Image Relighting Using Shading Proxies

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Abstract. *We present a practical solution to the problem of single-image relighting of objects with arbitrary shapes. It is based on a shading-ratio image obtained from some user-provided guess of the original and target illuminations. Our approach is flexible and robust, being applicable to objects with non-uniform albedos and arbitrary shapes, as well as to non-photorrealistic depictions. We demonstrate its effectiveness by relighting many photographs, paintings, and drawings containing a variety of objects of different materials. Additionally, our technique can transfer smooth normal and depth maps from 3-D models to pictures. Preliminary evaluation has shown that our approach is intuitive, allowing novice users to relight images in just a couple of minutes.*

1. Introduction

Image relighting tries to recreate the appearance of a pictured object or scene under new illumination. This is useful, for instance, when a picture cannot be (easily) retaken in the desired lighting condition, when one would like to re-target a painting to draw attention to a certain area or to convey a distinct mood. This is, however, a difficult problem, as a single image carries no explicit information about the scene's original lighting, or about the objects' shapes and material properties. Although some techniques can estimate scene illumination from photographs under certain conditions [Lopez-Moreno et al. 2010, Lalonde et al. 2012], no general solution to this problem is available. Also, recovering object's shape from a single image is an under-constrained task, for which satisfactory results are not attainable for arbitrary shapes [Wu et al. 2008, Barron and Malik 2012, Chen et al. 2013].

1.1. Contributions

In this thesis, we present a practical solution to the problem of single-image relighting of objects with arbitrary shapes. Instead of recovering the object's geometry from the input image, we use a *shading proxy*, an approximate 3-D model representation for the object, which is interactively transformed and warped to mimic the view of the pictured object. Then, correspondences among salient features between the image of the object and the image of the proxy are defined and used for creating a 2-D mapping between them. By illuminating the proxy with (an approximation to) the original lighting conditions as well as with the desired illumination, our method computes a *shading-ratio image* that is used for relighting. In practice, very good results can be obtained even with poor approximations of the original illumination. This is possible because the relighting process provides real-time visual feedback. Thus, one can obtain a desired relighting effect interactively by changing the shading ratio in a transparent way. Figure 1 shows the relighting of a

Figure 1. Relighting of a famous photograph by Steve McCurry: Sharbat Gula the "Afghan Girl". (Left) Original photograph. (Center) Relit from the top. (Right) Relit from the bottom.

photograph by Steve McCurry. Note how a smooth change in the illumination can modify the mood of the scene, making the girl appears more relaxed or more mysterious.

Our technique benefits from a wide range of freely and commercially available 3-D models, which can be used as proxies. While most single-image relighting techniques are specific to face relighting [Blanz and Vetter 1999, Wen et al. 2003], our method can be applied to objects with arbitrary shapes, as well as to non-photorealistic depictions, such as paintings and drawings. In addition, it can be used for transfering smooth normal and depth maps from the 3-D proxies to pictures.

Our approach can achieve good results for relighting different types of objects, even ones with non-uniform albedo. Our method also supports multiple light sources of different colors. Furthermore, the warping and correspondence mapping provide enough power to create a variety of proxies from a single model. Thus, a small set of 3-D models can be used to relight a large number of pictures.

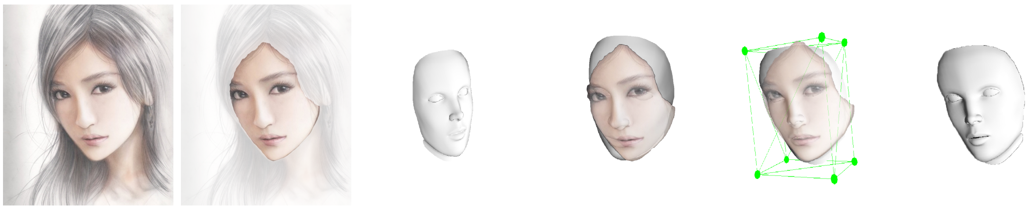
Due to space restrictions, this paper cannot present all the details of our relighting technique. We encourage the readers to visit the thesis website (`www.inf.ufrgs.br/~bhenz/master_thesis/`), where one can find a video and a long list of results illustrating the use of our technique, as well as the thesis itself. The core of the thesis was published in a paper [Henz and Oliveira 2015] in the Proceedings of the *Computer Graphics International 2015* conference, and an extended version of the paper has been invited for submission to *The Visual Computer* journal.

2. Image Relighting

Estimating illumination and geometry from single images is a difficult problem, especially when dealing with arbitrary objects with non-uniform albedo. Previous techniques have simplified the problem by narrowing the classes of objects (e.g., faces), while others make strong assumptions about material properties and lighting conditions (full Lambertian surfaces, uniform albedo, arbitrary lighting conditions). Our technique does not require any previous information about the image. It uses *shading proxies* and user interaction to achieve plausible relighting of arbitrary shapes. It consists of three steps: (i) image-model registration; (ii) creation of a feature-correspondence mapping; and (iii) actual relighting, which are detailed in the following sub-sections.

2.1. Image-Model Registration

Given an input image containing a reference object to be relit, we choose a 3-D model representation that will be used to create a proxy. The thesis document discusses how



(a) (b) (c) (d) (e) (f)

Figure 2. Image-model registration. (a) Input image I. (b) Segmented reference object O (face). (c) 3-D face model M used to create a proxy for O. (d) Initial image-model registration by translating, rotating, and scaling M to fit O. (e) Deformed model using Green coordinates to improve the fitting of M to O. (f) Resulting transformed and deformed model (shading proxy).

to automatically identify suitable models to be used as proxies. Our system allows the user to interactively perform a series of translation, rotation, and scaling operations in order to approximate the imaged object. The user can also warp the model using Green coordinates [Lipman et al. 2008]. These operations are illustrated in Figure 2. At the end of the registration process, the transformed and warped model resembles the object to be relit, and it is called a *shading proxy* (Figure 2 (f)).

2.2. Feature-Correspondence Mapping

After performing image-model registration, one needs to establish a pixel-wise correspondence between the image of the object to be relit and the image of the shading proxy. For this, our technique matches a few key points and interpolates their positions to create a coherent correspondence mapping. The correspondences between key points are defined automatically (in the case of silhouettes) or interactively if additional key points are needed. These corresponding pairs are used to obtain a Delaunay triangulation that defines a dense *feature-correspondence mapping* between the image and the proxy.

(a) (b) (c) (d) (e) (f) (g)

Figure 3. Our image-relighting pipeline. (a) Input image. (b) and (c) Image and proxy with color-coded matched key features. (d) and (e) Source and target shadings over the warped proxy. (f) RGB shading-ratio image. (g) Relit image.

2.3. Actual Relighting

An image can be expressed as the product of illumination (*shading*) and reflectance (*albedo*). Thus, we perform image relighting by retrieving the object's albedo and multiplying it by the new shading. This is equivalent to multiplying the original image by a pixel-wise shading ratio (computed as the ratio between the target and source shadings). These target and source shadings are specified by the user on the proxy (Figures 3 (d) and (e)). The real-time feedback provides an easy way to control these shadings untill the user obtains the desired effect. Figure 3 illustrates our image-relighting pipeline.

Figure 4. Relighting of a Vang Gogh's painting. (Left) Original. (Center) Relit from the left using our artistic-relighting method. (Right) Relit from the front. Note how the shading-color relationship is preserved by our artistic relighting technique.

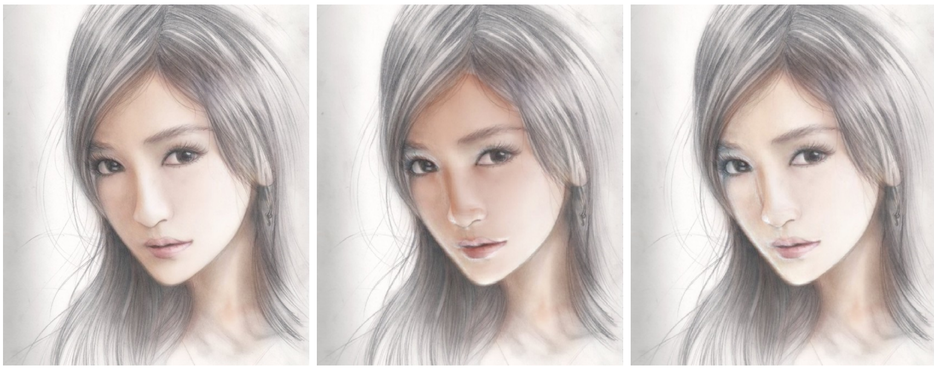


Figure 5. Relighting of a pencil drawing, by Ray Sun (Sunnyrays). (Left) Original drawing. (Center) Relit from below. (Right) Relit using two light sources.

3. Artistic Relighting

Photographs and other photorealistic images can be successfully relit by modulating each color channel by the shading-ratio image. In the case of paintings and drawings, however, artists often use color, as opposed to lightness, to encode shading information. For instance, in the *Portrait de l'Artiste sans Barbe* shown in Figure 4 (left), van Gogh used proportionally more red for in-shade areas than for lit ones, which appear yellowish. Thus, naively multiplying each channel by the same ratio image would produce less pleasing results, as it would tend to over-stress the use of some colors. We propose a novel technique to mimic the artist's color-usage intention. We do so by modulating each color channel by a different scale. The user must indicate a shadow and lit region, which are used to generate functions that encodes how each color channel changes as we increase (or decrease) shading values. Figures 4 (center) and (right) show results obtained using our artistic-relighting technique applied to van Gogh's painting. Note the red shades used to represent darker regions.

Figure 5 shows our artistic-relighting technique applied to a pencil drawing by Ray Sun. The original drawing is shown on the left and, unlike the example in Figure 4, this exhibits smooth shading. The images in the center and on the right were relit from below, and using two light sources (to lit both sides of the face), respectively. Figure 6

Figure 6. Relighting of a Camaro drawing by Elisabeth K. (Lizkay). (left) Original, with 3-D proxy as inset. (center) Relit from the right. (right) Relit from above.

illustrates the use of our technique to relight a car drawing by Elisabeth K. This example demonstrates the versatility of our technique to relight objects with arbitrary shapes.

4. Transferring Normal and Depth Maps to Images

The feature-correspondence mapping generated by our method can be useful for many others applications. For instance, it makes it straightforward to transfer information from the shading proxy to the input image. We exploit this possibility to transfer normal and depth maps from the 3-D proxies to pictures. Note that conventional techniques for estimating normal maps from images do so based on image gradients and, therefore, would not work for these examples. Our approach is capable of transferring smooth normal maps that capture the essence of different images, even when the proxies derive from the same 3-D model (Figure 7). This observation also applies to depth maps.

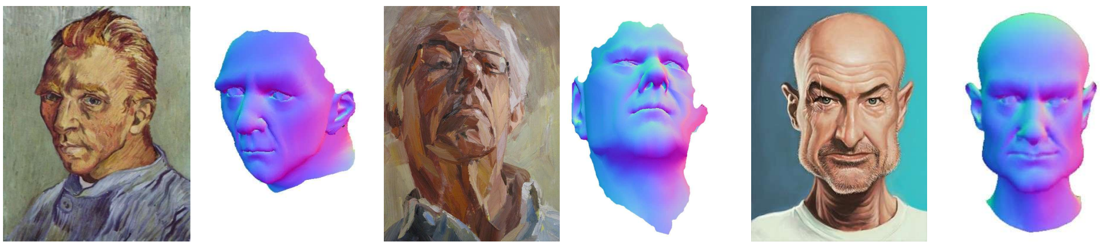


Figure 7. Normal maps transfered from the proxies to images using our method. Note the smooth normal maps, even for images containing heavy brush strokes. The proxies used for these examples were obtained from the same 3-D model.

5. Conclusion

We have presented a practical solution to the problem of single-image relighting of objects with arbitrary shapes. Our approach can be used with photographs, paintings, and drawings. It uses shading proxies and user interaction to guide the relighting process, and works by computing a shading-ratio image which is used to map the input lighting condition to a target illumination. Our solution is flexible and robust, being applicable to objects composed of non-uniform albedos. As far as we know, this is the first method to perform relighting of paintings. Furthermore, our method can be used to transfer smooth normal and depth maps from the 3-D proxies to images, even in the case of non-photorealistic paintings and outline drawings.

We have demonstrated the effectiveness of our technique by performing real-time relighting and normal and depth-map transfers on a large number of photographs, paintings, and drawings. Preliminary evaluation has shown that our technique produces convincing results, and novice users can relight images in just a couple of minutes. Given its flexibility, robustness, and easy of use, our technique can help artists, photographers, and casual users to experiment with various lighting effects on existing images, enabling new and creative applications.

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