Effects of Global Illumination Approximations on Material Appearance (Supplementary Material)

This is the supplementary material for the paper entitled *Effects of Global Illumination Approximations on Material Appearance* by Jaroslav Křivánek, Jim Ferwerda and Kavita Bala published in ACM Transactions on Graphics, Volume 28, Issue 3, 2010. This document contains additional details on the experiments, a detailed result table for direct-and-indirect illumination, the results of multiple factor analyses of variance (ANOVA) on the data from the two experiments, details on the selection of images for the validation experiments, and examples of outliers that do not follow the broad trends observed in the data.

1 Details on Experiments

This section details the experiment setup described in Section 4 of the paper.

1.1 Stimuli

The scene used to create the stimulus images was of an art gallery café with dimensions of 4×3×2.6 metres. The diameter of the test object was approximately 1.2 metres. A 3ds Max model of the scene is included with the auxiliary material (file stimulus2.max). A view of the scene from the outside of the room is shown in Figure 1.

Lighting included both spot and area fixtures. The geometry of the spot fixtures was not present in the scene to save modeling effort. We ran the experiments with two different versions of illumination: indirect-only and direct-and-indirect. In the *indirect-only* version, only the spot lights were on. These were configured such that they

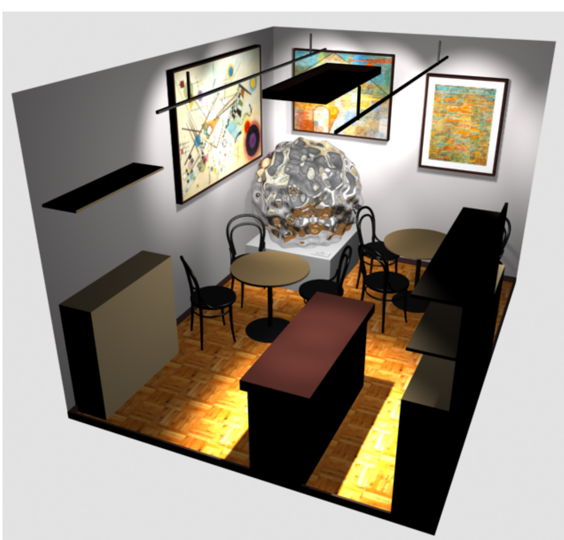
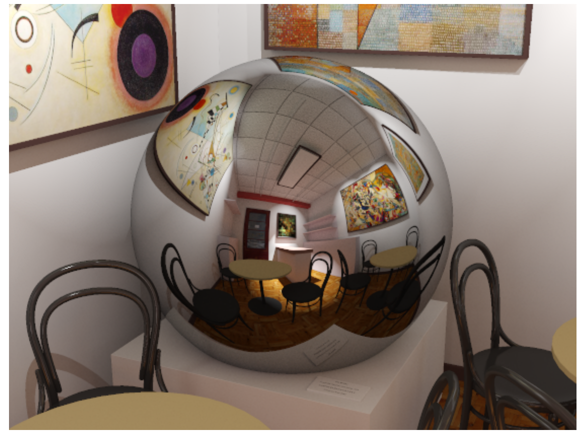


Figure 1: *A rendering of the art gallery café scene used to create the stimulus images. The walls adjacent to the camera and objects thereon were hidden in this image to allow an unobstructed view of the interior. Note that this image was rendered in 3ds Max using a different rendering algorithm than the one we used to produce the stimulus images, and therefore should not be considered as a reference for illumination.*



(a) indirect-only

(b) direct-and-indirect

Figure 2: *Rendering of the scene reflected in a mirror sphere. (a) indirect-only illumination, (b) direct-and-indirect illumination.*

did not illuminate the test object directly; some were pointed at paintings on the walls, others illuminated the café bar behind the camera. Figure 2 (a) shows the scene with indirect-only illumination reflected in a mirror sphere.

The *direct-and-indirect* illumination used the same spot lights and an additional area light source attached to the ceiling. This light source contributed direct illumination to the test object and formed pronounced highlights on its surface. Note that direct illumination was not affected in any way by approximations in VPL rendering. Figure 2 (b) shows the scene rendered with the direct-and-indirect illumination.

Reference stimulus images from the indirect-only set are shown in Figure 5 of the paper. Figure 7 in this document shows the stimuli for the direct-and-indirect illumination. Two different camera viewpoints were used in our experiments to make the task object-focused rather than image-focused. Figure 3 shows the two viewpoints.

Figure 4: *Familiarization image shown to subjects prior to the artifacts threshold study.*

The images were rendered in high dynamic range (HDR) and were all tone-mapped for display using the global version of Reinhard et al.'s photographic tone mapping operator [2002]. The tone-mapping parameters were set manually such that the low reflectance objects ($\rho_d = 0.03$) appeared black. We used two different tone mapping settings for the direct-and-indirect and indirect-only illumination to equalize the energy differences in the images. The same tone-mapping curve was then used for all shapes, materials, VPL counts, and clamp levels.

1.2 Procedure

Artifact experiment. Prior to testing, the experimenter engaged in the following interaction with the subject.

"Our research is on perceptually-based rendering, which means that we are trying to take advantage of the properties of human vision to make the computer graphics rendering process more efficient. If we do our job well the images look good and the renderings go fast, but if we push things too hard then artifacts can appear in the images. Here on the screen are examples of some of the images you will see in the experiment. [Shows the image in Figure 4, a composite of 12 different stimulus images, some with visible artifacts.] *Do you see any images that you would say have artifacts?* [Subject typically points to an image with clearly visible spots and speckles.] *Do you see others?* [Subject points to other images with artifacts of lesser degree.] *In the experiment you will be shown pairs of images like these and your task is to say which one in the pair has artifacts. Since this is a threshold study some cases will be harder than others. If you're not sure, make your best guess. Do you think you have a good sense of what the task is? Do you have any questions?"*

Figure 3: *The two camera viewpoints used to render stimulus images for the experiments.*

Material experiment. Only images judged as artifact-free were included for testing in the material study. Here we give details of the image pruning procedure. Since material appearance change is known to increase with clamping level, for each object/VPL level combination, log unit clamping levels, starting at the most severe ($C10 = 0.01$), were selected until the clamping level corresponding to the artifact threshold was hit. If the artifact threshold fell on a half-log unit clamping level this VPL/clamp level combination was also included in the test set. For example if for a particular object/VPL combination the artifact threshold was found to be 31.6 then images corresponding to clamp levels 0.01, 0.1, 1.0, 10.0 and 31.6 were tested. This procedure resulted in a test image set of 519 images.

Prior to testing, the experimenter engaged in the following interaction with the subject:

[Subject was shown a sample "trial" from the experiment.] *"In each set of images that you will be shown, the spatial layout of the scene, the shapes of the objects, and the lighting will always be the same. The viewpoints of the reference image and the test image pair will always be slightly different, so the reference and test images will never be identical pixel for pixel."*

"In this study we are interested in the material properties of objects on the pedestal. On each trial your task is to say which of the test objects is made out of a different material than the reference object. So for example if you were shown this set of images which one would you choose. [Subject typically chooses the one where the object properties look different.] *Here's another... Again, since this is a threshold study some cases will be harder than others. If you're not sure, make your best guess. Do you think you understand what the task is? Do you have any questions?"*

1.3 Data Analysis

Figure 8 gives the complete result table for the direct-and-indirect illumination. The two tables in Figure 5 show the results of

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob$>F$
geometry	240.31	3	80.1036	28.25	0.0000
illumination	37.84	1	37.8400	13.35	0.0003
matl. diff. refl. ρ_d	38.12	1	38.1242	13.45	0.0003
matl. spec. refl. ρ_s	2.42	1	2.4167	0.85	0.3563
matl. roughness α	0.96	1	0.9648	0.34	0.5599
clamp level	17.27	10	1.7268	0.61	0.8065
VPL count	7.58	2	3.7909	1.34	0.2636
Error	1304.12	460	2.8350		
Total	1902.33	479			

(a) artifact visibility experiment

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob$>F$
geometry	155.01	3	51.669	20.96	0
illumination	0.41	1	0.406	0.16	0.6849
matl. diff. refl. ρ_d	1.93	1	1.932	0.78	0.3766
matl. spec. refl. ρ_s	290.36	1	290.359	117.78	0
matl. roughness α	64.19	1	64.187	26.04	0
clamp level	662.33	11	60.212	24.42	0
VPL count	118.04	2	59.021	23.94	0
Error	1013.20	411	2.465		
Total	2789.25	431			

(b) material change experiment

Figure 5: *ANOVA results for the artifact visibility experiment (a), and the material change experiment (b).*

multiple factor analyses of variance (ANOVA, see Snedecor and Cochran [1989]) on the data from the two experiments. In the artifact visibility experiment, object geometry (G0–G3), illumination (direct-and-indirect / indirect-only) and material diffuse reflectance (ρ_d) showed significant effects at the ($p < 0.001$) level. In the material change experiment, all factors showed significant effects at the ($p < 0.001$) level except illumination (direct-and-indirect / indirect-only) and material diffuse reflectance (ρ_d).

2 Validation

The validation study used the same experimental design and procedure as the main experiments with a slight difference in how images were selected for the material experiment, as detailed below.

For efficiency reasons, we ran the two experiments (artifact visibility and material change) in the same session. So we could not use the threshold from the artifact study to prune the stimuli for the material study. Instead, we included all whole log unit clamping levels ($C10 = 0.01$, $C8 = 0.1$, etc.), excluding images that in pre-testing appeared to be far above the estimated artifact visibility and material change thresholds. Consequently, some images with visible artifacts appeared in the material experiment of the validation.

3 Outlier Examples

Figure 6 shows examples of outliers that do not follow the broad trends observed in the data.

References

REINHARD, E., STARK, M., SHIRLEY, P., AND FERWERDA, J. 2002. Photographic tone reproduction for digital images. In *Proc. SIGGRAPH 2002*, 267–276.

SNEDECOR, G. W., AND COCHRAN, W. G. 1989. *Statistical Methods*. Ames: Iowa State University Press.

(a) indirect-only, G3, MS → MR, 100k, C2

(b) indirect-only, G3, MS → BS, 100k, C1

(c) indirect-only, Dragon, GS → diffuse, 100k, C2

(d) direct-and-indirect, G1, BS, 100k → 5M, C6

Figure 6: *Examples of outliers that do not follow the broad trends observed in the data. Each row shows a pair of stimulus images rendered using parameters given below the row. Only one parameter varies within one row, as indicated with the arrow (param. left → param. right). In each row, as we move from the left image to the right one, the equivalence should increase according to the broad trends, but it decreases in the data. The trends corresponding to the rows are: increase of equivalence with surface roughness (a); increase of equivalence with lower contrast gloss (b) and (c); and increase of equivalence with higher VPL count (d).*

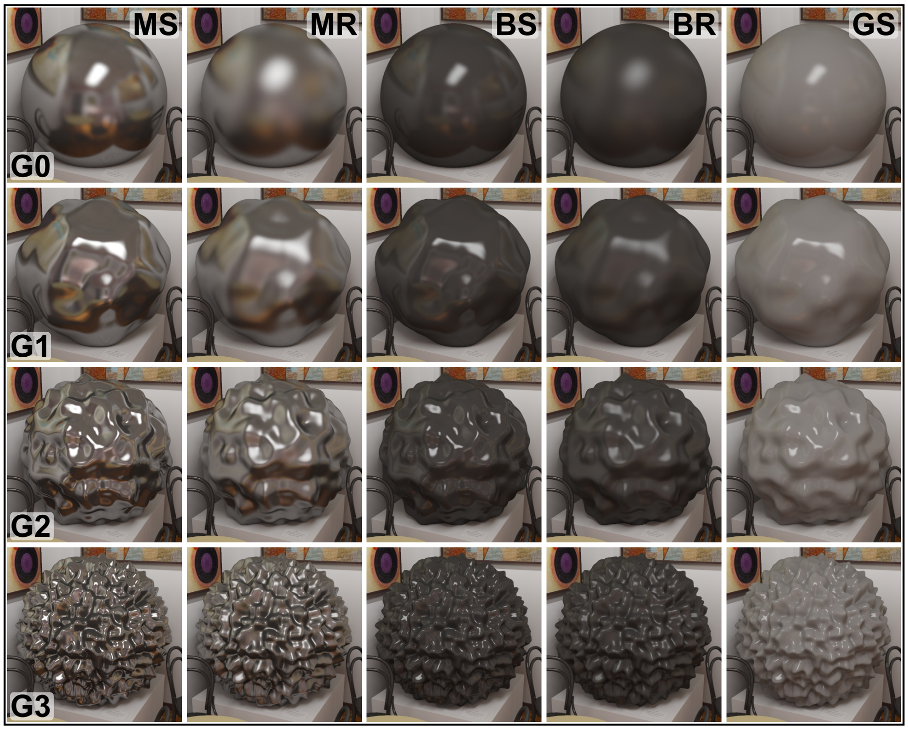


Figure 7: *Reference renderings of stimulus objects used in the main study with direct-and-indirect illumination. The corresponding images for the indirect-only set are shown in Figure 5 of the paper.*

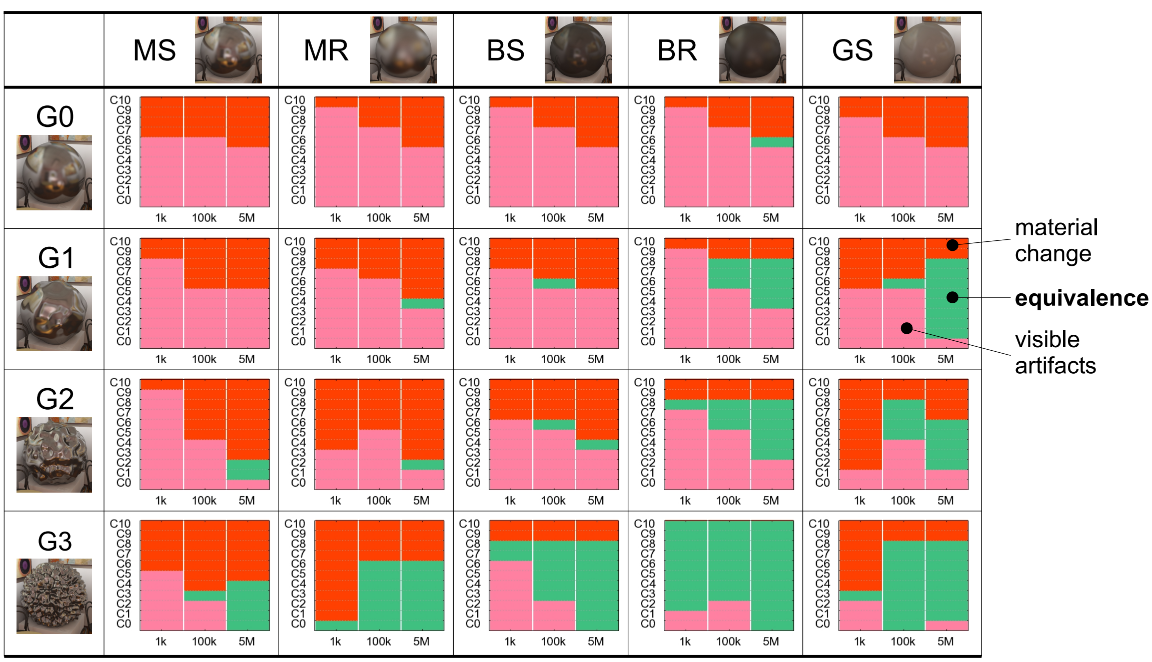


Figure 8: *Results of the artifact and material experiments with direct-and-indirect illumination. Rows correspond to shapes G0–G3 (top to bottom). Columns correspond to different materials. The corresponding table for the indirect-only illumination is shown in Figure 7 (a) of the paper.*