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IBRelight: An Image-Based 3D Renderer for Cultural Heritage

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Abstract

IBRelight is an interactive image based rendering program that allows archivists to create realistic pictures of shiny, inhomogeneous, and three-dimensional cultural heritage artifacts from flash photographs of those objects. The software provides an easy to use interface that has features similar to those provided by existing computer graphic rendering packages, but it is built on previously developed technology that can generate new images from novel viewpoints while relighting the object using point light and environmental lighting setups. Because the rendered image is created directly from the original photographs, it retains the visual fidelity of those photos, and the rendered tristimulus values can be interpreted using color management information archived with the flash photographs.

Introduction

Image-based rendering (IBR) has the potential to become a powerful tool for cultural heritage institutions. IBR is a category of computer graphics techniques in which novel images are derived from a set of pre-existing photographs. The new images maintain a level of visual fidelity which is close to that of the original photos because they are derived directly from those photos. Recent results have shown that IBR is a particularly effective technique when an artifact needs to be documented whose appearance is shiny and not homogeneous [1] [2] [3]. This could have substantial value in cultural heritage: with IBR, objects can be photographed once, and at a later time new images can be produced without taking the object off display or out of storage. Even more importantly, if an object that has been photographically documented for the purposes of IBR were to subsequently deteriorate or become damaged, IBR could be used to give an accurate impression of how the object might have appeared before the damage occurred. Furthermore, because IBR works with photographs, established color management techniques and standards for traditional photography can be applied to each photograph in an IBR dataset.

Related Work

Numerous publications, both old [4] [5] [6] and recent [1] [2] [3] have demonstrated the practical applicability of IBR to cultural heritage. It is easy to envision that, eventually, most institutions' digital archives will be filled with systematically taken photographs that can be pulled up anytime for image-based rendering. However, 3D image-based rendering software is still not extensively utilized by the cultural heritage community. This is likely because nearly all image-based rendering results in computer science have not been accompanied by any release of the software that was used to produce the results.

Figure 1*. A child's tiger hat from the Minneapolis Institute of Art being rendered from 67 photographs according to the technique described in [2]. The manipulators drawn in white are a feature of IBRelight that allows the user to control the light sources illuminating the object.*

Many institutions currently use photogrammetry pipelines like the commercial product Agisoft PhotoScan[1], which is very effective at acquiring geometry, but for texture and appearance uses very basic texture stitching that fails to capture the appearance of objects whose reflectance is shiny or otherwise non-diffuse. An alternative technique might to use photogrammetry software like PhotoScan primarily for geometry acquisition and then use modeling software like Autodesk Maya[2] to specify the reflectance properties of the object's material, which control how shiny and how metallic it is. However, the difficulty of using software like Maya to accomplish this task increases with the amount of variation in the appearance of the object. For a complex and inhomogeneous 3D cultural heritage artifact, this is not an ideal solution. Moreover, reflectance properties that have been specified manually in software like Maya by visual inspection are not grounded in any physical measurement of the object and, while potentially useful for public engagement, are not sufficient for professional archiving purposes.

IBRelight

IBRelight is a new three-dimensional rendering program that provides controls similar to those found on existing computer graphic programs for image synthesis, but which employs image based rendering to create novel realistic pictures of an artifact from

[1] Agisoft PhotoScan: http://www.agisoft.com/

[2] Autodesk Maya: https://www.autodesk.com/products/maya/overview

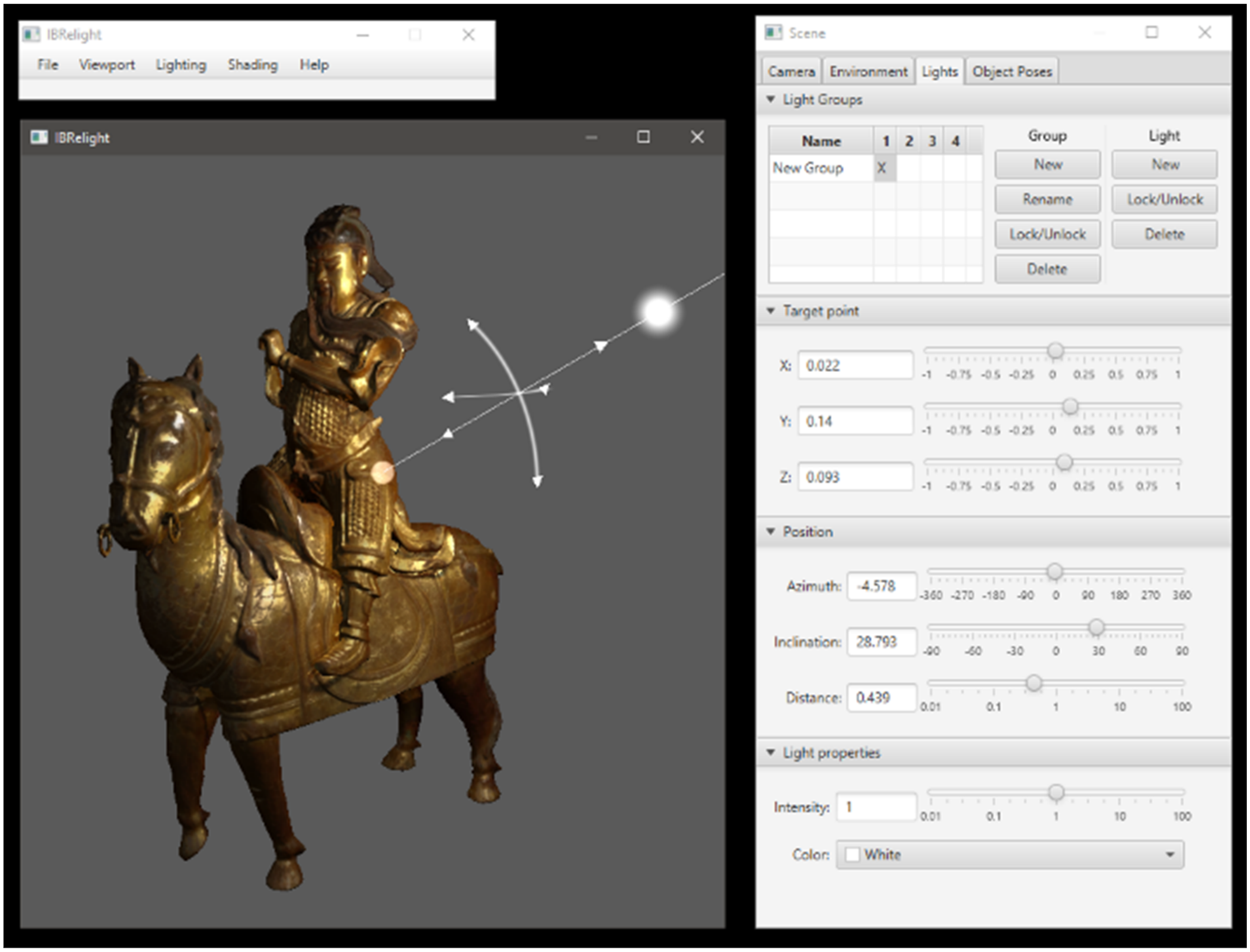

***Figure 2**. A bronze statue of Guan Yu from the Minneapolis Institute of Art being rendered from 56 photographs. The full interface of IBRelight is shown. Above, the Program Control window contains the standard menus (File, etc.). On the left, the 3D View shows an interactive rendering of the object with superimposed light manipulation widgets. On the right, the Scene window provides controls for fine tuning and switching between configurations.*

flash photographs of that object. The technical aspects of it are built on the results of recent publications [1] [2] [3], using a variant of the unstructured lumigraph rendering algorithm proposed by Buehler et al. [4] that blends photos after projecting them onto a geometric proxy. The photographs are obtained by using a camera with a single mounted flash so that the light source in each photograph is nearly coincident with the viewpoint. Photogrammetry software can be used to align the photographs and produce a model of the object's geometry, both of which are needed by IBRelight. IBRelight has built-in compatibility for the commercial photogrammetry product Agisoft PhotoScan in order to make the process of importing the camera alignment and 3D model as simple as possible.

It should be noted that, in practice, a light source can never be perfectly coincident with a camera. Although there are photographic workarounds for this limitation, for example, using a ring flash, it is also possible in IBRelight to specify a small offset between the light source and the camera, thus permitting them to not be perfectly coincident. For the time being, this offset must be specified by the user manually; fortunately, shadows cast by the flash in the original photographs can serve as an effective visual indicator of whether the offset is specified correctly; the offset is correct when these shadows disappear. In the future, this offset could be determined automatically using a combination of indicators including shadows, shading and specular highlights.

IBRelight supports two methods of illuminating the object. The first method, shown in Figures 1, 2, and 3, uses light sources that are assumed to be relatively small and are defined by their intensity and position. This method is effective for modeling spot lights and similar kinds of lamps. The second method, shown in Figures 6 and 7, uses environment lights that are defined using a high dynamic range image of the surrounding environment [7] [8]. This is effective for creating images set anywhere from an outdoor scene to a gallery or a studio. In addition, the two methods are not mutually exclusive; an environment can be enhanced with the addition of lamps that use the first method, in order to highlight the object in desirable ways.

The renderer runs at interactive or near-interactive speed (depending on the size of the data set and the hardware being used), which makes it possible to see results in real-time. This makes the software easy to use for photographers who are used to this kind of feedback in real-world photography. It also opens new possibilities for public engagement; for example, IBRelight could run on a kiosk in an exhibit to facilitate user interaction, or it could be deployed on a computer lab in a school so that students could interact with the artwork remotely.

User Interface

The user interface (Figure 2) for IBRelight was designed to give the operator of an image based rendering program the same functionality that is found in traditional image synthesis programs such as *Maya* and *Keyshot*. A key feature of IBRelight is the ability to save multiple camera and object poses, and multiple environment and point light configurations. This allows a virtual photographer to experiment with different combinations of photographic setups, and even save their work and return later to make further changes. IBRelight supports both point light sources and Radiance HDR environment maps which gives the user some flexibility in defining the illumination conditions.

The user interface for IBRelight consists of three separate windows. The Program Control window (shown on the top left in Figure 2) has the standard pull down menus for opening and closing files, controlling various program settings, and exiting the program. The 3D View window (shown on the left in Figure 2) displays the object and allows direct manipulation using the mouse and keyboard. Finally, the Scene window (shown on the right in Figure 2) permits numerical values to be entered for camera, light source, and object positions, and it provides a facility for creating and switching between “presets” for these fixed locations.

The 3D View window is where the mouse and keyboard are used to produce direct manipulation of the camera, environment, lights, and object. Each mouse button and key has a different meaning in the context of the 3D View window. In general, the left mouse button performs rotation actions, while the right mouse button performs move and scale actions. Using combinations of the Shift, Ctrl, and Alt modifier keys, it is possible to perform many actions, including orbiting, panning, and dollying the camera, rotating and translating the object, and rotating and modifying the brightness of the surrounding environment.

It is also possible to manipulate individual lights using a 3D widget that is rendered in the 3D View window. Each point light source has its own widget, which consists of three double arrows that intersect at a point that is in the same direction as the light. There is also another point to which this widget is connected, rendered as a circle, which controls the center point which the light source rotates around. Figure 3 illustrates how the light manipulation works. Hovering over one of the rotation arcs will show a complete circle around the center point. Clicking on the arc will cause the other arrows to disappear, and dragging will move the light source around this circle.

While the 3D View window provides controls for modifying the camera, environment, lights and the pose of the object being rendered, the Scene window provides the additional functionality of being able to create different “presets” for each of these and then quickly switch through different viewing and illumination conditions. It also provides a mechanism for fine tuning the properties of each camera, environment, light, and pose by directly editing their numerical values.

One important feature that is accessible through the Scene window is the ability to set an environment image that illuminates the object as described earlier, and optionally a different image called a *backplate* that is displayed behind the object but does not illuminate it. An environment image is loaded from a file in the Radiance HDR format, which allows for the image to have a *high dynamic range* between the brightest and darkest places in the image, which is essential when using an image to perform illumination. When an environment image is being used, there is an intensity slider which controls the brightness of the environment image. This affects the total amount of light the environment casts on the object, as well as the appearance of the environment in the background if no backplate is specified.

Backplates are just simple images like a PNG or a JPEG. If a backplate is not used, IBRelight will render the environment image in the background if one has been specified, or a solid color otherwise. There is another intensity slider associated with backplates that controls the brightness of the background rather than the environment. Regardless of whether a backplate image is being used, this slider will affect the intensity of whatever is being displayed behind the object, whether it is an environment map, a backplate, or a solid color. However, this intensity slider does not affect how much light the environment casts on the object. This gives the user the ability to introduce a physical inconsistency between the brightness of the object and the brightness of the environment displayed in the background, for the trade-off of producing a more aesthetically pleasing result.

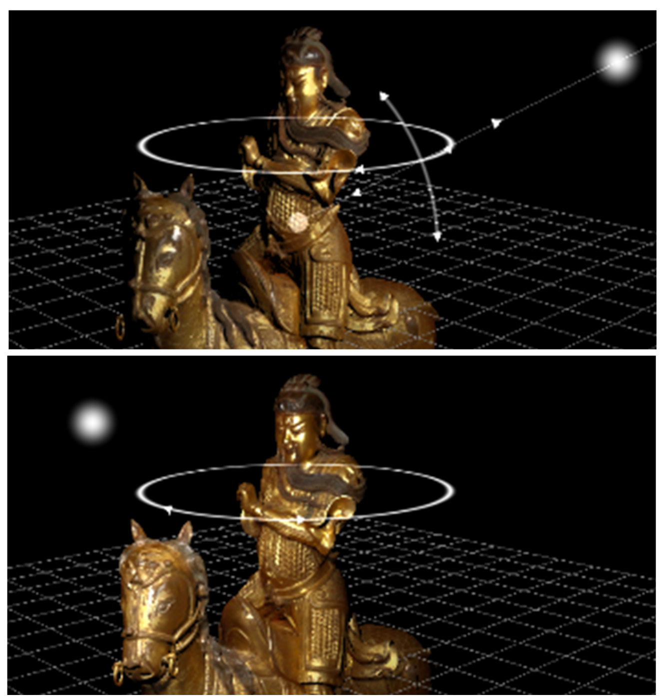

Figure 3*. IBRelight’s light manipulation widget. Above, the azimuth rotation circle is displayed as the user hovers over the corresponding arrows of the widget. Below, the widget disappears and only the circle is displayed as the user drags around the circle to move the light source.*

***Figure 4**. An example of a flash photograph containing an X-Rite Color Checker chart that can be used to calibrate the tone curve in the flash photographs used by IBRelight.*

Color Management

As mentioned above, one fundamental advantage of image-based rendering is the ability to leverage established tone and color management techniques for 2D photography. The camera and light source that are used to take the photographs can have their color and tone response characterized and the resulting information can be stored with the images. Even relatively simple techniques, such as photographing a test chart like the X-Rite Color Checker[3], can be used to linearize the color pixel data and achieve physically accurate relighting.

The X-Rite Color Checker can be used to calibrate a tone mapping curve for the case when all the flash photographs were taken under a light source with the same intensity and have had the same tone mapping applied. This is accomplished by leveraging the fact that each of the grayscale squares on the Color Checker chart has a known reflectance value. The chart must be photographed directly in front of or next to the object, under the same flash lighting and with the camera in the same place as another image that was taken for image-based rendering. Figure 4 shows an example of what such a photograph looks like. It is then possible to use an "eyedropper" tool in an image manipulation program to obtain a representative pixel values for each of the grayscale squares. The user then enters these values into IBRelight. By associating the known reflectance of the squares with the pixel values observed, IBRelight is able to then map the pixel values in any of the photographs to absolute reflectance values. The software is additionally able to account for the falloff in intensity as the distance from the light source increases.

While this is a simple demonstration of how tone management information can be used, in the future more color management data could eventually be leveraged to guide the reproduction more finely. Even without additional software development, archivists also can leverage the property that the tristimulus values produced by IBRelight have the same meaning as those in the original flash photographs. As a result, any color calibration performed when the photographs were taken can be applied to the images rendered by IBRelight to interpret the tristimulus values correctly and conceivably even compensate for differences between display devices.

Integration with Existing Lighting Software

The environment illumination feature of IBRelight is a powerful tool that can allow photographers to see an object in any environment for which they have high dynamic range imagery. However, obtaining such imagery can be a challenge. Various methods exist for obtaining HDR environment maps: a chrome ball can be photographed in an environment and be subsequently unwrapped into an environment image [8], or 360-degree lenses are also available which produce a similar effect [9]. Alternatively, it is possible to stitch together an unstructured set of ordinary photographs into a panorama that can serve as an environment [10]. There are also many environments acquired by experts in one of these ways which are available for free or for purchase online. Several free-to-use environments are included in the IBRelight distribution.

However, for the application of simulating studio photography, there is an alternative to photography for acquiring an environment map. The studio lighting environment can be virtually created from a library of typical studio lights that have been previously characterized, using separate software designed for this purpose. Figure 5 shows an example of such an environment. This lighting setup can then be exported as an HDR environment map and loaded into IBRelight. This allows IBRelight to render the object with the power of image-based rendering under the illumination specified in software designed for professional photographers. In this way the

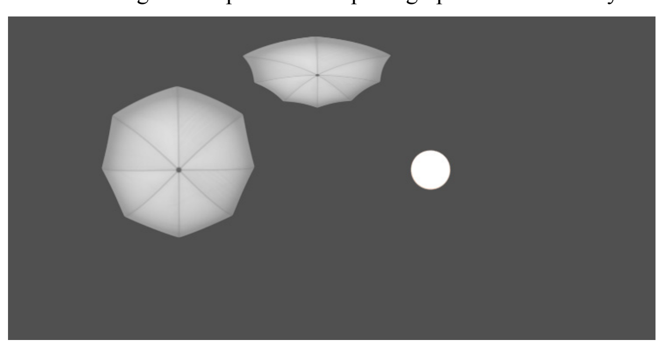

***Figure 5**. A studio illumination environment created using HDR Light Studio. The brightness in this figure is adjusted to show the relative intensities of the light sources.*

[3] X-Rite ColorChecker Classic:
http://xritephoto.com/colorchecker-classic

***Figure 6**. The child's tiger hat rendered in IBRelight under the studio illumination environment shown in Figure 5.*

entire process, from taking the original flash photographs to designing the lighting, leverages skill sets that professional photographers already possess. This could be particularly powerful for small studios without a wide variety of high grade equipment, who could use a library of virtual light sources to gain access to equipment that would otherwise be outside of their budget. An example of professional lighting software that exists for this purpose is HDR Light Studio[4] which has been tested with IBRelight and integrates seamlessly.

Conclusion

IBRelight, downloadable for free from the website listed below, is the first-ever release to the cultural heritage community of real-time 3D image-based rendering software with support for relighting. With an interface designed for photographic work, awareness of color management, and straightforward integration with software that is oriented towards photographers, it opens many new possibilities for institutions to use image-based rendering both for archiving purposes as well as public engagement. The relatively simple flash based photographic process is also accessible to museums with limited professional photographic staff. It is therefore hoped that the release of IBRelight will finally enable photographers to use image-based rendering to support archival work in the domain of cultural heritage.

Website

https://sites.google.com/view/ibrelight

Supplemental Video

https://goo.gl/ETg54r

[4] HDR Light Studio: https://www.lightmap.co.uk/

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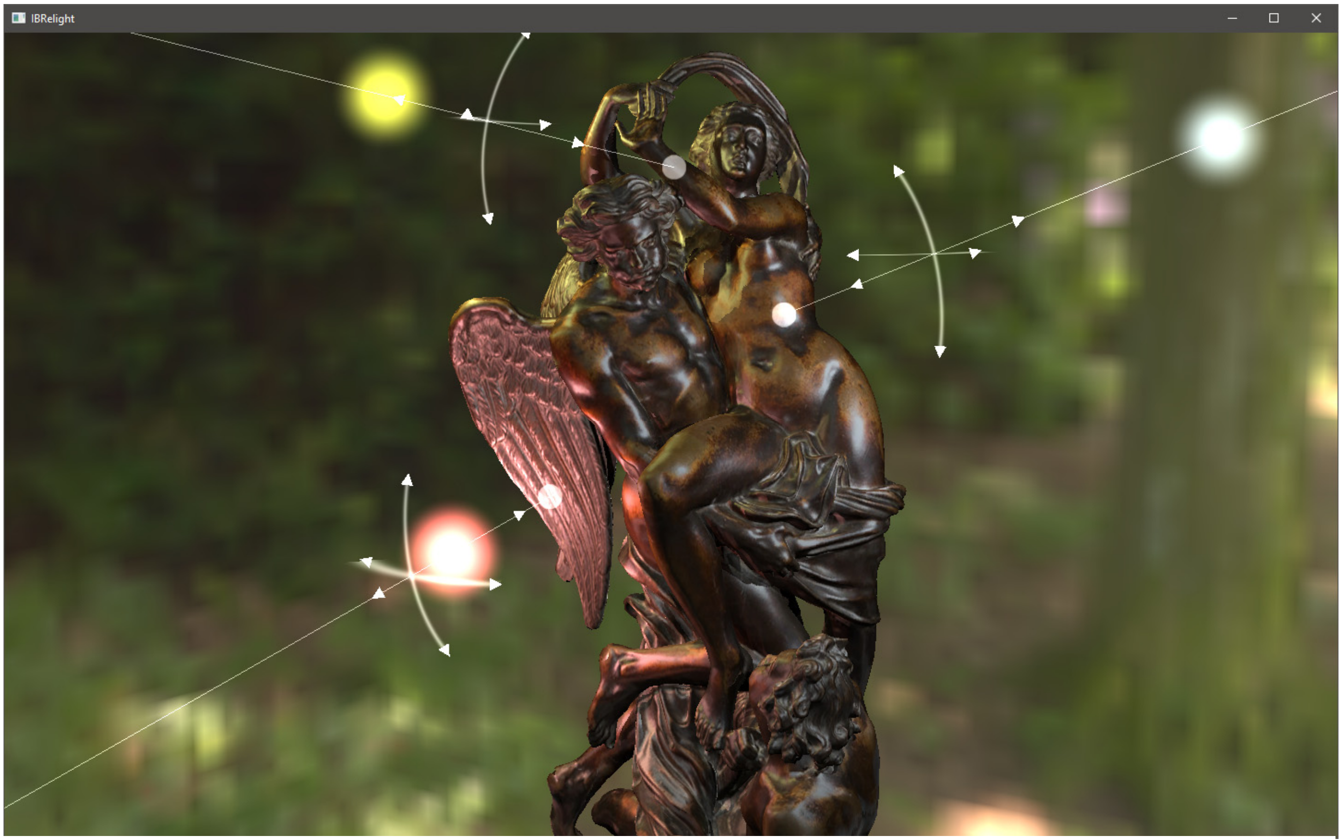

Figure 7*. "Boreas Abducting Orithyia" from the Minneapolis Institute of Art, being rendered in IBRelight from 55 photographs. In addition to the colored point lights, the environment seen in the background also applies illumination to the object as described in [3].*