

Light warps for enhanced surface depiction: Supplementary results

1 Alternative inputs

Toler-Franklin et al. [2007] have introduced RGBN images to create different styles (such as toon shading, line drawing, curvature shading, and exaggerated shading) for shape depiction. An RGBN image is the combination of a classical color image used as texture, the corresponding normal field, and an occlusion map that can be used as silhouette weights. Such a representation can thus be directly used with our approach (see Figure 3).

2 Objects with creases

As said in the paper, our descriptor consists of a set of visible surface points on silhouettes and creases, and interior surface points for which we can compute view-centered curvature. In Figure 1 we show the influence of creases that occurs on CAD-like objects.

3 View- vs object-centered curvatures

We compare view- and object-centered curvature tensors in Figure 2. For this purpose we use a wave object, which has been perturbed with noise on half of its surface. Mean curvature is displayed on the object with the color gradient used in the paper, at two different depths, and at a grazing angle. In the left column, object-centered curvature is used. Note how the perturbations on the left are kept unchanged in both settings, a configuration that would make the final rendering cluttered with noisy details in our light warping approach. In contrast, our view-centered curvature naturally abstracts out these details, as shown in the middle column. It is quite similar to the object-centered descriptor though. This is made possible by the restriction of pixel neighborhoods to silhouettes. For comparison, we show the view-centered curvature without taking silhouettes into account in the right column; note the fake concavities that appear around silhouettes.

4 Additional real-time renderings

We have experimented with our light warping for direct lighting with numerous styles, materials and objects. Some results are gathered in this Section. Our approach works well with a large range of lightings, from diffuse (see Figure 5) to glossy (see Figures 5 to 9) and even toon-shading (see Figure 9). We use the Ashikhmin's BRDF model [Ashikhmin et al. 2000] for diffuse to glossy direct and indirect illumination. For toon-shading like results, we simply quantize the reflected intensity as suggested by Winnemöller et al. [Winnemöller et al. 2006].

Our approach is controlled by two main parameters: the warping itself and the contrast enhancement. As shown in Figures 5 to 9, the light warping increases the perception of surface details. Without warping, the contrast enhancement has no effects (see the first row of Figures 7 and 8). But it still results in large improvements of shape perception when combined with light warping (see Figure 5 to 9). For maximum contrast, we are also getting away from the original realistic rendering. Designed for directional lighting with natural statistics, our approach still works well with smooth illumination. In Figure 4, despite the fact that the environment map is a simple gradient from white to black, light warping still offers a large improvement in shape depiction.

5 Additional off-line renderings

The current implementation of light warping for real-time rendering is currently limited to direct lighting with a restricted number of light directions. We have also integrated our light warping approach into our path-tracer [Dutr e et al. 2006]. To try our approach on more complex illuminations such as direct and indirect lighting, ambient occlusion (see Figures 10 and 11) and refractive materials (see Figures 12 to 14). This implementation is not optimized, and the overhead of warping is about 20% for direct lighting. This overhead is reduced with the number of indirect reflections. Note that the descriptor is still computed on the GPU. As stated in the paper, the inverse formulation (i.e., Equation 2) is more suited for direct lighting. In our implementation, each pixel of the environment map is used as an independent directional light source. We use the direct formulation of light warping (i.e., Equation 1 of the paper) to estimate the ambient occlusion and the indirect lighting. For ambient occlusion [Pharr and Green 2004], we simply sample the hemisphere and warp the corresponding directions. The visibility is computed for these warped directions. For indirect lighting, rays issued from the view-point are stochastically reflected at the first intersection. This reflected direction is warped before continuing the ray propagation.

This implementation shows some large improvements even for pure specular and refractive materials. Note how eyes' shape is more easily perceived in Figure 14, and how all column details are enhanced in Figure 13. Some improvements are also noticeable on ambient occlusion: this is due to the fact that warping increases or reduces the visible part of the hemisphere. As shown in Figures 12, 14 and 13, specular and refractive materials exhibit some limitations of our approach. Since light warping increases spatial variations in image, it also increases aliasing problems along main surfaces features. Similarly, noise is also increased in naive Monte-Carlo estimation (as shown in Figure 10). Moreover, the environment map should exhibit some "natural statistics" [Fleming et al. 2004] that is, some uniform frequency of details everywhere without strong anisotropic features, to depict accurately the shape. In Figure 14, the eyes are enhanced by the warping since the reflected part of the environment map contains some strong variations, but the mouth shape is attenuated due to the low variation of the new corresponding part of the environment map. A full enhancement would require to take into account the characteristics of incident lighting.

References

- ASHIKHMIN, M., PREMOZE, S., AND SHIRLEY, P. 2000. A microfacet-based BRDF generator. In *Proc. ACM SIGGRAPH '00*, ACM, 65–74.
- DUTR E, P., BALA, K., AND BEKAERT, P. 2006. *Advanced Global Illumination (Second Edition)*. A. K. Peters, Ltd.
- FLEMING, R. W., TORRALBA, A., AND ADELSON, E. H. 2004. Specular reflections and the perception of shape. *J. Vis.* 4, 9 (9), 798–820.
- PHARR, M., AND GREEN, S. 2004. *GPU Gems*. Addison-Wesley, ch. Ambient Occlusion.
- TOLER-FRANKLIN, C., FINKELSTEIN, A., AND RUSINKIEWICZ, S. 2007. Illustration of Complex Real-World Objects using Images with Normals. In *NPAR '07: Proc. international symposium on Non-photorealistic animation and rendering*, ACM, 111–119.
- WINNEM LLER, H., OLSEN, S. C., AND GOOCH, B. 2006. Real-time video abstraction. *ACM Trans. Graph. (Proc. SIGGRAPH 2006)* 25, 3, 1221–1226.

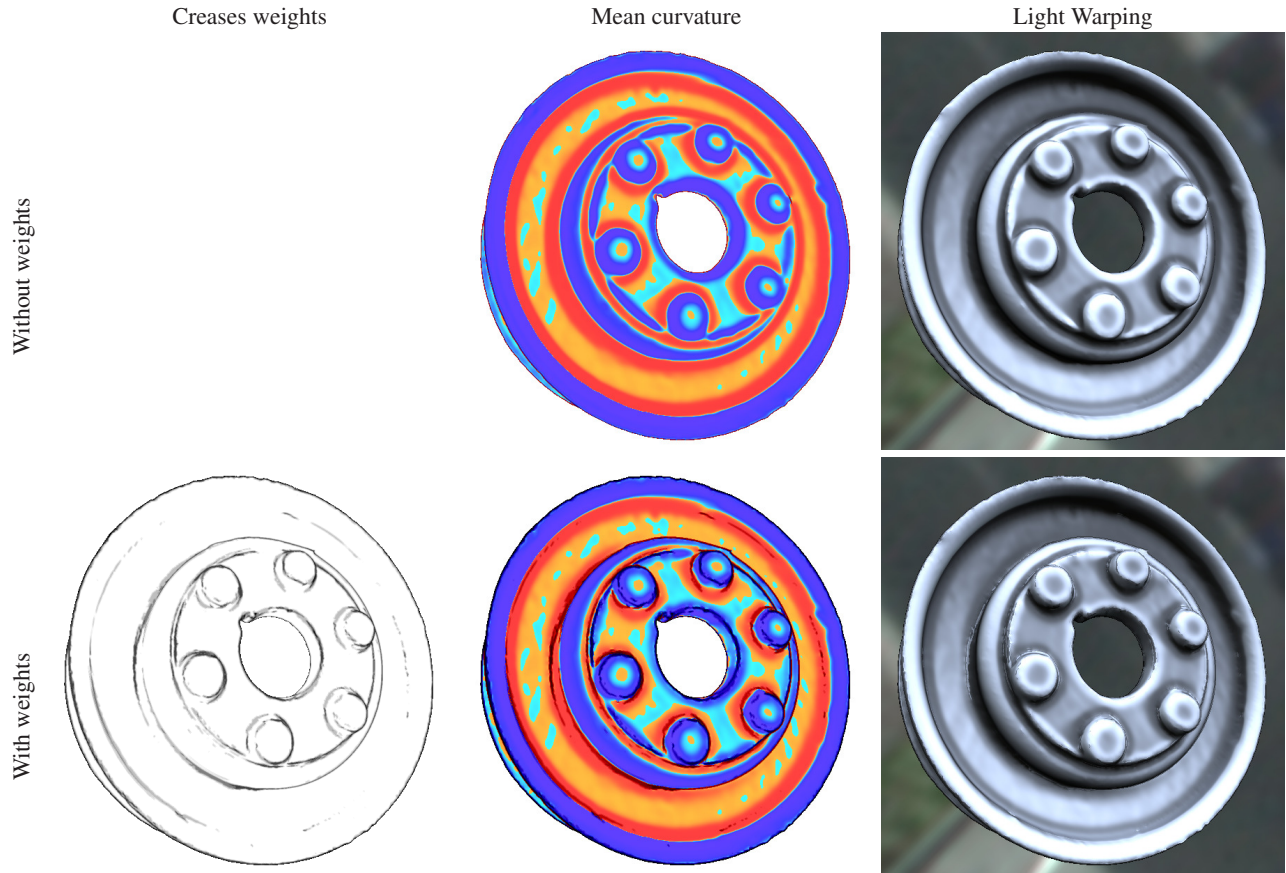


Figure 1: Influence of view-dependent creases on our local shape descriptor. Thanks to our anisotropic diffusion weighted by the creases and silhouettes, our descriptor can smooth out some small details while preserving original discontinuities. We display silhouettes and creases in black, as well as concave and convex regions in cold and warm hues respectively

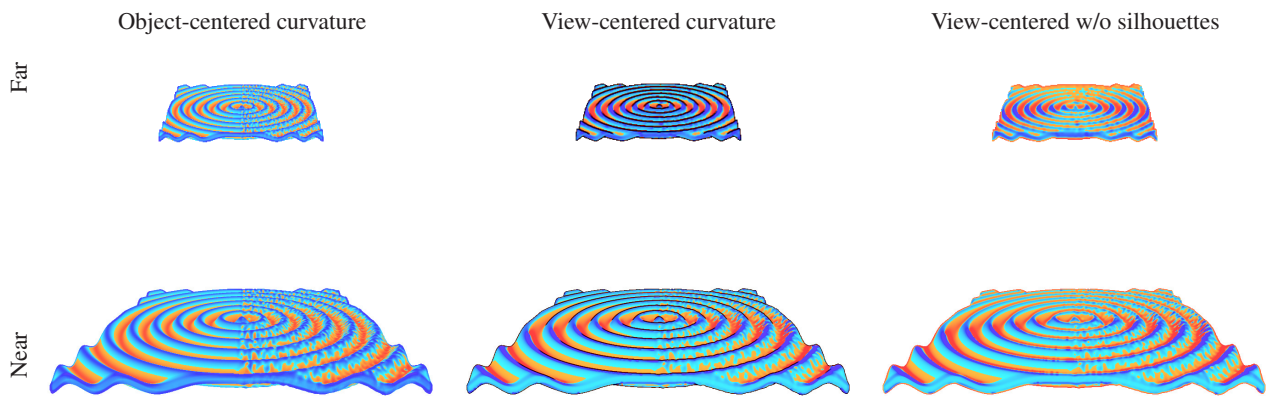


Figure 2: Comparison between object-centered mean curvature (left) and view-centered mean curvature (middle) for a wave-like object located at different depths. Half of the object has been corrupted with noise. While object-centered measures represent all curvature details at every scale, view-centered measures represent only the pertinent details for the current scale. Observe in particular how the noise has been smoothed out in the far view configuration. Silhouettes are mandatory as easily seen when comparing the middle and right columns: if not taken into account, they result in fake concavities.

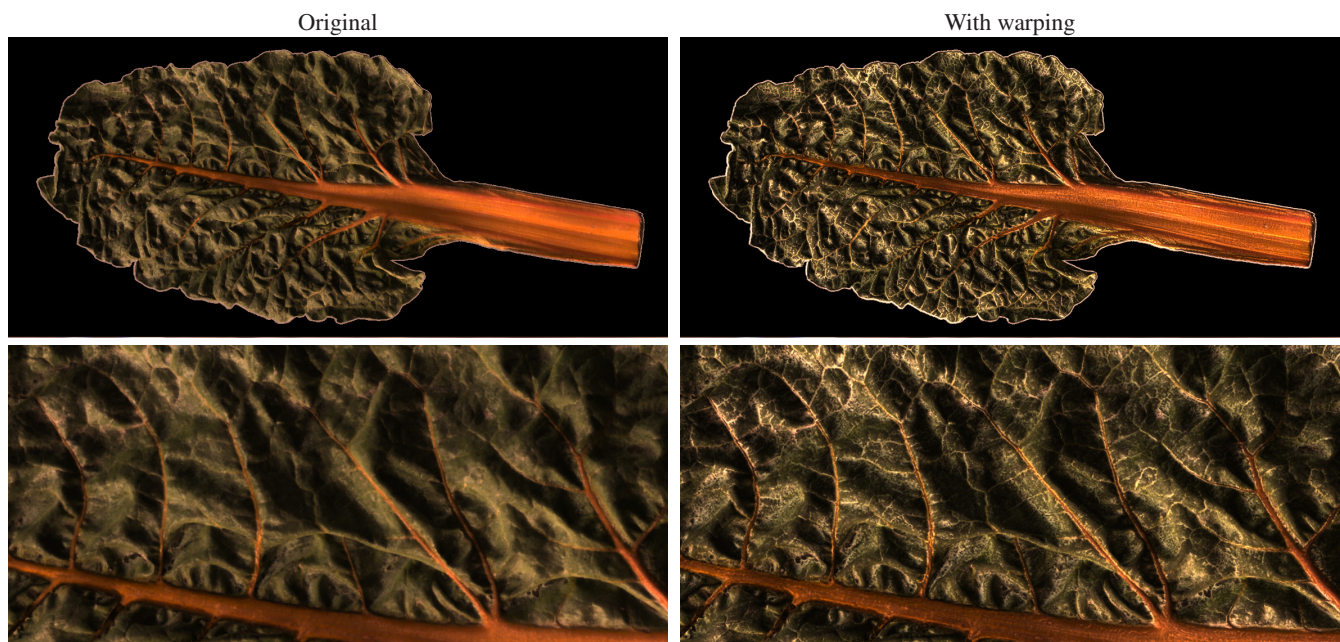


Figure 3: Since our descriptor works directly from normal distributions, we have experimented it on RGBN images. The zoom shows how well surface details are revealed.

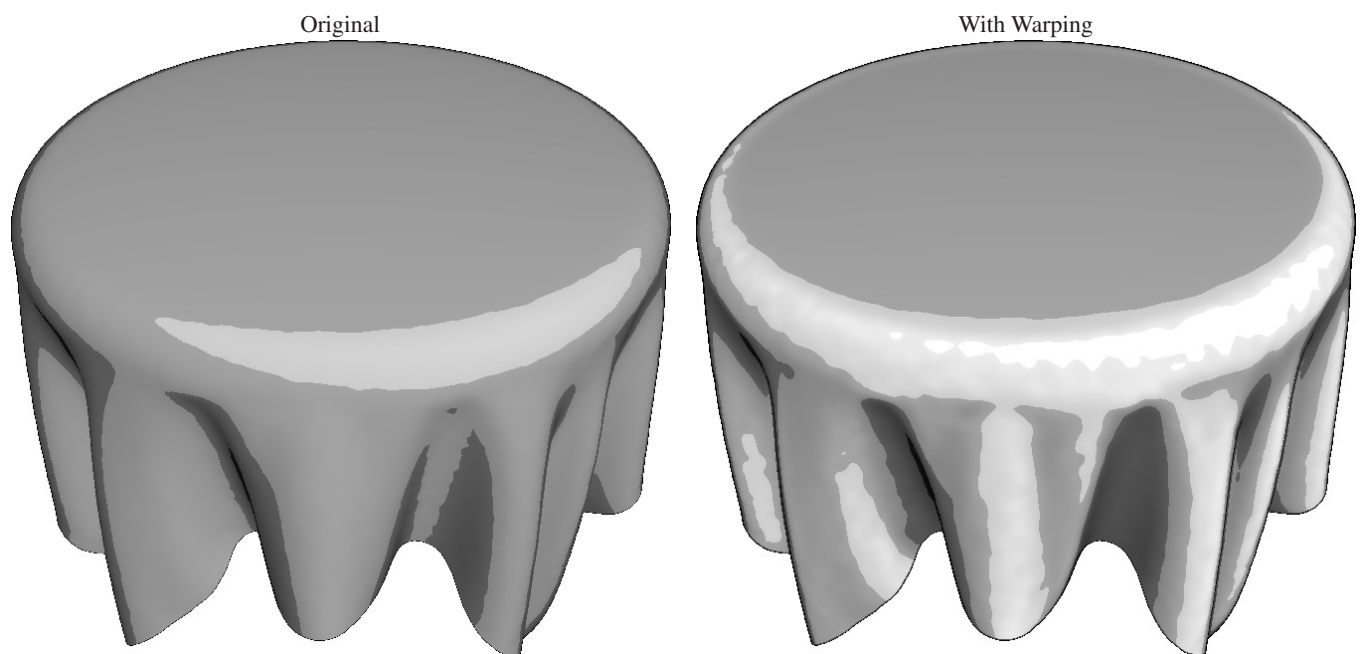


Figure 4: Minimal lighting. For this toon-like style, the environment map is a simple gradient from white to black, that does not contain any strong variations. Light warping still improves the surface depiction.

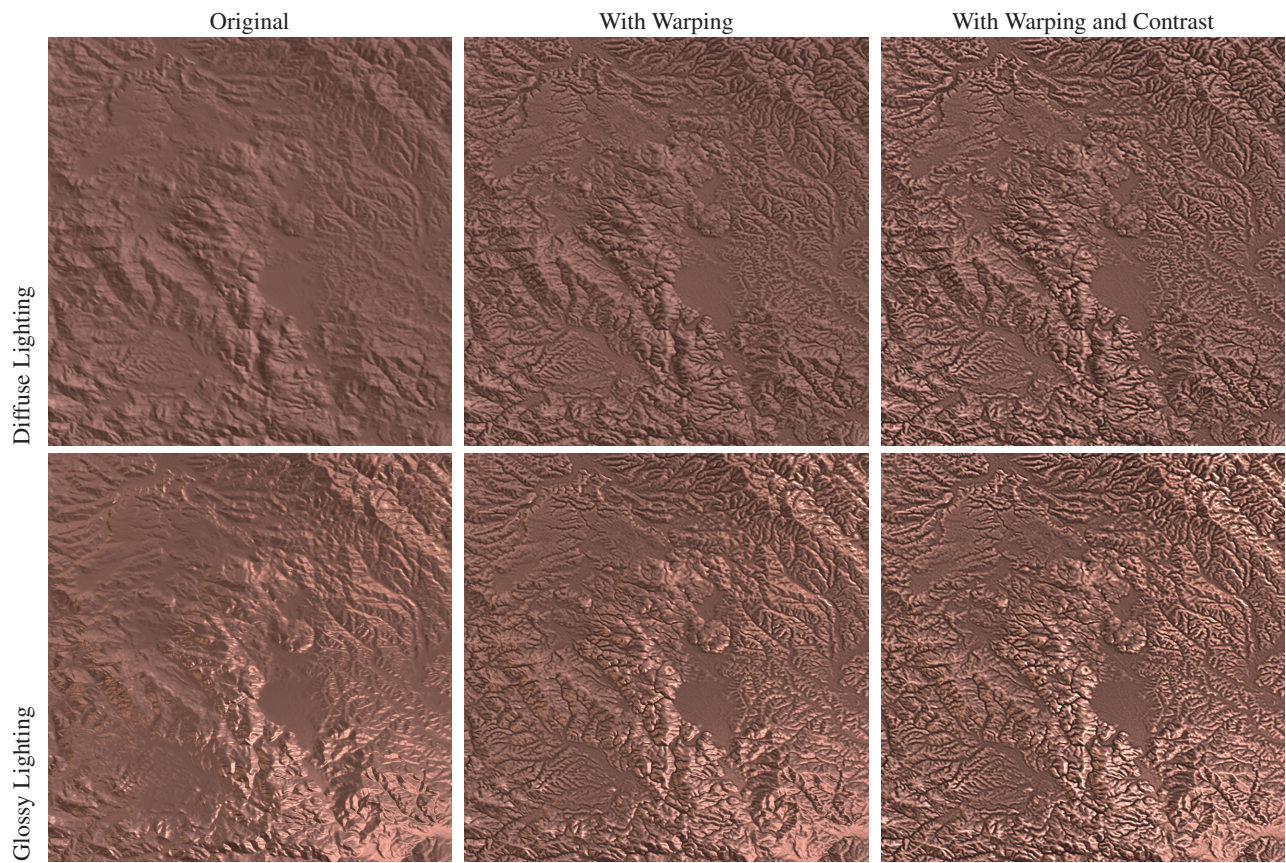


Figure 5: Real-time rendering on a terrain model for different materials, with and without contrast enhancement.

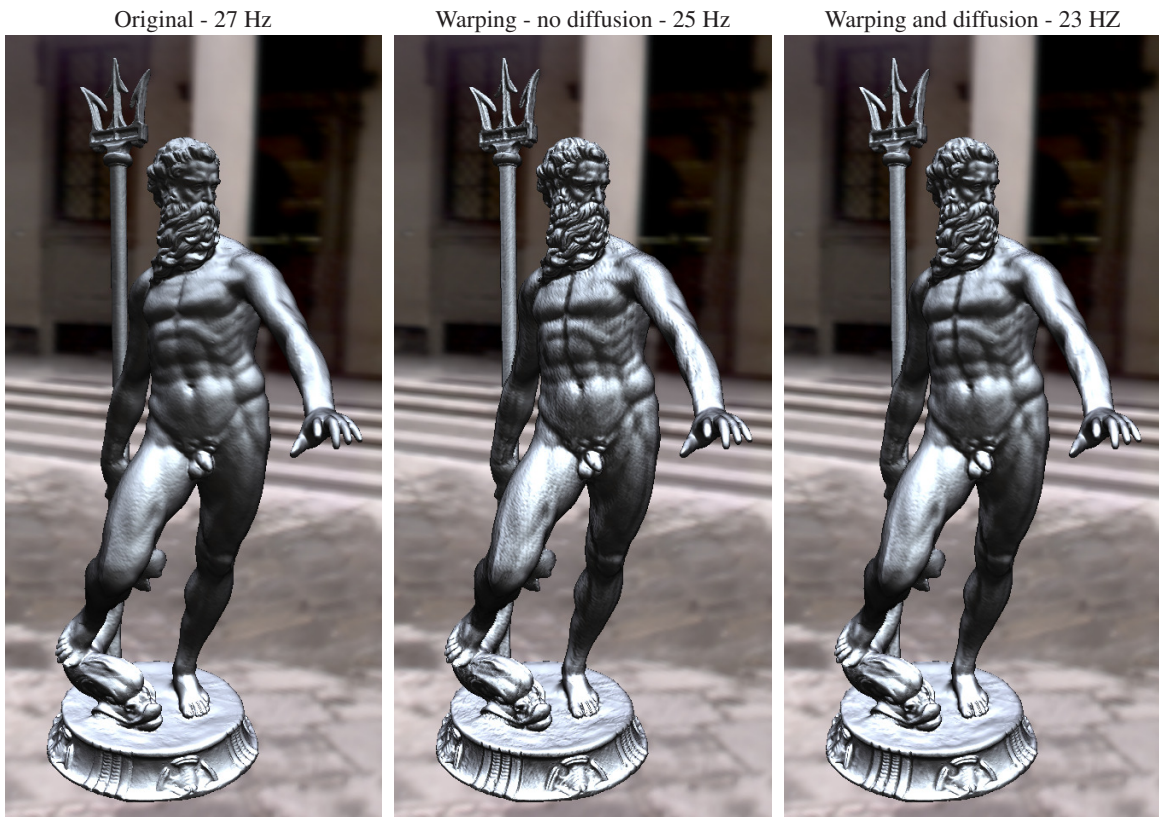


Figure 6: Real-time rendering of Neptune statue with glossy material using 96 directional lights as pre-sampled environment map.



Figure 7: Combined influence of light warping and contrast enhancement on Bambino statue.



Figure 8: Combined influence of light warping and contrast enhancement on Caesar model.

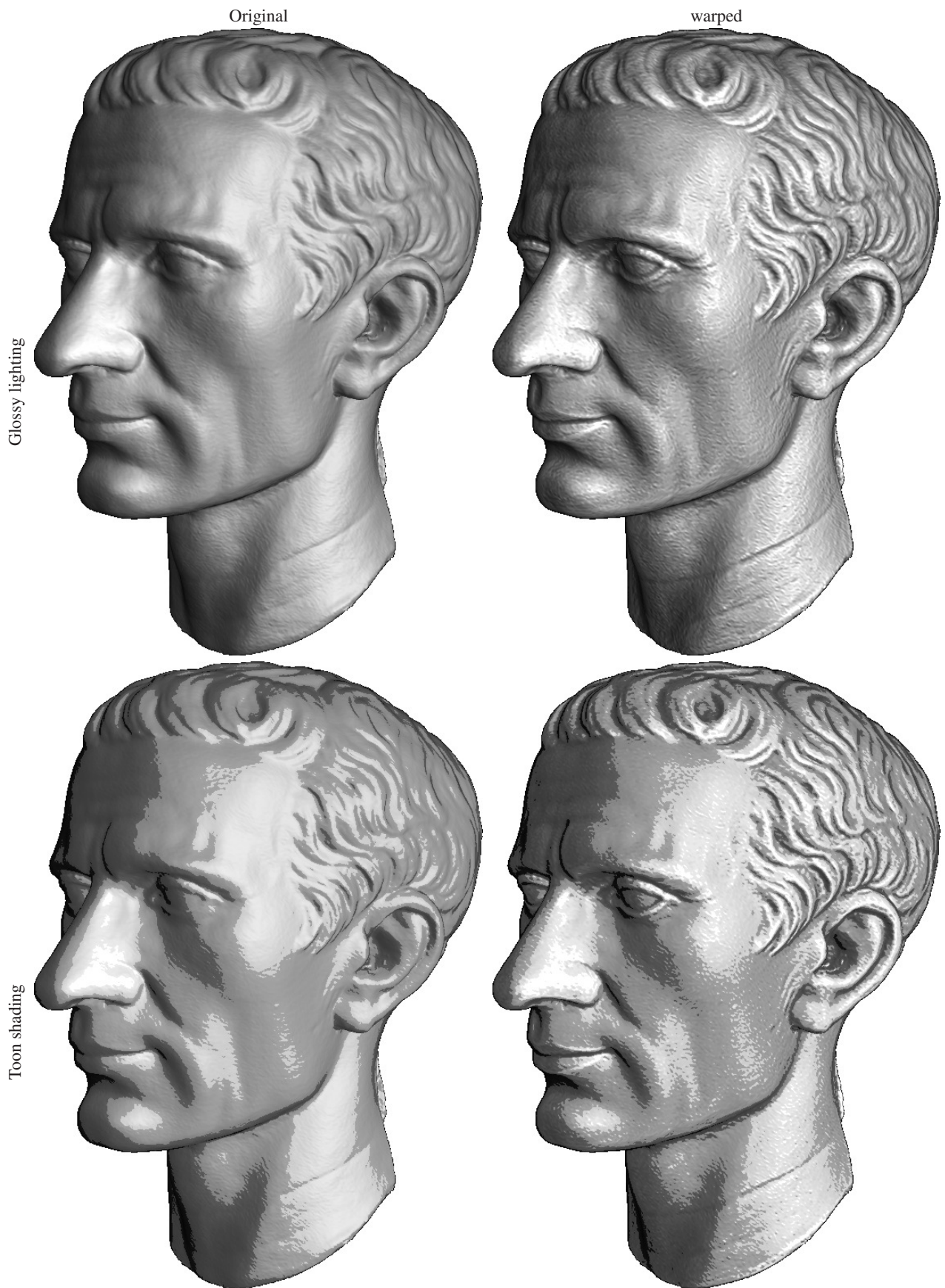


Figure 9: Real-time rendering of Caesar model at 50 frames-per-second with 24 directional light sources as pre-sampled environment map.

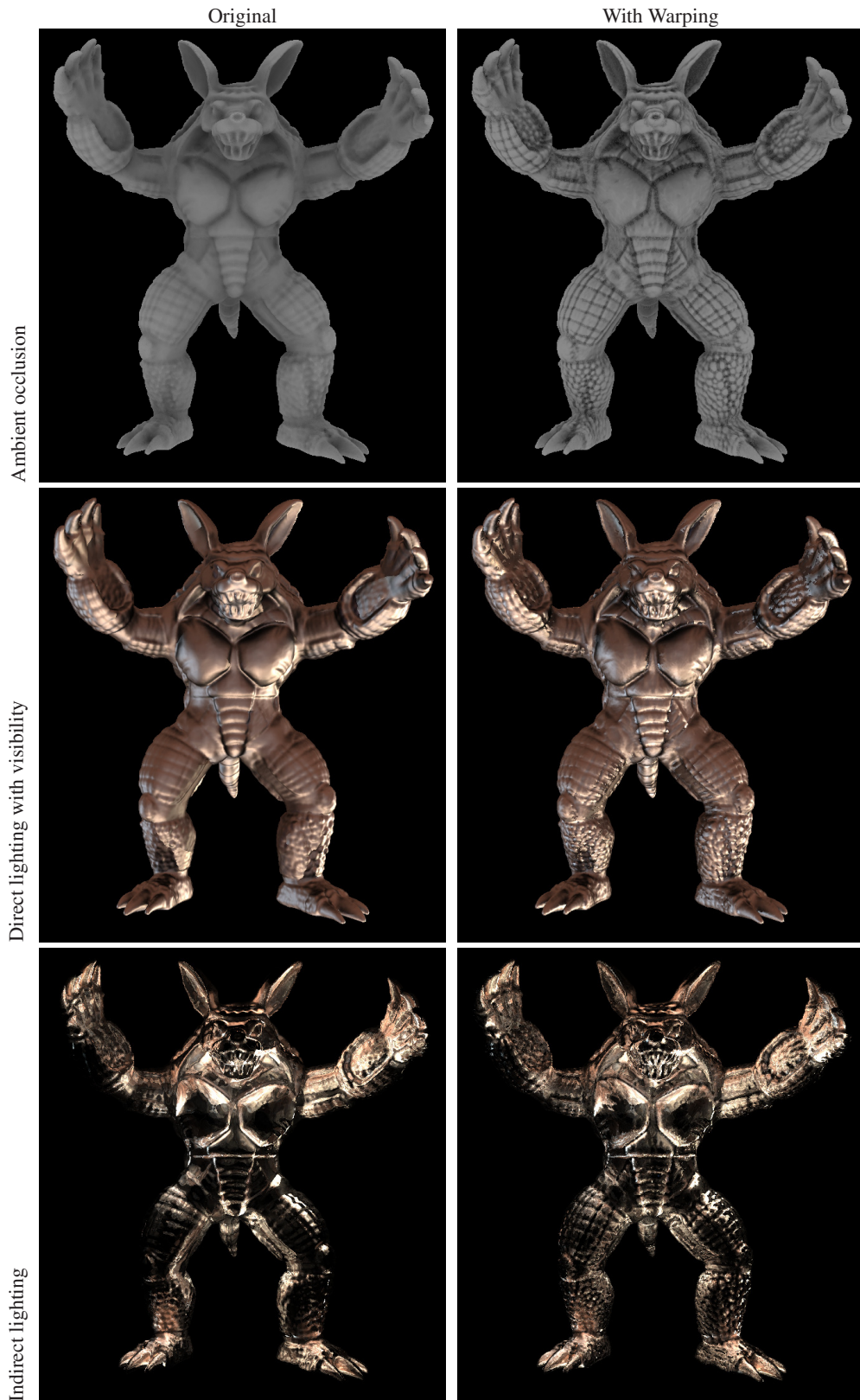


Figure 10: Off-line rendering of armadillo model, using our path-tracer. We warp light directions during the computation of ambient occlusion, direct and indirect reflections of the environment map. With a small number of rays (25) for the evaluation of indirect lighting, noise is still present, and accentuated in the warped version.

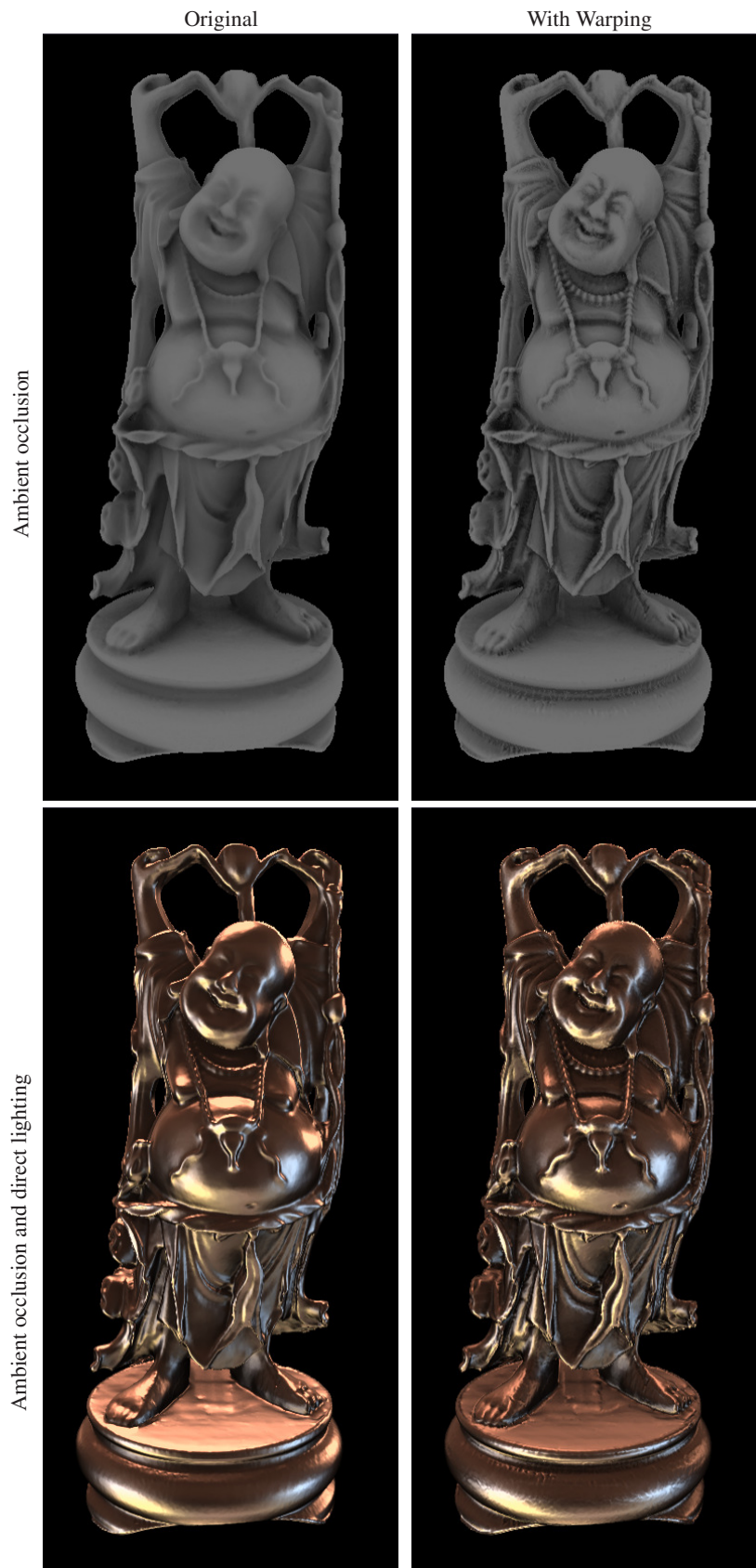


Figure 11: *Off-line rendering of Happy-Buddha model our path-tracer. We warp light directions during the computation of ambient occlusion and the evaluation of direct environment map reflection.*

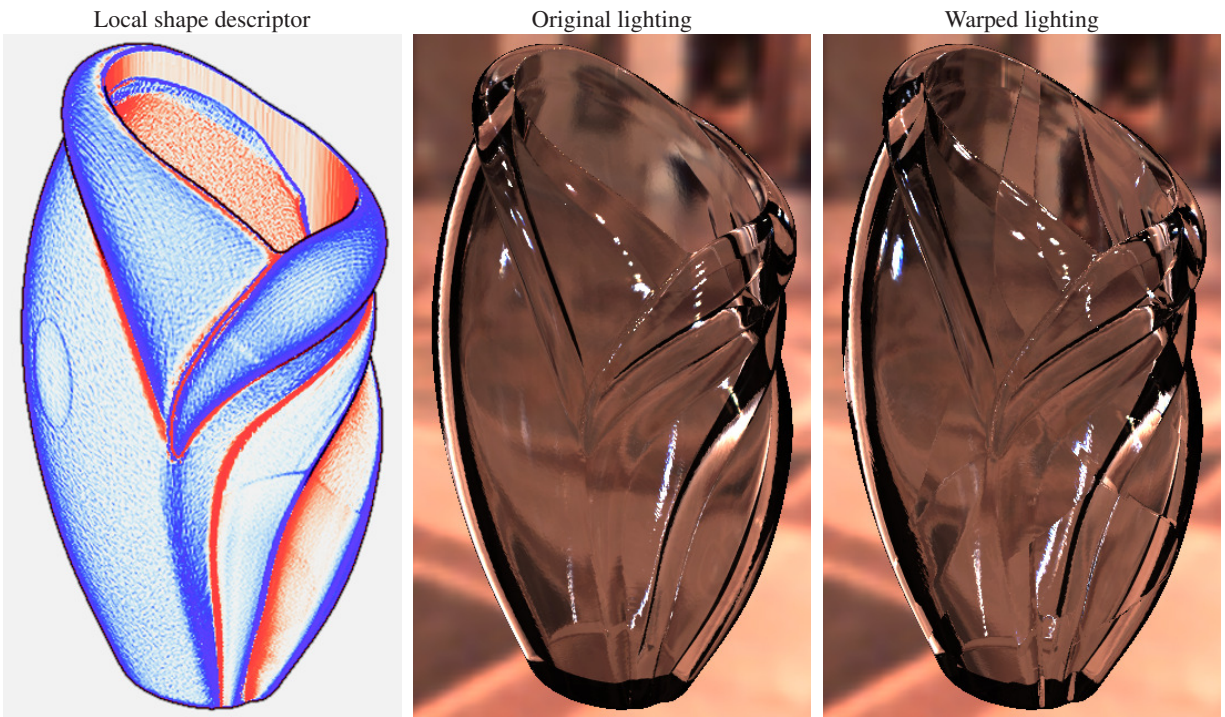


Figure 12: Ray-traced pure specular and refractive vase. Light warping exhibits some of the features present in the original model that were not noticeable with classical rendering. Note that these features are artefacts of the 3D scanning.



Figure 13: Ray-traced column with a pure specular and refractive material. Note how much the column details are more perceptible with light warping.

Original



With warping

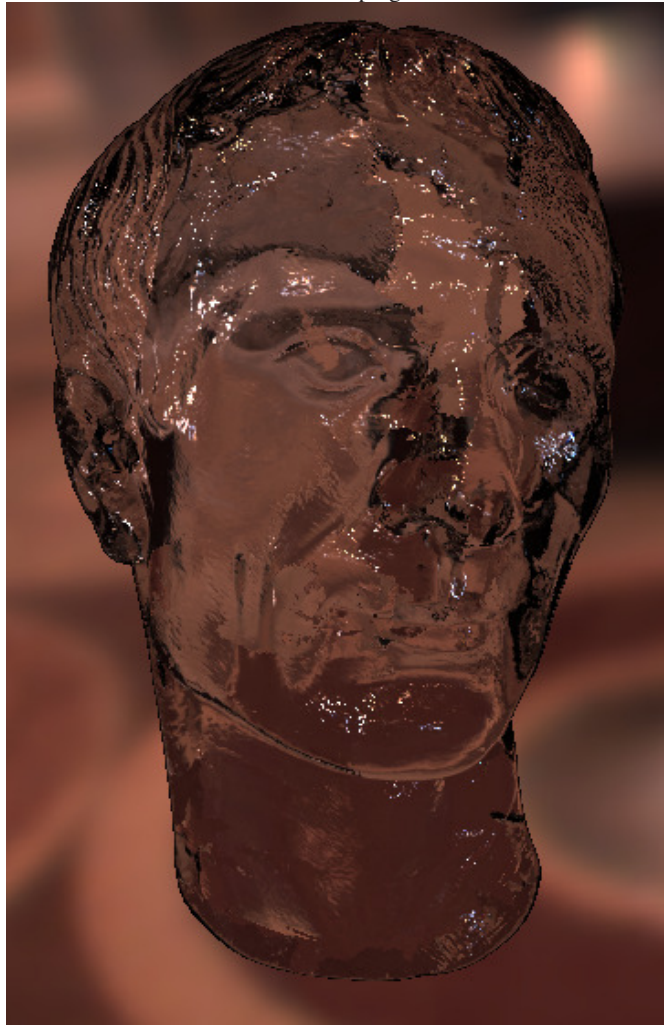


Figure 14: Ray-traced pure specular and refractive Caesar model. Note how much the eyes' shape is more perceptible with light warping.