DiCE: Dichoptic Contrast Enhancement for Binocular Displays

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ABSTRACT

In stereoscopic displays, such as those used in VR/AR headsets, our two eyes are presented with different views. The disparity between the views is typically used to convey depth cues, but it could be used for other purposes. 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 the level of enhancement and binocular rivalry, we conduct a series of experiments that lead to a new finding, explaining the factors that dominate the rivalry perception in a dichoptic presentation where two images of different contrasts are displayed. With this new finding, we demonstrate that the enhancement can be quantitatively measured and binocular rivalry is well controlled.

CCS CONCEPTS

• **Computing methodologies → Perception**; **Virtual reality**; *Rendering*; *Graphics systems and interfaces*;

KEYWORDS

Visual Perception, Head Mounted Displays, Stereo, Binocular Vision

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Figure 1: 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.

1 INTRODUCTION

Image contrast is one of the key factors of perceived image quality. Images of higher contrast tend to be perceived as more realistic and 3-dimensional [Vangorp et al. 2014]. Higher contrast can be reproduced on bright high-dynamic-range displays, but they consume more power, and may introduce flicker in low-persistence VR/AR displays. Local tone mapping operators are effective at enhancing local contrast, but they can also lead to unnatural look and artifacts in video and can be computationally expensive, especially in time-critical VR/AR applications, in which every GPU cycle matters and dropping frames is not an option.

The proposed approach utilizes a byproduct of the perceptual mechanism of binocular contrast fusion to produce enhanced images. When each eye sees images with different contrasts, the fused perception is much closer to that of the eye with higher contrast. This property is exploited in the form of interleaved tone-curves, which boost or reduce contrast in different tonal ranges. The main challenge we face how to control the amount of enhancement so that the contrast is maximized while the images are still comfortable to fuse. We run a series of experiments that lead us to a new psychophysical finding explaining the factors that dominate rivalry perception when an observer is dichoptically presented with images of different contrasts. We apply this finding to our technique so that contrast gain can be quantitatively measured and binocular rivalry is well controlled.

The binocular domain has been explored before to achieve higher perceived richness, details and contrast of images [Yang et al. 2012; Zhang et al. 2018]. Unlike these approaches, which rely on existing or custom-designed HDR tone-mapping operators, we can apply our enhancement to any image, including low-dynamic-range. Also,

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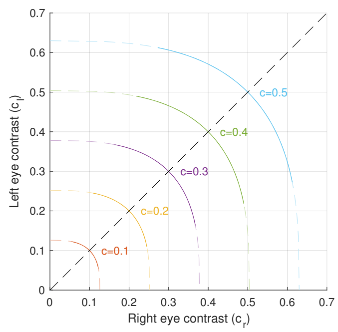

Figure 2: For each level of contrast (c = 0.1 .. 0.5), the color lines show the combination of of the left and right eye contrast that produces the match.

unlike these approaches, we can apply the enhancement to video and animation in real-time, such as a VR scene.

2 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 [1981] 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, matched dioptic contrast c_m is:

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

This rule biases the perceived binocular contrast to the higher of the two monocular contrasts. It is illustrated in Figure 2.

3 DICHOPTIC CONTRAST ENHANCEMENT

3.1 Tone-curves and contrast enhancement

For our consideration we define a tone curve as 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.

From Equation 1 we can find that the gain in perceived contrast is the highest when the slope is maximized on one eye and minimized 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, such as one shown in Figure 3. The tone-curves interleave segments in which a high-slope and therefore high contrast is presented to one eye and low-slope

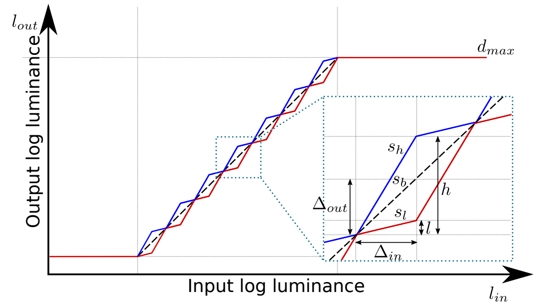

Figure 3: The tone-curve for the right eye shown in red and for the left eye in blue. The piece-wise curves consists of interleaved low- and high-slope segments. We denote the lower slope as $s_l = l/\Delta_{in}$ and the higher slope as $s_h = h/\Delta_{in}$.

and lower contrast to the other. Since contrast fusion is biased toward the eye receiving higher contrast signal (refer to Equation 1 and Figure 2), the overall perceived contrast is higher.

3.2 Contrast gain 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 reduced. Based on a series of experiments, we found that the best indicator of rivalry is the ratio of contrasts, that is l/h in Figure 3. 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.

4 CONCLUSIONS

We propose a contrast enhancement technique for stereoscopic presentation, which is derived in a principled way from Legge and Rubin's contrast fusion model. We found that a simple ratio of contrasts can explain the level of visual discomfort and let us easily control the shape of the dichoptic tone curves. Since the parameter is content independent and it does not require any analysis of input images, our technique can be easily combined with existing VR/AR rendering at almost no computational cost.

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REFERENCES

Gordon E Legge and Gary S Rubin. 1981. Binocular interactions in suprathreshold contrast perception. *Attention, Perception, & Psychophysics* 30, 1 (1981), 49–61.

Peter Vangorp, Rafat K Mantiuk, Bartosz Bazyluk, Karol Myszkowski, Radosław Mantiuk, Simon J Watt, and Hans-Peter Seidel. 2014. Depth from HDR: depth induction or increased realism?. In *ACM Symposium on Applied Perception - SAP '14*. ACM Press, New York, New York, USA, 71–78. https://doi.org/10.1145/2628257.2628258

Xuan Yang, Linling Zhang, Tien-Tsin Wong, and Pheng-Ann Heng. 2012. Binocular Tone Mapping. *ACM Transactions on Graphics* 31, 4, Article 93 (July 2012), 10 pages. https://doi.org/10.1145/2185520.2185589

Zhuming Zhang, Xinghong Hu, Xueting Liu, and Tien-Tsin Wong. 2018. Binocular Tone Mapping with Improved Overall Contrast and Local Details. *Comput. Graph. Forum* 37, 7 (2018), 433–442. https://doi.org/10.1111/cgf.13580