Image Relighting Using Shading Proxies

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Fig. 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.

***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.**

***Keywords*-image relighting; painting relighting; normal-map estimation; shading transferring;**

I. 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 conditions, 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 [1], [2], 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 [3], [4], [5].

A. Contributions

In this thesis[1], 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 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 [6], [7], [8], [9], 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

[1]This work relates to a M.Sc. thesis.

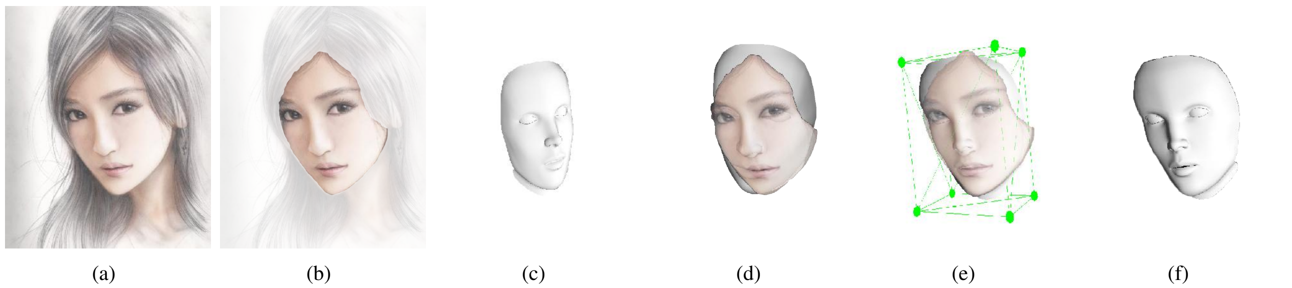

Fig. 2. Image-model registration. (a) Input image I. (b) Segmented reference object O (face). (c) 3-D face model M used to create a proxy for O. (d) Initial image-model registration by translating, rotating, and scaling M to fit O. (e) Deformed model using Green coordinates to improve the fitting of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

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, offering control over their intensities. 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 [10] 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.

B. Related Work

Image relighting has been addressed in different ways over the years. Essentially, existing techniques can be classified as *geometry-based* and *image-based*, and most of them focus on face relighting. Geometry-based techniques use a 3-D representation for rendering an object under new illumination, while image-based methods rely on multiple images for relighting.

1) Geometry-Based Methods: Inverse-lighting techniques try to, given a geometric descriptor of the scene, estimate and modify its illumination. In order to acquire geometry and reflectance information, they rely on 3-D scanners [11], [12], use multiple photographs taken under controlled settings [13], or create a virtual scene using 3-D models [14]. These techniques require access to the original scene and/or information about scene geometry and reflectance, which is hard to recover from a single image.

For face relighting, many methods use simple models, such as ellipses [15] or a generic face model [7]. Others use morphable models to recover an approximated 3-D face representation [6]. Wang et al. combine morphable models and spherical harmonics to relight faces under harsh lighting [8]. All these techniques are specific for faces.

Some interactive techniques allow the user to specify or reconstruct **normal maps**. Okabe et al. use a pen-based interface to draw sparse surface normals, which are then interpolated into a normal map [16]. Wu et al. proposed an interactive approach based on a simple markup procedure for normal reconstruction from single images [3]. These normal-map recovering methods are heavily dependent on the *single-albedo assumption*, and cannot be used with images with non-uniform albedos.

2) Image-Based Methods: Debevec et al. use a light-stage device to acquire a sparse set of viewpoints from a face under a dense set of lighting directions [17]. These data are used to re-render the face under any combination of the captured light directions. Tunwattanapong et al. presented a method to reduce the number of required photographs [18]. Malzbender et al. generate images of captured objects under new illumination by interpolating data from a set of photographs [19]. All these techniques require a large number of images taken under controlled illumination.

Some relighting techniques create a mosaic combining separate parts of various images [20], [21]. Others, compute a linear combination of some basis images [22], [23]. These techniques require a set of images taken from the same viewpoint, and the range of possible results is limited by the captured images.

Several techniques have used ratio images to perform image relighting, some using images taken under linearly independent lighting conditions [24], by using a light-stage device [25], or infrared images [9]. The main difficult of these techniques is the alignment between the original and reference images.

For the specific case of *face relighting*, Li et al. proposed a logarithmic total variation model to retrieve the illumination component and transfer it between faces [26]. Chen et al.'s method uses edge-preserving filters to decompose the image into large-scale and fine-scale detail layers, transferring the large scale (that represents luminance variance) between aligned faces [27]. In a subsequent work, Chen et al. used *shadow* and *light templates* copied by artists from professional portraits to perform face illumination [28].

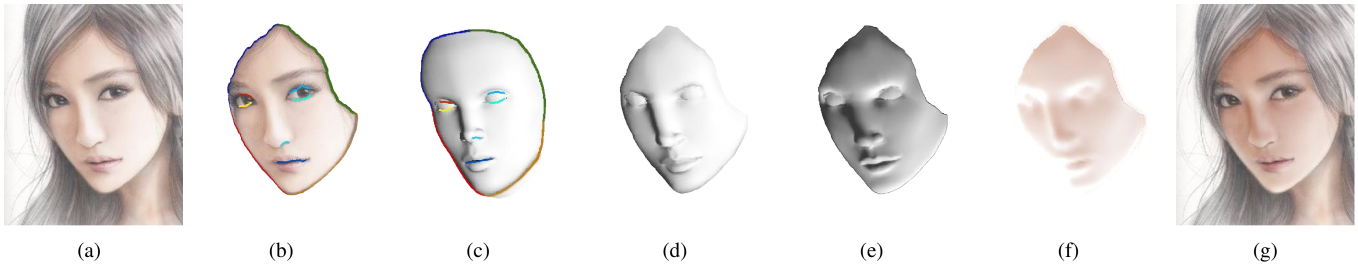

Fig. 3. Our image-relighting pipeline. (a) Input image. (b) and (c) Image and proxy with color-coded matched key features. (d) and (e) Source and target shadings over the warped proxy. (f) RGB shading-ratio image. (g) Relit image.

II. 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.

A. 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 paper does not discuss how to automatically identify suitable models to be used as proxies (as this is not the core of the thesis, we have suppressed it from this paper). 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 [29]. 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)).

B. 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, by using [30] and [31]) or interactively (using intelligent scissors [32]) 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.

Fig. 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.

C. Actual Relighting

An image can be expressed as the product of illumination (*shading*) and reflectance (*albedo*) [33]. 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 the shadings in order to obtain the desired effect. Figure 3 illustrates our image-relighting pipeline.

The feature-correspondence mapping avoids image-model misregistration artifacts. However, the occurrence of high-frequencies in the shading-ratio image may introduce artifacts when mapped to smooth regions of the input image. Such situations tend to result from proxy features not found in the input image or from topological issues in the 3-D models construction. We avoid these artifacts by removing gradients in S_{ratio} that are perceived as undesirable when transferred to the relit image. We do so by performing a shading-ratio inpainting (using the technique of [34]) on regions indicated by the user.

III. 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*

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

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 (see full thesis for detailed description). 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.

IV. RESULTS

We used our approach to relight a large number of images including paintings, drawings, and other kinds of artwork. Our technique not only allows one to change the direction of the light source, but also its intensity, its color and the number of light sources. In the full thesis we present several examples exhibiting those cases.

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 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.

Figure 7 (left) shows a portrait by Andrew Myers created using screws. Figures 7 (center) and (right) show versions of the original image relit from the left and using two light sources (top and left), respectively, using our artistic relighting technique. Note how high-frequency details are properly preserved through the relighting.

Figure 8 shows the relighting of a caricature by Mark Hammermeister. This example illustrates the ability of the correspondence mapping to deform the approximate 3-D model (see inset) to fit the image, generating results that are unlikely to be obtained with other techniques.

Fig. 7. Relighting of a portrait by Andrew Myers created with screws. (left) Original image. Portrait relit from left (center), and using two light sources (right).

Fig. 8. Relighting of a caricature by Mark Hammermeister. (left) Original. (center) Caricature relit from right. (right) Caricature relit from above.

A. User Evaluation

We performed a simple experiment to test the usability of our technique by novice users. For this, we asked 10 subjects to perform two simple image-relighting tasks. A brief explanation of how our system works was given for the subjects, and they were allowed to practice over the program, asking questions and requesting assistance. Then, the subjects were asked to perform two relighting tasks all by themselves. The first task involved relighting a hat, while the second consisted of relighting a human face (not shown here) using a 3-D model of a generic male face. Figures 9 (center) and (right) show examples of relit hat images created by two of our volunteers in under three minutes. For this experiment, we decided to not specify a target result. Its goal was to allow the volunteers to try distinct lighting effects on images, producing results they would find pleasing.

Fig. 9. Relighting examples produced by novice users. (left) Original image. (center) Relit by one subject in 172 seconds. (right) Relit by another subject in 137 seconds.

B. 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

Fig. 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.

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 11). This observation also applies to depth maps. Our technique can also transfer shading from proxies to drawings, giving a 3-D flavor to simple outline images (Figure 10).

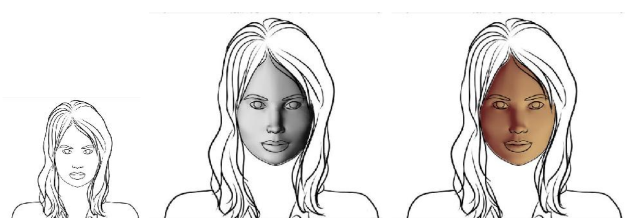

Fig. 10. Transferring shading from proxies to 2-D drawings. (left) Original drawing. Transferred shading: lit from the left (center), colored and lit from the right (right).

Fig. 11. Normal maps transfered from the proxies to images using our method. Note the smooth normal maps, even for images containing heavy brush strokes or just simple outlines. The proxies used for these examples were obtained from the same 3-D model.

C. Discussion and Limitations

Our work tackles the difficult problem of relighting image representations of objects with arbitrary shapes taking as input only the images themselves. No explicit information about the object/scene geometry and its original shading is provided. Our solution bridges this information gap offering a practical solution to this hard problem. Although it seems that one needs to precisely match the input image's shading on the proxy, in practice this is not required, and excellent results can be obtained even with poor approximations. This is so because the relighting process is guided by real-time feedback on the relit image. Thus, one can obtain the desired effect by compensating on the target shading.

Despite the need for 3-D models, the use of shading proxies makes the previously-mentioned difficult problems tractable. Currently, there is a wide range of both freely and commercially available 3-D models, and it is relatively easy to find models for essentially anything. We emphasize that the availability of large 3-D databases is not necessary. As we have shown, the warping and correspondence mapping provide enough power to create different proxies from single models. For instance, a single 3-D model was used to create proxies for all male faces shown in this paper, regardless of their representations (photographs, paintings, drawings). Thus, a small set of 3-D models should suffice for most cases. The user could incrementally build such a database according to his/her needs. Moreover, as the availability of 3-D models continues to increase and specialized web-based search engines (e.g., [35]) evolve, finding approximate models is expected to become even easier.

We have used OpenGL's point light sources because they lend to real-time rendering. Even though we have based our decision on performance considerations, nothing precludes the use of more sophisticated lighting models.

Defining correspondences among features in the input and in the reference images gives the user additional freedom to achieve specific relighting effects. In the full thesis we provide an example showing how we can achieve distinct relighting results by establishing correspondences between segments.

Our technique has some **limitations**. Since our artistic relighting uses colors to represent dark and bright shades, it is sensitive to the choice of such colors. Our current implementation does not remove shadows. This might be addressed using shadow mapping [36]. Also, if the object to be relit has unusual geometric features, a suitable 3-D model for use as a shading proxy might not be immediately available. In addition, since our technique relights segmented objects, the users should be careful to not introduce noticeable inconsistencies in the scene illumination. Also, our method is not capable of recovering information for clamped regions (highlights or shadows).

V. 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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