Eye-dominance-guided Foveated Rendering Supplementary Material

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Abstract— This document is the supplementary material for Eye-dominance-guided Foveated Rendering. Optimizing rendering performance is critical for a wide variety of virtual reality (VR) applications. Foveated rendering is emerging as an indispensable technique for reconciling interactive frame rates with ever-higher head-mounted display resolutions. Here, we present a simple yet effective technique for further reducing the cost of foveated rendering by leveraging *ocular dominance* – the tendency of the human visual system to prefer scene perception from one eye over the other. Our new approach, eye-dominance-guided foveated rendering (EFR), renders the scene at a lower foveation level (higher detail) for the dominant eye than the non-dominant eye. Compared with traditional foveated rendering, EFR can be expected to provide superior rendering performance while preserving the same level of perceived visual quality.

Index Terms—Virtual reality, foveated rendering, perception, gaze-contingent rendering, ocular dominance, eye tracking

1 Pilot User Study

In this supplementary material, we provide the result and analysis of the pilot study in "Eye-dominance-guided Foveated Rendering" [2].

1.1 Results of the Slider Test

The raw results of σ_{UF} and σ_{NF} in the slider test are shown in Table 1. We conducted a one-way ANOVA test [1, 3] of the null hypothesis that the feedback of the participants is related to the choice of scenes. From the one-way ANOVA test, we did not find a significant effect of the choice of scenes on the feedback (with $p = 0.8708 > 0.01$) for the slider test.

We considered the averages of σ_{UF} and σ_{NF} over different scenes to calculate the per-user foveation parameter for the dominant eye $\sigma_{UF,i}$ and non-dominant eye $\sigma_{NF,i}$ for user i. We also calculated $\frac{\sigma_{UF,i}}{\sigma_{NF,i}}$ and $(\frac{\sigma_{UF,i}}{\sigma_{NF,i}})^2$. The results for each study participant are presented in Table 2 and shown in Figure 1. The response of each participant to each of the five scenes is depicted by a dot. Hence, there are five red ($\sigma_{NF,i}$) and five blue ($\sigma_{UF,i}$) dots for each participant i.

As an example, for User 09 with $\sigma_{UF,09} = 1.20$ and $\sigma_{NF,09} = 3.00$, the fold change is $\frac{\sigma_{UF,09}}{\sigma_{NF,09}} = \frac{1.20}{3.00} = 0.40$. For this user, the dominant eye significantly dominates the visual perception and eye-dominance-guided foveated rendering is likely to achieve significant speedup.

1.2 Results of the Random Test

The raw results of σ_{UF} and σ_{NF} in the random test are shown in Table 3. For *Scenes 1* and 2 for User 13, *Scene 4* for User 12, and *Scene 1* for User 15, we received $S_{NF}(x) \leq 4$ for all comparisons in the non-dominant eye foveation parameter estimation. In the post-study interviews, Users 12, 13, and 15 revealed that they were overly aggressive with estimation of σ_{UF} in the uniform foveation parameter estimation and therefore, all the non-dominant eye foveation parameter estimation renderings for the above scenes were too blurry for them. Therefore, we discarded these data in our subsequent analysis.

We conducted a one-way ANOVA test of the null hypothesis that the feedback of the participants is related to the choice of scenes and one-way ANOVA rejects the null hypothesis with $p = 0.4314 > 0.01$.

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We use the average of σ_{UF} and σ_{NF} over various scenes to calculate the per-user foveation parameter for the dominant eye $\sigma_{UF,i}$ and the non-dominant eye $\sigma_{NF,i}$ for user i. Next, we calculated $\frac{\sigma_{UF,i}}{\sigma_{NF,i}}$ and $\left(\frac{\sigma_{UF,i}}{\sigma_{NF,i}}\right)^2$. The results are presented in Table 2 and depicted in Figure 2. From $\sigma_{UF,i}$ and $\frac{\sigma_{UF,i}}{\sigma_{NF,i}}$, we reach a conclusion similar to the one with the slider test: the disparity between the visual acuity in the dominant eye and the non-dominant eye is significant for most users.

References

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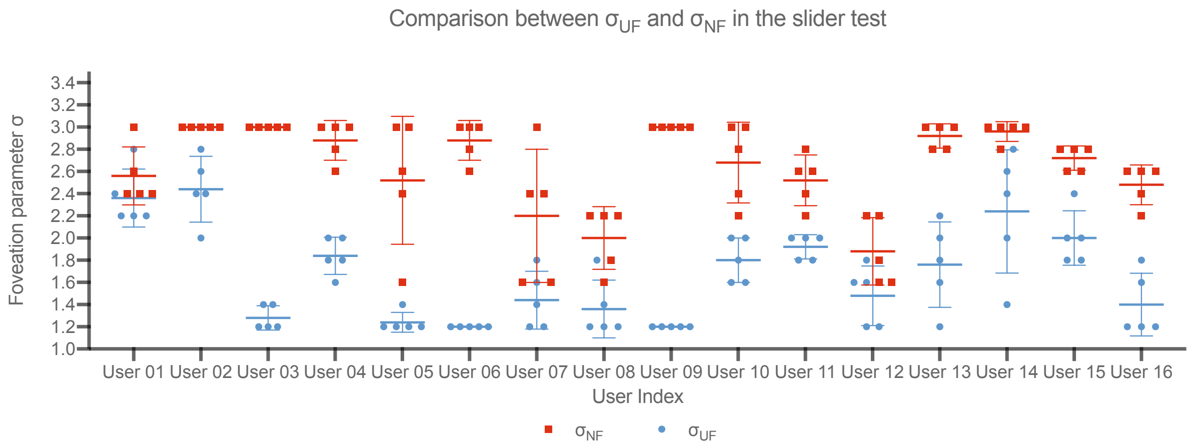

Fig. 1. The distribution of σ_{UF} and σ_{NF} in the slider test. We can notice a gap between the mean of σ_{UF} and σ_{NF}, which reveals the difference of the visual acuity of the dominant eye and the non-dominant eye.

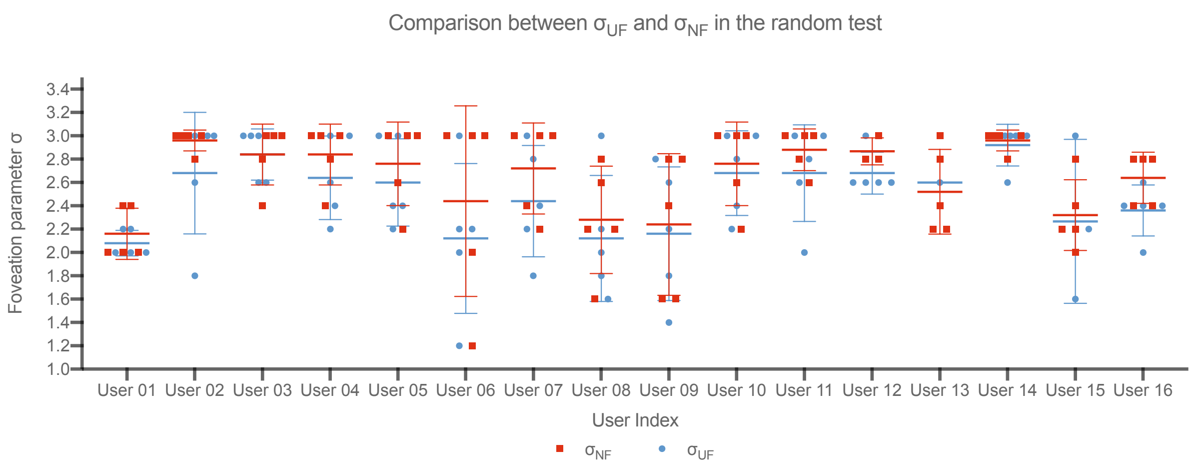

Fig. 2. The distribution of σ_{UF} and σ_{NF} in the random test. We notice a gap between the mean of σ_{UF} and σ_{NF}, which reveals the difference of the visual acuity of the dominant eye and the non-dominant eye.

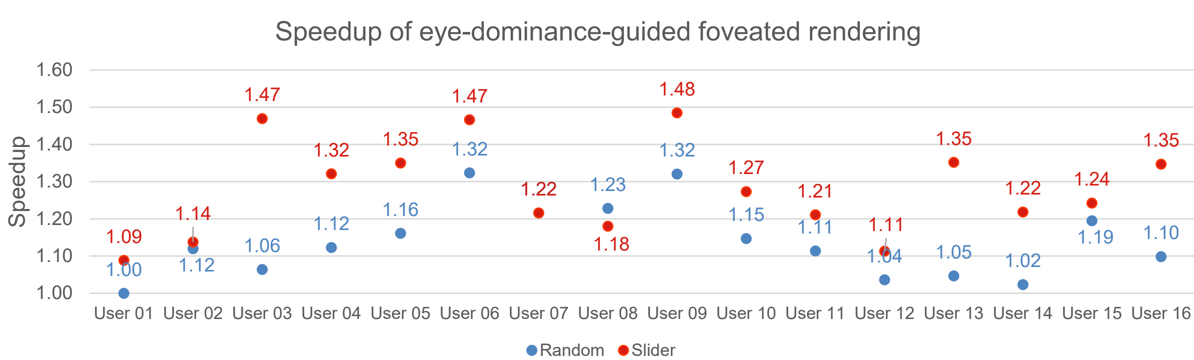

Fig. 3. The measured speedup of eye-dominance-guided foveated rendering (measured with $2 \times 3840 \times 2160$) over traditional foveated rendering ranges between $1.09\times$ and $1.48\times$ for the slider test (average speedup of $1.28\times$) and between $1.00\times$ and $1.32\times$ for the random test (average speedup of $1.14\times$). The speedup of the slider test is higher than the speedup of the random test for most of the participants. Note that the speedups for user 07 for both random and slider are identical at $1.22\times$.

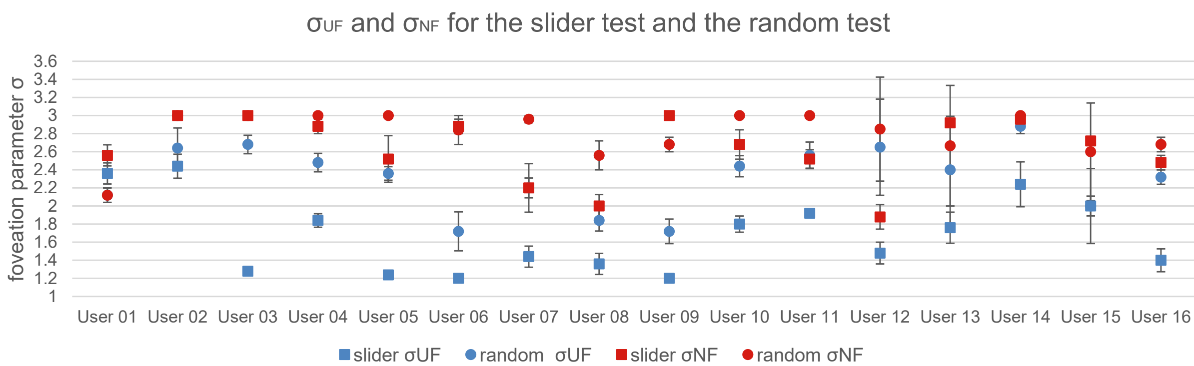

Fig. 4. The average value with the standard error of σ_{UF} and σ_{NF} in the slider test and the random test. A gap mostly exists between the two σ_{UF} in the slider test and the random test. While, there is no obvious gap between σ_{NF} in the slider test and σ_{NF} in the random test.

User index	Scene 1		Scene 2		Scene 3		Scene 4		Scene 5	
	σ_{UF}	σ_{NF}	σ_{UF}	σ_{NF}	σ_{UF}	σ_{NF}	σ_{UF}	σ_{NF}	σ_{UF}	σ_{NF}
01	2.2	2.4	2.4	2.6	2.8	3.0	2.2	2.4	2.2	2.4
02	2.0	3.0	2.4	3.0	2.6	3.0	2.4	3.0	2.8	3.0
03	1.2	3.0	1.4	3.0	1.4	3.0	1.2	3.0	1.2	3.0
04	1.6	2.6	1.8	2.8	2.0	3.0	2.0	3.0	1.8	3.0
05	1.2	1.6	1.4	2.6	1.2	3.0	1.2	2.4	1.2	3.0
06	1.2	2.6	1.2	3.0	1.2	2.8	1.2	3.0	1.2	3.0
07	1.6	3.0	1.2	1.6	1.2	2.4	1.8	2.4	1.4	1.6
08	1.4	2.2	1.2	1.6	1.8	2.2	1.2	2.2	1.2	1.8
09	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0	1.2	3.0
10	2.0	3.0	2.0	3.0	1.6	2.4	1.8	2.8	1.6	2.2
11	1.8	2.4	2.0	2.2	1.8	2.6	2.0	2.6	2.0	2.8
12	1.2	1.8	1.2	1.6	1.8	2.2	1.6	2.2	1.6	1.6
13	2.2	3.0	1.2	2.8	1.8	2.8	2.0	3.0	1.6	3.0
14	1.4	3.0	2.8	3.0	2.6	3.0	2.0	2.8	2.4	3.0
15	1.8	2.8	1.8	2.8	2.4	2.6	2.0	2.8	2.0	2.6
16	1.6	2.2	1.2	2.4	1.2	2.6	1.2	2.6	1.8	2.6

Table 1. Results of the Slider Test.

i	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average
$\sigma_{UF,i}$	2.36	2.44	1.28	1.84	1.24	1.20	1.44	1.36	1.20	1.80	1.92	1.48	1.76	2.24	2.00	1.49	1.69
$\sigma_{NF,i}$	2.56	3.00	3.00	2.88	2.52	2.88	2.20	2.00	3.00	2.68	2.52	1.88	2.92	2.96	2.72	2.68	2.64
$\frac{\sigma_{UF,i}}{\sigma_{NF,i}}$	0.92	0.81	0.43	0.64	0.49	0.42	0.65	0.68	0.40	0.67	0.76	0.79	0.60	0.76	0.74	0.56	0.65
$(\frac{\sigma_{UF,i}}{\sigma_{NF,i}})^2$	0.85	0.66	0.18	0.41	0.24	0.17	0.43	0.46	0.16	0.45	0.58	0.62	0.36	0.57	0.54	0.32	0.44

Table 2. Average per-user data in the slider test: the first row is the average foveation parameter for the dominant eye σ_{UF}; the second row is the average foveation parameter for the non-dominant eye σ_{NF}; the third row is the ratio between σ_{UF} and σ_{NF}; the fourth row is the ratio between $(\sigma_{UF})^2$ and $(\sigma_{NF})^2$.

User Index	Scene 1 σ_{UF}	Scene 1 σ_{NF}	Scene 2 σ_{UF}	Scene 2 σ_{NF}	Scene 3 σ_{UF}	Scene 3 σ_{NF}	Scene 4 σ_{UF}	Scene 4 σ_{NF}	Scene 5 σ_{UF}	Scene 5 σ_{NF}
01	2.2	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.4	2.4
02	1.8	3.0	2.6	3.0	3.0	3.0	3.0	3.0	2.8	3.0
03	2.6	3.0	2.6	3.0	3.0	3.0	2.4	3.0	2.8	3.0
04	2.2	3.0	2.6	3.0	2.4	3.0	2.8	3.0	2.4	3.0
05	2.4	3.0	2.4	3.0	2.2	3.0	2.2	3.0	2.6	3.0
06	2.0	3.0	2.2	2.2	1.2	3.0	1.2	3.0	2.0	3.0
07	1.8	2.8	2.2	3.0	2.4	3.0	2.2	3.0	2.4	3.0
08	1.6	3.0	2.0	2.2	1.8	2.6	2.2	2.8	1.6	2.2
09	1.4	2.8	1.8	2.6	2.2	2.8	1.6	2.4	1.6	2.8
10	2.4	3.0	2.2	3.0	2.8	3.0	2.6	3.0	2.2	3.0
11	2.0	3.0	2.6	3.0	2.8	3.0	2.8	3.0	2.6	3.0
12	2.6	3.0	2.6	2.6	2.6	2.8	–	–	2.8	3.0
13	–	–	–	–	2.6	3.0	2.2	2.2	2.4	2.8
14	2.6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.8	3.0
15	1.6	3.0	–	–	2.2	2.4	2.2	2.8	2.0	2.2
16	2.0	2.6	2.4	2.4	2.4	2.8	2.4	2.8	2.4	2.8

Table 3. Results of the Random Test.

i	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	Average
$\sigma_{UF,i}$	2.12	2.64	2.68	2.48	2.36	1.72	2.20	1.84	1.72	2.44	2.56	2.65	2.40	2.88	2.00	2.32	2.31
$\sigma_{NF,i}$	2.12	3.00	3.00	3.00	3.00	2.84	2.96	2.56	2.68	3.00	3.00	2.85	2.67	3.00	2.60	2.68	2.81
$\frac{\sigma_{UF,i}}{\sigma_{NF,i}}$	1.00	0.88	0.89	0.83	0.79	0.61	0.74	0.72	0.64	0.81	0.85	0.93	0.90	0.96	0.77	0.87	0.82
$\left(\frac{\sigma_{UF,i}}{\sigma_{NF,i}}\right)^2$	1.00	0.77	0.80	0.68	0.62	0.37	0.55	0.52	0.41	0.66	0.73	0.86	0.81	0.92	0.59	0.75	0.69

Table 4. Average per-user data in the random test: the first row is the average foveation parameter for the dominant eye σ_{UF}; the second row is the foveation parameter for the non-dominant eye σ_{NF}; the third row is the ratio between σ_{UF} and σ_{NF}; the fourth row is the ratio between $(\sigma_{UF})^2$ and $(\sigma_{NF})^2$.