Supplementary Material: Towards Foveated Rendering for Gaze-Tracked Virtual Reality

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1 Contrast Preservation

As described in the main text, we use a contrast-preserving post-process kernel inspired by existing work in the area of image filtering and downsampling [Öztireli and Gross 2015; Grundland et al. 2006; Kim et al. 2011]. While our implementation is most closely related to the work by Grundland et al. [Grundland et al. 2006], it differs in the following ways:

- We vary the size of neighborhood for and magnitude of contrast enhancement with the degree of foveation, i.e. the contrast enhancement increases with retinal eccentricity.
- Since we don't have an estimate for the actual loss of contrast (e.g. ratio of standard deviation), we use a user defined constant factor of enhancement.

In practice, our approach consists of a sequence of three postprocess passes. We first compute average color for each pixel using a radially increasing filter width. We implement a separable filter, so this step takes two passes. Next, we boost the contrast for each pixel. The following describes the final pass:

$$p'_{ij} = \bar{p}_{ij} + f_e \cdot (1 + \sigma_{ij}) \cdot (p_{ij} - \bar{p}_{ij})$$

Where, p_{ij} and p'_{ij} are the pixel colors before and after contrast enhancement, respectively; $\bar{p}_{ij}$ is the pixel color averaged over a radially increasing region; σ_{ij} is the degree of foveation measured as the effective filter width (i.e. 0 in the fovea), and f_e is a user-defined constant (set to 0.2 in our implementation).

Following is a code snippet that implements our approach:

```
vec3 enhanceContrast(vec3 pix, vec3 pmean, vec2 sigma)
{
    // computer amount of contrast enhancement
    // based on degree of foveation (sigma)
    float cScale = 1.f + length(sigma) * gParams.fe;
    vec3 scaledColor = pmean + (pix - pmean) * cScale;
    return clamp(scaledColor, vec3(0), vec3(1));
}
```

Note that we can optimize our implementation by removing the first two passes, and instead generating mipmaps of the input image. The final pass would then fetch from the appropriate mip level based on the retinal eccentricity. However, using mipmapping for contrast enhancement reduces image quality in a noticeable manner.

2 Psychometric Functions

We now present psychometric functions obtained from our user studies. To obtain these functions, we used the *psignifit* tool [Schütt et al. 2016] to fit a logistic function to our experimental data. The following sections describe each set of psychometric functions.

2.1 Emulated Foveated Rendering

In our emulated foveated rendering setup, we compare the artifact detectability threshold for introducing (a) temporal stability, and (b) temporal stability and contrast preservation. We ran the experiment for two different setups: using a desktop-based gaze tracker, and a HMD-based gaze tracker. For each setup, we have psychometric functions for four subjects.

Figure 1 shows the psychometric functions for four users who participated in our HMD setup, and Figure 2 shows the psychometric functions for participants of our desktop study. The horizontal axis represents the rate of change of peripheral blur, so higher is better. The trends for each user in both setups are consistent with the overall conclusion from the main text.

2.2 Proposed Rendering System

Figure 3 shows the psychometric functions obtained from the study comparing our proposed renderer to the one proposed by Guenter et al. [Guenter et al. 2012]. The horizontal axis of these plots, unlike the above plots, represents the size of transition regions between the high and low detail levels. Since the transition size is inversely related to the degree of foveation, lower is better. In this experiment as well, the trend across all users is consistently in favor of our renderer.

References

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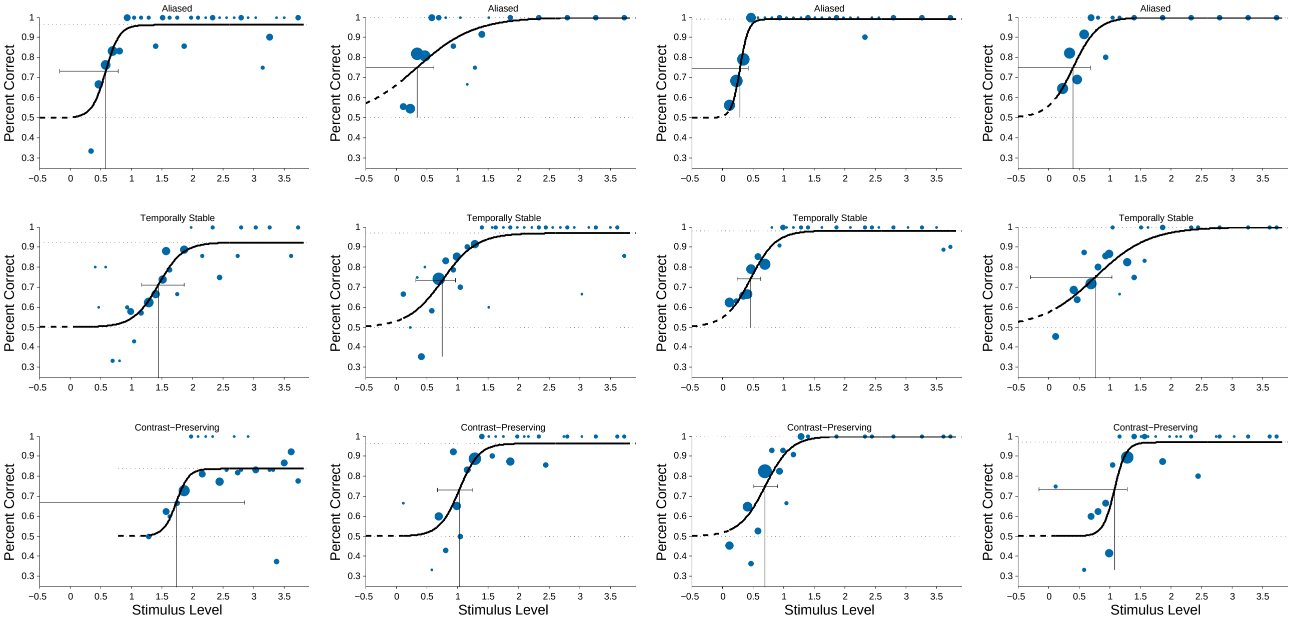

Figure 1: *Psychometric functions for emulated foveated rendering using our HMD setup. Each column shows the psychometric functions for a different user. The top row shows the psychometric functions for Aliased foveation, the middle row shows the psychometric functions for Temporally Stable foveation, and bottom row shows the psychometric functions for contrast-preserving foveation. The x-axis indicates the stimulus level i.e. blur rate measured in arcminutes per degree. Higher is better.*

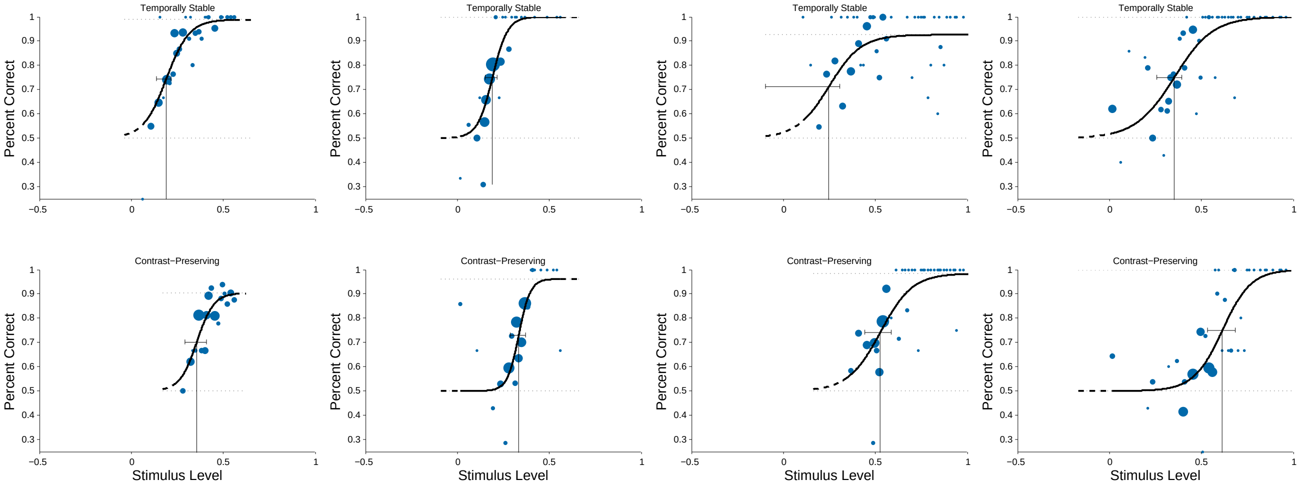

Figure 2: *Psychometric functions for emulated foveated rendering using our Desktop setup. Each column shows the psychometric functions for a different user. The top row shows the psychometric functions for Temporally Stable foveation, and bottom row shows the psychometric functions for contrast-preserving foveation. The x-axis indicates the stimulus level i.e. blur rate measured in arcminutes per degree. Higher is better.*

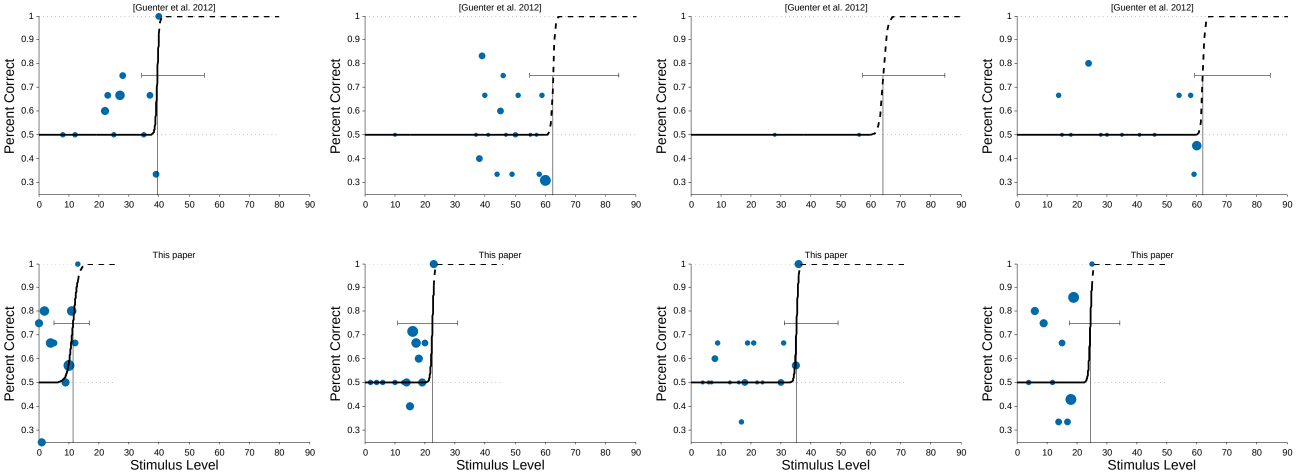

Figure 3: *Psychometric functions for our comparison between Guenter et al [Guenter et al. 2012] and our proposed rendering system. Each column shows the psychometric functions for a different user. The top row shows the psychometric functions for Guenter et al [Guenter et al. 2012], and bottom row shows the psychometric functions for our proposed renderer. The x-axis indicates the transition size in degrees. Lower is better.*