Unlighting the Parthenon

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We present a method that extends techniques in [Yu and Malik 1998] and [Debevec 1998] to estimate the surface colors of a complex scene with diffuse surfaces lit by natural outdoor illumination. Given a model of the scene's geometry, a set of photographs of the scene taken under natural illumination, and corresponding measurements of the illumination, we can calculate the spatially-varying diffuse surface reflectance. The process employs a simple iterative inverse global illumination technique to compute the surface colors for the scene which, when rendered under the recorded illumination, best reproduce the appearance in the photographs. The results can then be used to render the scene under novel illumination.

We apply these techniques to capturing the reflectance of the Parthenon on the Acropolis in Athens, Greece. We use a novel lighting capture technique to record the full dynamic range of both sunlit and cloudy illumination conditions using a set of calibrated specular and diffuse spheres (Figure 1, top left). This configuration was photographed simultaneously with each photograph taken of the structure. All photographic equipment was carefully calibrated to achieve accurate results.

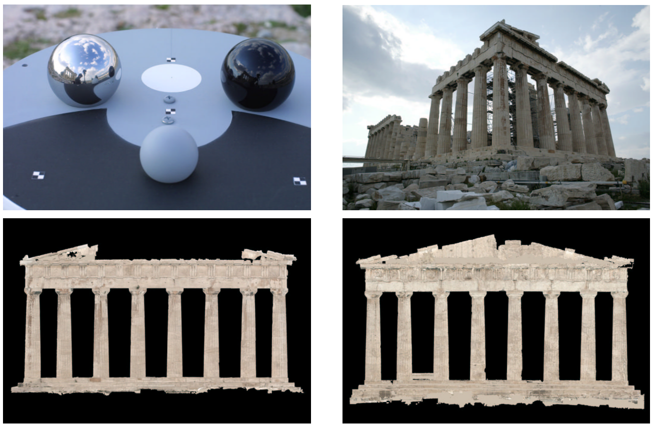

Figure 1: **(top left)** Incident illumination measurement, **(top right)** Photograph of the Parthenon under the illumination **(bottom)** Reflectance of the east and west sides of the Parthenon, calculated from a total of eight photographs under five different illumination conditions.

The basic algorithm we use proceeds as follows:

1. Assume initial reflectance properties for all surfaces
2. For each photograph of the structure:
   (a) Render the surfaces of the scene with a global illumination algorithm, using the photograph's viewpoint and lighting
   (b) Determine a reflectance update map by comparing the radiance values in the photograph to radiance values in the rendering
   (c) Compute weights for the reflectance update map
3. Update the reflectance estimates using the weights and update maps from all photographs
4. Return to step 2 until convergence

(a) (b) (c) (d)

Figure 2: **Computing reflectance properties (a)** Iteration 0: 3D model with initial reflectance properties, illuminated by captured illumination **(b)** Corresponding photograph, projected onto the geometry **(c)** Iteration 1: New reflectance properties computed by comparing (a) to (b). **(d)** Iteration 2: New reflectance properties computed by comparing a rendering of (c) to (b).

For diffuse surfaces such as the Parthenon, the most natural update for a surface pixel's color is to multiply it by the ratio of its color in the photograph to its color in the corresponding rendering. Thus, the surface will be adjusted to reflect the correct proportion of the light (Figure 2). However, the indirect illumination on the surface may change as other surfaces in the scene will also have new reflectance properties, requiring further iterations. We further modified this process to use measured BRDFs, allowing us to model the retro-reflective and forward scattering properties of the materials.

Since each photograph will suggest somewhat different reflectance updates, we weight the influence a photograph has on a surface's reflectance by a confidence measure composed of two factors. First we use the cosine of the angle at which the photograph views the surface, to prefer photographs that view the surface more directly. Second, we downweight a photograph's influence near occlusion and shadow boundaries, since small misalignments in lighting or camera position can generate large errors in these regions.

In order to process the laser-scanned Parthenon model, composed of over 90 million polygons, we subdivide the geometry into voxels. During each iteration we separately update each voxel's reflectance using low resolution representations of the other voxels for the global illumination calculation. The results, shown in Figure 1, are the first measurements of this type to be shown to be consistent with ground-truth reflectance measurements, agreeing with traditionally measured reflectance samples to within 5%. A detailed description of this technique will appear in [Debevec et al. 2004].

References

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