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Improving Quality of Anti-Aliasing in Virtual Reality

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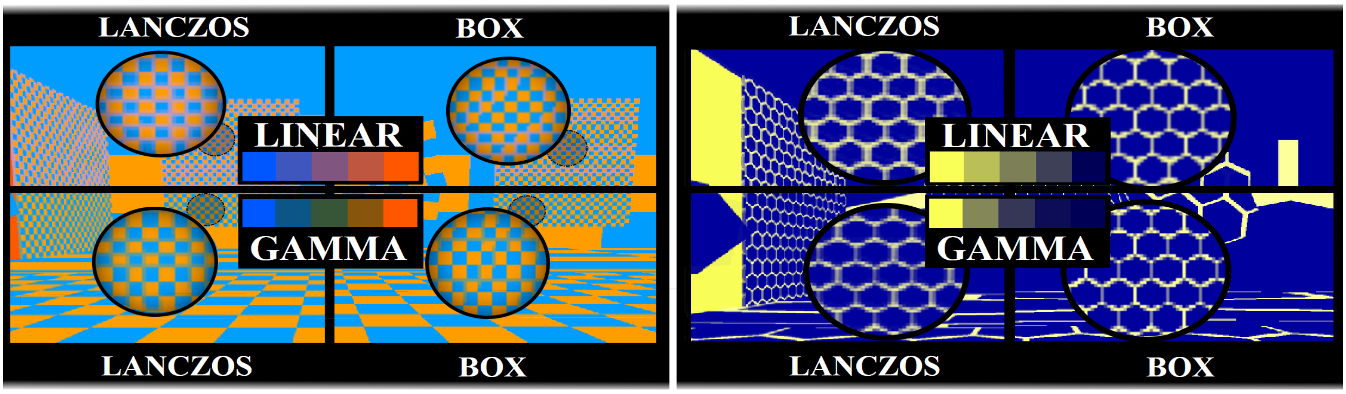

Figure 1: *Our work demonstrates that even a poor quality filter can substantially reduce visibility of aliasing when computed in the linear color space.*

CCS Concepts

•**Computing methodologies** → **Rendering; Virtual reality;** *Perception;*

1. Introduction

Various anti-aliasing (AA) techniques have been developed to improve the visual quality of real-time graphics. While these techniques have become less important for high resolution displays, such as those which approach the resolution limit of the eye, virtual reality (VR) headsets offer much lower resolution, meaning that AA is essential for high quality rendering. A number of AA techniques typically used in real-time graphics can also be used in VR applications, for example multisampling anti-aliasing (MSAA) or fast-approximate anti-aliasing (FXAA). Currently, MSAA x 4 is considered a technique that provides the minimum acceptable quality in VR, while MSAA x 8 is considered a gold standard [Vla15]. Regardless of AA technique used, the quality of a rendered scene could be affected by the color space in which the AA is performed. Currently, there is no clear consensus as to which color space should be used, with AA performed mainly in a gamma-corrected sRGB [Lot09]. In this work we run a psychometric experiment to evaluate the quality of AA performed in a linear or a gamma-corrected space in VR, using either a computationally inexpensive box filter, or an accurate but expensive Lanczos filter. Our hypothesis is that a significant improvement in quality can be achieved when AA is performed in linear color space, regardless of the type of filter used. This is because a linear space more closely approximates the loss of resolution due to optical factors in the eye: aberration and scattering of the light in the lens, aqueous humour, vitreous body and on the retina.

2. Experiment

2.1. Setup

The experiment was conducted on an HTC Vive VR headset at the recommended rendering resolution of 1512 x 1680 pixels per eye. Participants sat in a swivel chair but were encouraged to move their heads around. Head movement is an important factor because aliasing artifacts are amplified by motion. Prior to the session participants were trained to recognize aliasing artifacts.

2.2. Stimuli

The experimental stimuli consisted of two scenes with different procedurally-generated patterns: checkerboard and honeycomb (see Fig. 1). The scenes were designed to increase the visibility of aliasing artifacts. Four different pairs of colors were used to generate the patterns. The color pairs were chosen to maximize the CIE delta E 2000 color distance [SWD05] between the results of anti-aliasing performed in linear and in gamma-corrected space and also to ensure a variety of color pairs. Stimuli were generated using one of the following four techniques: (BL) downsampling with a box filter in the linear RGB space, (BG) downsampling with a box filter in the gamma-corrected sRGB space, (LL) downsampling with a Lanczos filter in the linear RGB space, and (LG) downsampling with a Lanczos filter in the gamma-corrected sRGB space. The experiment was implemented in the Unity3D game engine.

2.3. Implementation

The scene was rendered (separately for each eye) to the buffer two times of the target's size, then downsampled to the target's resolution using either a box filter or a two-pass Lanczos2 filter (where 2 refers to window size parameter) with kernel size 11. For AA in linear the RGB space, downsampling was performed before converting to sRGB. For AA in the gamma-corrected space, the conversion to sRGB was performed first, followed by down-sampling. All operations were performed on floating point textures, only the final result was written to an 8-bit raster buffer.

2.4. Task

In each trial, participants were presented with one of the two scenes, which contained either checkerboard or honeycomb pattern using one of the four color pairs. For each scene, participants were asked to switch between two AA techniques and to pick the one that possessed better visual quality and less aliasing artifacts. We used a full pair-wise comparison design, in which all combinations of pairs of techniques were compared. Each observer saw each pair three times, resulting in 288 trials per observer. The order of all trials was randomized.

2.5. Participants

Ten participants aged from 19 to 40 years old, with normal color vision took part in the experiment.

3. Results

The results of the experiment were scaled under Thurstone Model V assumptions in just-objectionable differences (JODs) using *pwcmp* software (available at `https://github.com/mantiuk/pwcmp`). JODs quantify the relative quality differences between the techniques. A difference of 1 JOD means that 75% of the population can spot a difference between two conditions. The details of the scaling procedure can be found in [POM17]. As JOD values are relative, the box linear (BL) condition was fixed at 4 JOD for better presentation.

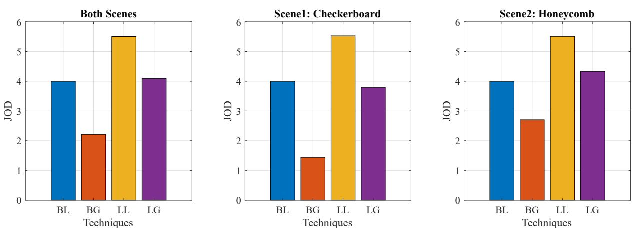

Figure 2: *Overall results of our pairwise comparison experiment. A clear advantage to performing AA in linear RGB can be observed, regardless of the filter used. The technique labels are explained in the text.*

The overall results as shown in Fig. 2, indicate a significant improvement in quality when a better low-pass filter is used (Lanczos2) and when AA is performed in the linear color space. The improvement was observed for both scenes, but was more pronounced for the checkerboard scene. This is likely to be due to the fact that spatial filtering artifacts tend to be more visible on the checkerboard pattern. The advantage of performing AA in the linear color space was greater for the scenes where the lower quality box filter was used. Overall, downsampling in linear RGB space using an inexpensive box filter and downsampling in sRGB space with the Lanczos2 filter produced results of comparable quality. Kendall's W revealed a significant agreement among participants in ranking of the four techniques ($W = 0.90$, $p < .001$).

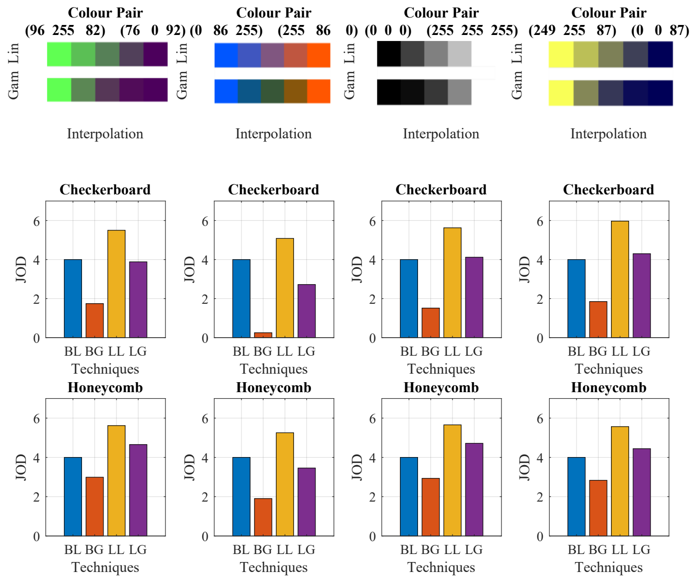

Figure 3: *The results for individual color pairs used in the experiment for checkerboard and honeycomb patterns.*

The results were fairly consistent across all colour pairs (see Fig. 3). The difference in perceived quality between techniques where downsampling was performed in the linear or the gamma-corrected color space, was most pronounced for Color Pair 2, with a box filter in the linear color space, producing even better perceived quality images than the Lanczos2 filter in the gamma-corrected space. This could be due to a hue distortion, which is present when a color pair is averaged in a gamma-corrected space.

4. Conclusions and Future Work

In conclusion, both the quality of a downsampling filter and the color space in which filtering is performed have a significant effect on the quality of rendered images. AA is currently predominantly performed in a gamma-corrected color space using inexpensive filters, such as a box filter. Our results demonstrate that this is the worst choice and that rendering can be significantly improved by operating in the linear color space and by using better filters. Furthermore, even an inexpensive box filter can substantially reduce visibility of aliasing when computed in the linear color space.

Our future work we will investigate this further by introducing more color pairs with varying deltas and by looking at changes in hue and brightness across interpolations in different spaces. We will also investigate the effects of low-pass filtering separately for different spatial frequencies.

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