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Poster

Parallax-based Glyph Composition Technique with Colour-Blending Glyphs (Supplementary Materials)

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Abstract

This document provides supplementary materials to "Parallax-based Glyph Composition Technique with Colour-Blending Glyphs." It includes additional information, diagrams, and statistics not found in the poster paper.

CCS Concepts

• Human-centered computing → Visualization design and evaluation methods; • Computing methodologies → Mixed / augmented reality;

1. Introduction

One can find additional information excluded from the main text. This information includes the design specification of the glyphs displayed in the study, the shader algorithm for the colourmap used in the study, the post-technique questionnaires and their results, and additional test statistics.

2. Glyph and Colourmap

In this section, we describe the glyph used in the study and the colourmap. Both Radial and Stacked are composed of square coloured glyphs. Each glyph is a 0.5cm-wide square. Its value is a unit interval number (i.e. between zero and one), and is represented by a divergent colourmap adopted from "Conifer Forest" found in ArcGIS [Arc22] (Fig. 1-RIGHT). Teal represents the minimum value (0), gray represents the midpoint (0.5), and salmon represents the maximum value (1). The colourmap is divergent because it has two hues [HB03]. This colourmap is appropriate for the study due to its relative isoluminance–i.e. maintaining the same luminance regardless of the value [CSH20, Kov19]. Typically, an isoluminant colourmap is not desirable because people with certain types of colour-vision deficiency (CVD) needs luminance to distinguish values [CSH20]. However, an additive HWD like Microsoft HoloLens v2 renders low-luminance colour as transparent. This means low-value glyphs become invisible [EKL*21]–effectively adding transparency into a confounding variable. A pilot study showed that the blue-yellow colourmap (Fig. 1-LEFT) was extremely affected by this issue, while the teal-salmon colourmap (Fig. 1-RIGHT) was not.

Figure 1: ***LEFT:*** *The top colourmap is a non-isoluminant one. The bottom colourmap is created by converting the top colourmap's luminance to opacity to simulate the visibility on an additive HWD. More opacity means better visibility. We observe that low-value colours are very transparent. A photo of a Masonic temple was used to illuminate the effect.* ***RIGHT:*** *The top colourmap is a more isoluminant colourmap used in the study. We can see that the visibility is higher for the lower values (bottom).*

To allow the constituent glyphs to blend multiplicatively, we use a specially designed shader with three passes:

White Pass The shader draws white pixels where the glyphs are to prevent multiplication with the transparent background. When

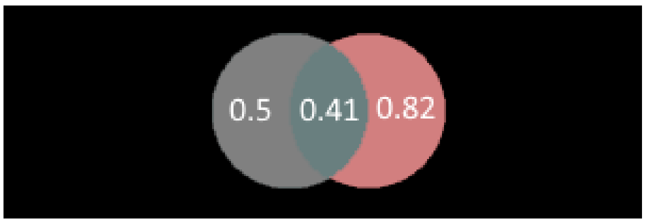

Figure 2: *Example of multiplicative colour blending with a Venn diagram with the isoluminant colourmap. Numbers denote values. Our shader-based colouring ensures the same colourmap still applies to the overlapping area.*

drawing, it also checks the stencil buffer to ensure that a pixel is drawn once.

Greyscale Blending The shader converts the glyph values into grayscale. Let $v \in [0,1]$ be the value of a glyph, then the colour RGB is $(v \times 255, v \times 255, v \times 255)$. Since this pass includes a multiplicative blending, the overlapping values multiplied.

Adding Fixed Colour To ensure the glyphs and their overlapping areas' colours are the same as the colourmap, we replace several colour channels with a fixed number. For the colourmap used in the study (Fig. 1-RIGHT), we replace the green and the blue channels with 127. Therefore, the final colour is $(w \times 255, 127, 127)$ where $w = \prod_{i=1}^{x} v_x$ where each v_i is an occluding glyph's value. To produce the non-isoluminant colourmap in Fig. 1-LEFT, we only fix the blue channel to 127. Fig. 2 shows an example of multiplicative blending.

3. Tablet Interface

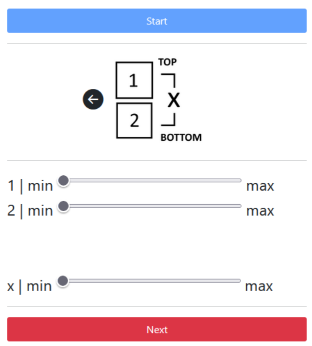

Figure 3: *The tablet menu the participants used to indicate values. The visual aid is for a trial with Double Stacked glyphs. Please refer to Fig. 4 for the visual aid variations.*

The tablet interface (Fig. 3) was used by the participants to input their values. The interface consists of a diagram of the glyph design, and the sliders. Fig. 4 contains all possible diagrams that the participants will see throughout the study. The participants move the slider to indicate the desired values. Each slider has the minimum value of 0, the maximum value of 1, and the step value of 0.01. If the glyphs appear off-screen (i.e., at 0.2m, and 1.5m), the tablet interface also displays a left arrow alongside the diagram.

4. UMUX Questionnaire

The main text does not include the questionnaire results, because we found the results to not have any noticeable impact on accuracy or trial duration. Still, the information is available here for those who are interested.

After completing the 54 experiment trials, the participants completed a Likert-scale questionnaire on their experience using a technique. The first four statements were from UMUX (see [LUM13]). We added four additional statements. In the end, the statements were (+ denotes our own statement.):

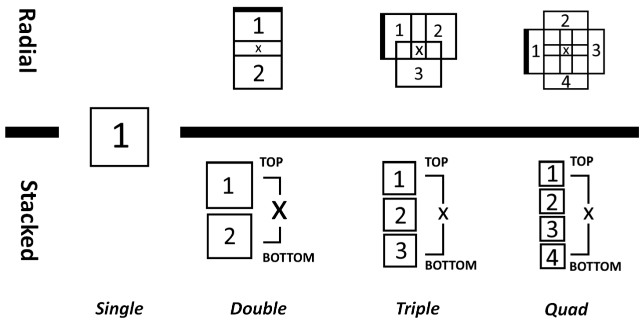

Figure 4: *Variations of the diagrams in Fig. 3. The figure also shows the relationship between GCS and the techniques. Radial and Stacked are indistinguishable when GSC=1 (Single). X denotes the area where the user can find the blended value of all glyphs; for Stacked, the participants must blend all glyphs to obtain the blended value. Thicker borders on some Radial glyphs are actually not present in AR; they are only to help the participants to identify the first glyph. Actual Stacked glyphs are orthogonal to the screen, not flat against the screen like in the figure.*

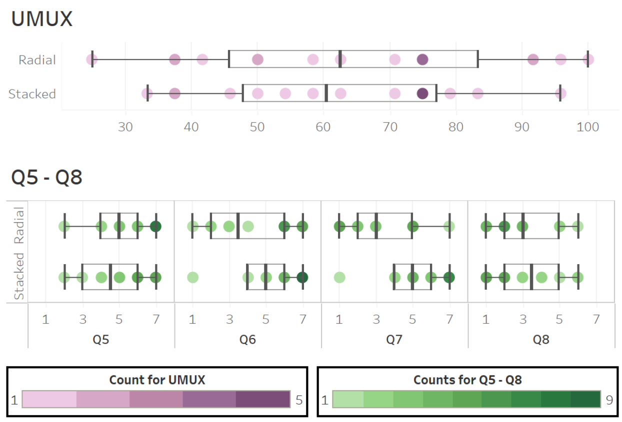

Figure 5: *The distributions of the UMUX scores and the questionnaire scores. Each purple/green dot represents the frequency of a specific score.*

Q1 The technique is good overall.
Q2 Using this technique is frustrating.
Q3 The technique is easy to use.
Q4 I spent too much time with the technique.
Q5+ The technique is easy to understand.
Q6+ I moved and rotated my head a lot with the technique.
Q7+ I moved my body a lot with the technique.
Q8+ I prioritized speed over correctness.

The pairwise statistical tests on the questionnaire were not significant. Fig. 5 shows the distributions of the UMUX scores. The median UMUX score for Radial was 66.667 out of 100, and the score for Stacked was 72.917 out of 100. Despite having different medians, the Wilcoxon signed-rank test comparing the UMUX distributions was not statistically significant ($W = 31.5, p = 0.929$). Then, we analyzed the answers to Q5 to Q8 which pertain to participants' movements. Fig. 5 shows the distributions of the participants' answers. The Wilcoxon signed-rank tests for Q5 ($W = 44.5, p = 0.692$), Q6 ($W = 23, p = 0.120$), and Q8 ($W = 31.5, p = 0.929$) were not statistically significant. However, the Wilcoxon signed-rank test for Q7 was ($W = 1.5, p = 0.005$)–albeit with a small Kerby's r [Ker14] of 0.011. This means that the participants believed they moved slightly more with Stacked. This had a very minimal impact on the accuracy and no effect on the trial durations.

5. Statistics on Accuracy

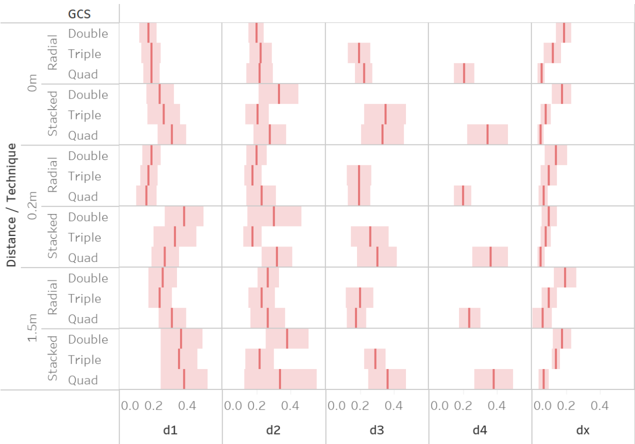

Figure 6: *The medians of AbsDiffs by distance, technique, GCS with 95% confidence intervals created using Tableau. Higher AbsDiff means less accuracy.*

	SS	F	p	R^2
Omnibus ($df = 1, df_{res} = 1719, \alpha = 0.05$)				
Technique	2.833	104.420	0.001*	0.046
Distance	0.280	10.320	0.001*	0.006
GCS	11.287	415.990	0.001*	0.183
MSD	0.159	5.860	0.002*	0.003
Tech. x Dist.	0.016	0.610	0.608	<0.001
Tech. x GCS	0.423	15.610	0.001*	0.007
Dist. x GCS	0.015	0.560	0.656	<0.001
Tech. x Dist x GCS	0.013	0.480	0.677	<0.001
Post-Hoc: Technique x GCS ($df = 1, df_{res} = 574, \alpha = 0.017$)				
Radial, Double v Stacked Double	2.771	62.602	0.001*	0.098
Radial, Triple v Stacked, Triple	1.424	40.042	0.001*	0.065
Radial, Quad v Stacked, Quad	1.874	48.743	0.001*	0.078
Post-Hoc: Technique ($df = 1, df_{res} = 574, \alpha = 0.05$)				
Stacked v Radial	2.833	83.117	0.001*	0.046
Post-Hoc: Distance ($df = 1, df_{res} = 1150, \alpha = 0.017$)				
0m v 0.2m	0.040	1.155	0.234	0.001
0m v 1.5m	0.205	5.655	0.001*	0.005
0.2m v 1.5m	0.250	6.833	0.001*	0.006
Post-Hoc: GCS ($df = 1, df_{res} = 1150, \alpha = 0.017$)				
Double v Triple	0.994	24.344	0.001*	0.021
Double v Quad	0.656	15.313	0.001*	0.013
Triple v Quad	0.682	17.384	0.001*	0.015

Table 1: *PERMANOVA tests. We used the Bonferroni adjustment for the post-hoc tests. * denotes p is lower or equal to the* α.

Fig. 6 shows the medians and their conditions based on the absolute difference (AbsDiff) of the participants' answers to the real values. $d1-4$ refers to AbsDiff of the first to the fourth glyphs in a composite. dx refers to the AbsDiff of the blended value. We note that dx decreases as GCS increases; this is due to the multiplied values are getting closer to zero with increased GCS. Fig. 6 can also be found in the main text. Table 1 shows the results of the omnibus PERMANOVA test (see [And17] for more information) on accuracy and the subsequent posthoc tests. We did not use a parametric test, because AbsDiff are bounded values which make them beta-distributed [Gup11].

6. Statistics on Trial Durations

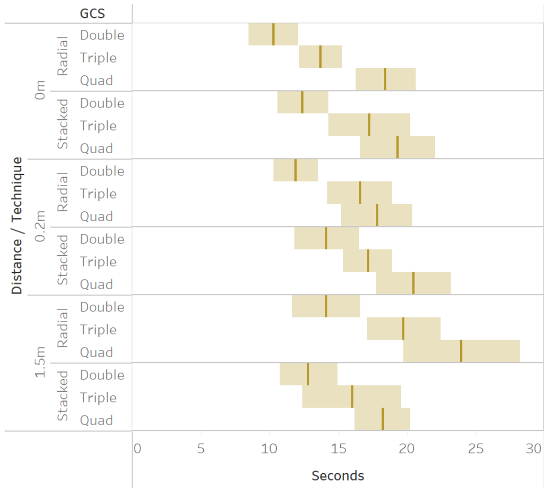

Figure 7: *The medians of the trial durations by distance, technique, and GCS with 95% confidence intervals generated using Tableau.*

	F	df	p	$\eta^2_{partial}$
Technique	0.005	1	0.941	≤ 0.001
Distance	9.701	2	$\leq 0.001*$	0.01
GCS	14.318	2	$\leq 0.001*$	0.14
Technique x Distance	2.257	2	$\leq 0.001*$	0.03
Technique x GCS	1.258	2	0.284	0.001
Distance x GCS	2.179	4	0.069	0.005
Technique x Distance x GCS	2.444	4	0.045*	0.006

Table 2: *The results of the omnibus mixed effect ART-ANOVA tests on duration with the participant as the random effect. The residual degrees of freedom for all sources are: 1695. * denotes* $p \leq 0.05$.

Fig. 7 shows the median trial durations and their confidence intervals. This figure can also be found in the main text. Table 2 shows the results of the omnibus ART-ANOVA test (see [WFGH11,EKHW21] for more information) for the trial durations. Table 3 shows the results of the posthoc contrast tests.

7. Head Movements

Fig. 8 shows the head movements as recorded by the HoloLens. It is also available in the main text.

	Estimate	SE	df	t	p	d
Technique x Distance x GCS						
Stacked-Radial & 0m-0.2m & Double-Triple	-111.1	114	1695	-0.971	0.332	-0.024
Stacked-Radial & 0m-1.5m & Double-Triple	-157.4	114	1695	-1.375	0.169	-0.034
Stacked-Radial & 0.2m-1.5m & Double-Triple	-46.3	114	1695	-0.405	0.686	-0.010
Stacked-Radial & 0m-0.2m & Double-Quad	15.2	114	1695	0.133	0.894	0.003
Stacked-Radial & 0m-1.5m & Double-Quad	-274.8	114	1695	-2.4	0.017*	-0.059
Stacked-Radial & 0.2m-1.5m & Double-Quad	-290	114	1695	-2.533	0.011*	-0.062
Stacked-Radial & 0m-0.2m & Triple-Quad	126.3	114	1695	1.104	0.270	0.027
Stacked-Radial & 0m-1.5m & Triple-Quad	-117.3	114	1695	-1.025	0.306	-0.025
Stacked-Radial & 0.2m-1.5m & Triple-Quad	-243.6	114	1695	-2.129	0.033*	-0.052
Technique x Distance						
Stacked-Radial & 0m-0.2m	7.81	46.6	1695	0.168	0.867	0.004
Stacked-Radial & 0m-1.5m	274.92	46.6	1695	5.901	<0.001*	0.143
Stacked-Radial & 0.2m-1.5m	267.11	46.6	1695	5.733	<0.001*	0.139
Distance						
0m-0.2m	-47.5	23.4	1695	-2.033	0.105	-0.049
0m-1.5m	-102.8	23.4	1695	-4.401	<0.001*	-0.107
0.2m-1.5m	-55.3	23.4	1695	-2.367	0.047*	-0.057
GCS						
Double-Triple	-222	22.3	1695	-9.956	<0.001*	-0.242
Double-Quad	-375	22.3	1695	-16.828	<0.001*	-0.408
Triple-Quad	-153	22.3	1695	-6.872	<0.001*	-0.167

Table 3: *The post-hoc tests (Tukey-adjusted) for the duration with Cohen's d. The unit is in millisecond. * denotes* $p \leq 0.05$.

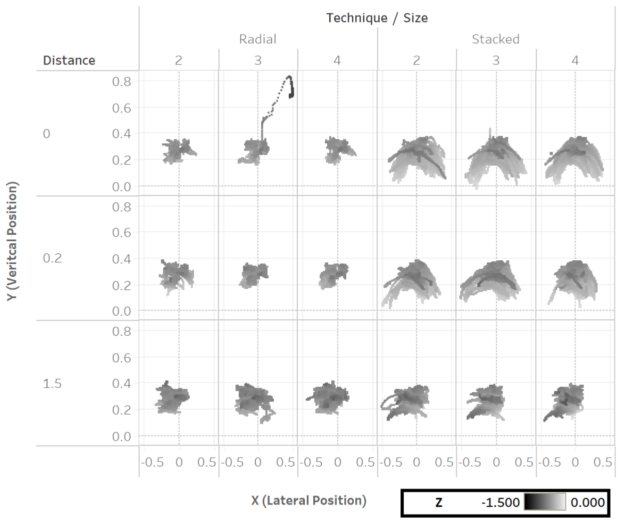

Figure 8: *Caption*

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