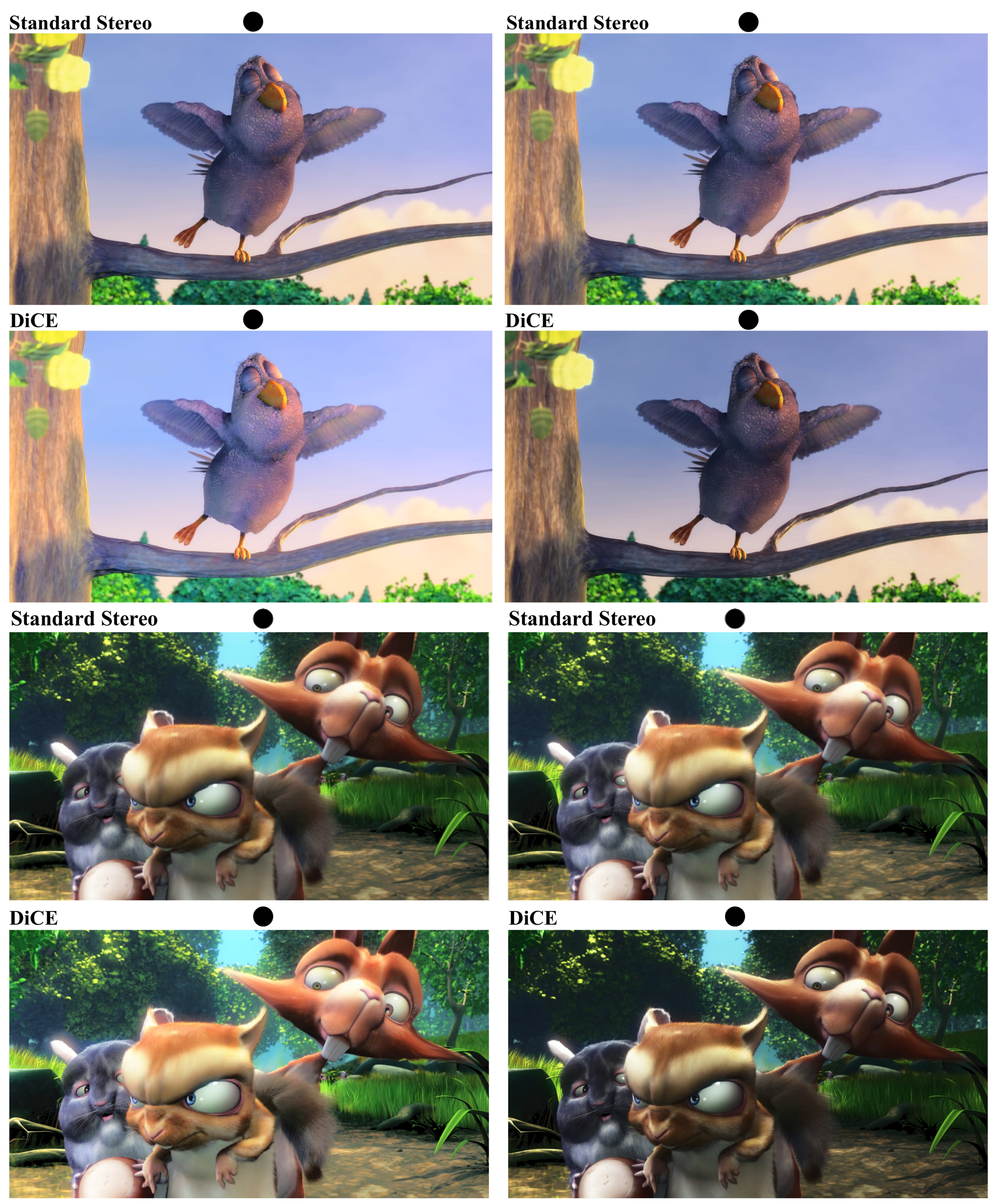
Motivation

In stereoscopic displays, such as those used in VR/AR headsets, our eyes are presented with two different views. The disparity between the views is typically used to convey depth cues, but it could be also used to enhance image appearance. We devise a novel technique that takes advantage of binocular fusion to boost perceived local contrast and visual quality of images. Since the technique is based on fixed tone curves, it has negligible computational cost and it is well suited for real-time applications, such as VR rendering. To control the trade-off between contrast gain and binocular rivalry, we conduct a series of experiments to explain the factors that dominate rivalry perception in a dichoptic presentation where two images of different contrasts are displayed. With this new finding, we can effectively enhance contrast and control rivalry in mono- and stereoscopic images, and in VR rendering, as confirmed in validation experiments.



Comparison of standard stereo images and the images with enhanced perceived contrast using our DiCE method. They can be cross-fused with the assistance of the dots above the images. Notice the enhanced contrast in the shadows and highlights of the scene.

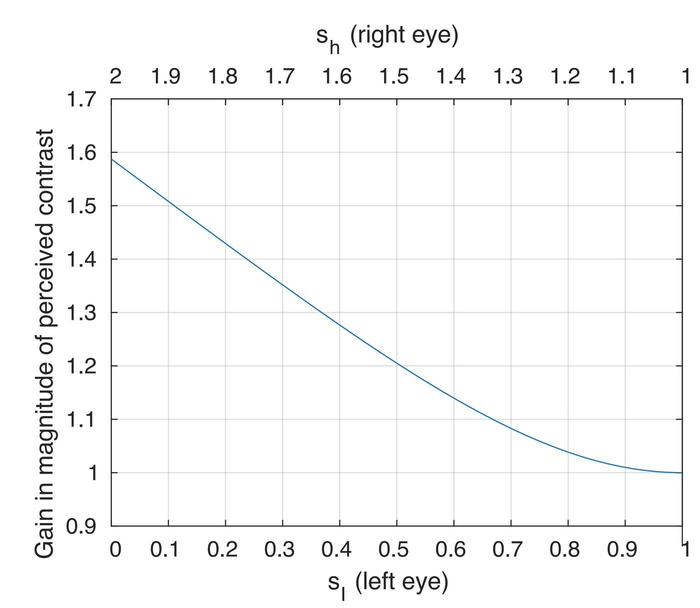
Background

In a binocular display, when a different image is presented to the two eyes, the viewer experiences **dichoptic presentation**, contrary to **dioptic presentation** where identical images are presented to the two eyes. When the dichoptic stimuli are too dissimilar to be fused into one stable percept, the viewer experiences **binocular rivalry**.

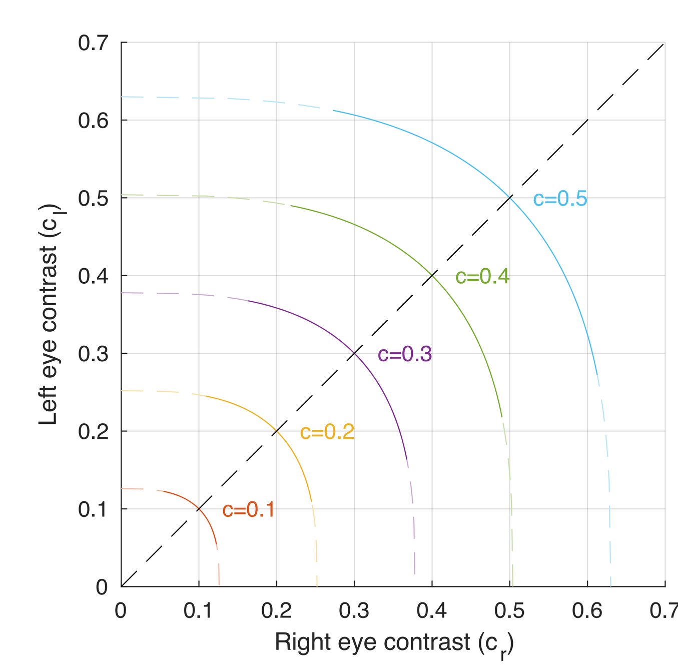
Fusion of contrast. Legge and Rubin investigated perceived contrast when two stimuli of the same spatial configuration but different contrasts are presented to the two eyes. If we present contrast c_l to the left eye and contrast c_r to the right eye, the magnitude of the perceived contrast c_m is:

$$c_m = \left(\frac{c_l^\beta + c_r^\beta}{2}\right)^{\frac{1}{\beta}}, \quad \beta \approx 3. \qquad (1)$$

This rule biases the perceived binocular contrast to the higher of the two monocular contrasts.



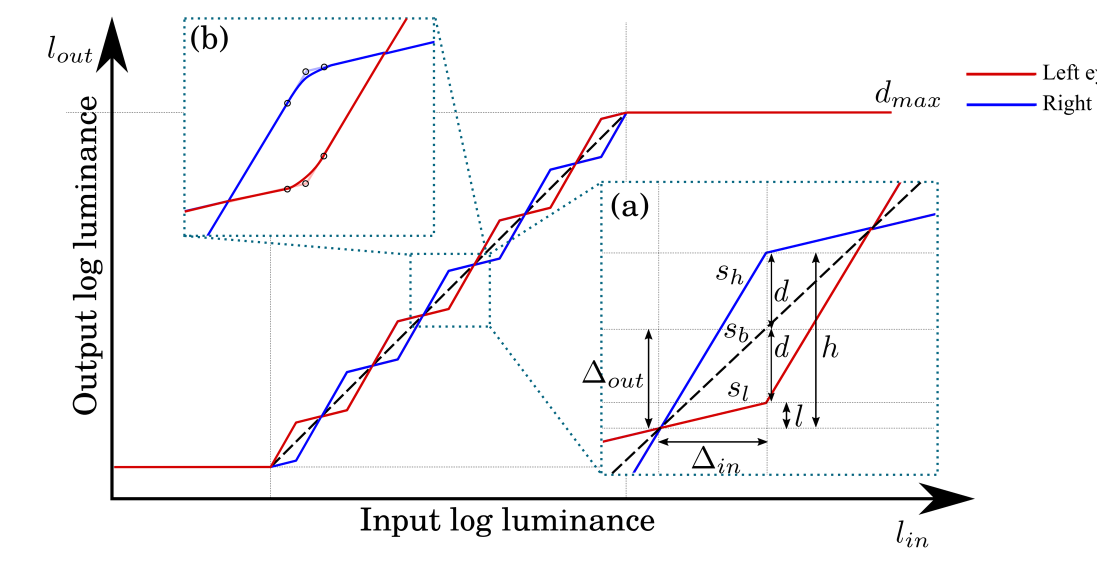
The perceived binocular contrast is higher than the numerical average of the two monocular contrasts.



For each level of dioptic/standard contrast ($c = 0.1\,..\,0.5$), the color lines show the combination of the left and right eye contrast that produces the match. The dashed portion of the color lines denote the range of contrast combinations that results in unstable percept and rivalry.

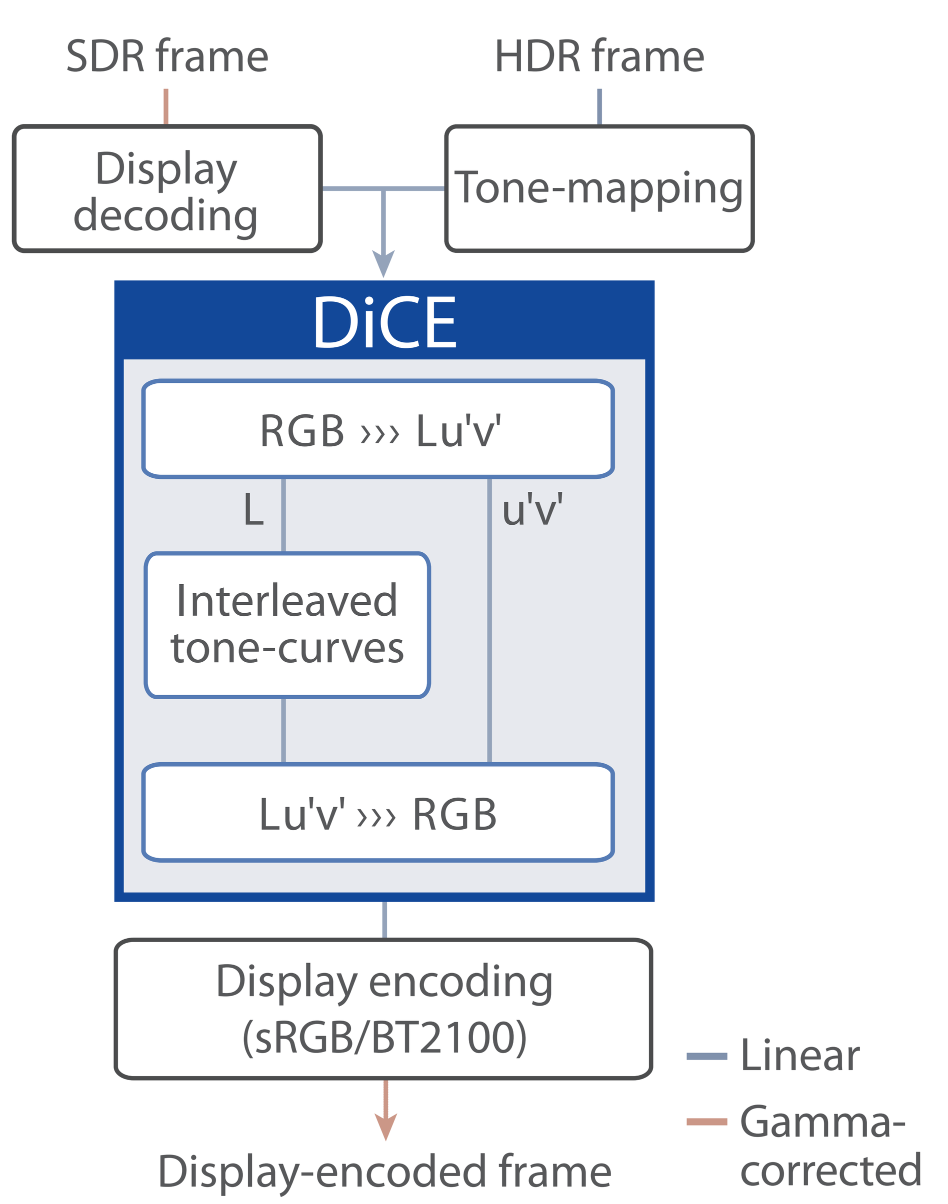
Dichoptic Contrast Enhancement

A tone curve is a function mapping the logarithmic luminance (base-10 logarithm) of the input image to the physical logarithmic luminance of the display device. Assigning a steeper slope in one part of the tone-curve, boosts contrast in that range.



DiCE interleaved tone-curves

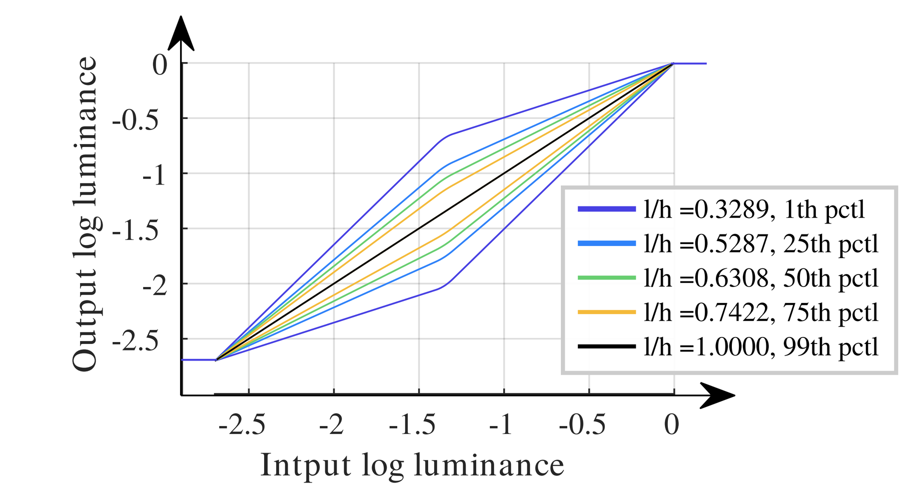
Using the red/blue lines to denote DiCE tone-curves on left/right eyes, the perceived contrast is boosted when the slope on one eye is enlarged and suppressed on another. However, to minimize rivalry, we want both left- and right-eye tone curves to be similar to each other. This can be achieved with an interleaved tone-curves.



DiCE as part of a tone-mapping pipeline can take both HDR and SDR frames as inputs.

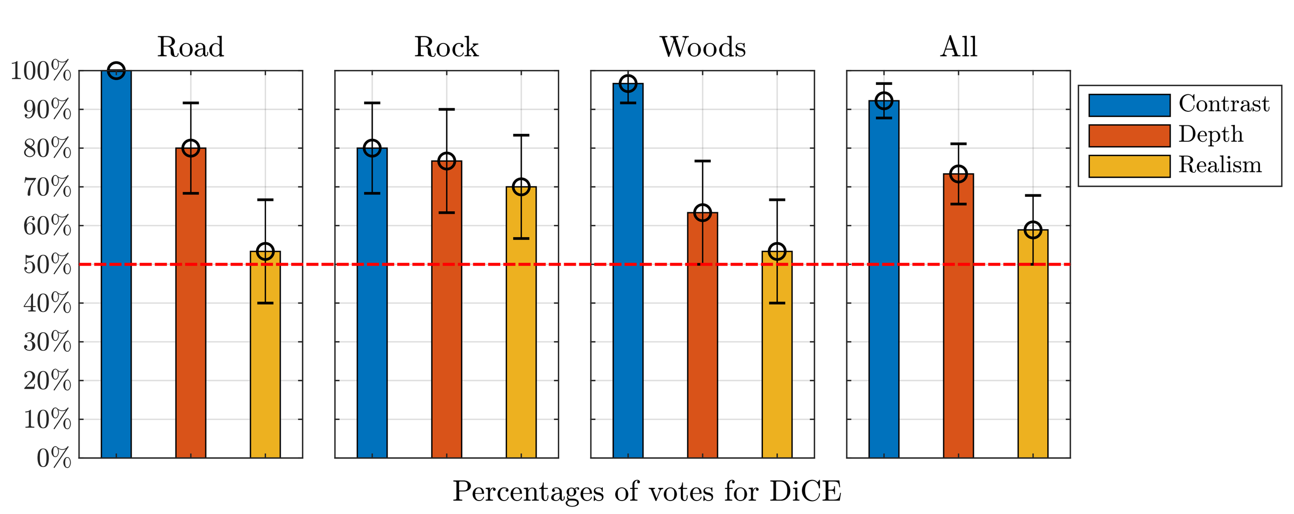
Contrast Gain Maximization and Rivalry Control

The biggest challenge is the choice of the slopes, s_l and s_r, and the number of segments, so that the contrast enhancement is maximized and the rivalry well maintained. Based on a series of experiments, we found that the best indicator of rivalry is the ratio of contrasts, that is l/h. The closer l/h is to zero, the more rivalry would be experienced. The indicator lets us find the best trade-off between contrast gain and rivalry control, and the optimum choices for the parameters of the tone curves.



The shape of the dichoptic tone-curves at different l/h ratios. The ratios were selected to represent 1st, 25th, 50th, 75th and 99th percentile of the data (across all images and observers) from our experiment.

VR Validation



We ran a validation experiment in VR asking the participants to compare the quality of contrast, depth perception and realism between standard VR scenes and DiCE-processed scenes. The results of are presented as percentages of participants who voted for DiCE for each of the three qualities. It shows that **DiCE method produces higher contrast perception and stronger depth perception**, compared with standard presentation for all VR environments.

References

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