Prelit Materials: Light Transport for Live-Action Elements in Production Rendering

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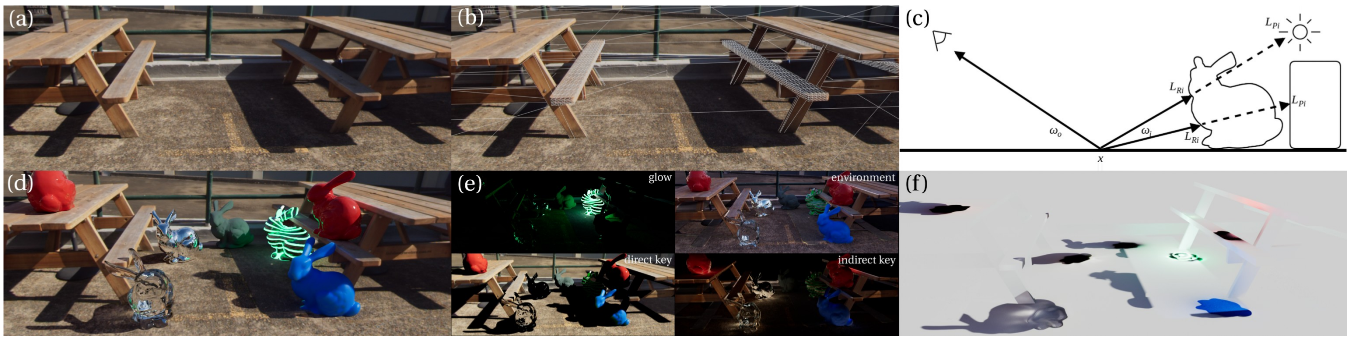

Figure 1: (a) live-action plate, (b) proxy geometry with prelit materials, (c) the ratio between the irradiance from the *relit* (L_{Ri}) and *prelit* (L_{Pi}) sub-scenes generates shadows and relighting, (d) single-render integration of synthetic objects, (e) various isolated light paths, (f) relighting multiplier including shadows, indirect light, synthetic relighting, and caustics.

ABSTRACT

We introduce a new conceptual model for including live-action footage in the light transport simulation of production renderers. By explicitly declaring which elements of the scene were present during photography, our pathtracer can generate realistic bidirectional lighting and shadowing between live-action and synthetic elements in a single pass. Using the film *Peter Rabbit* as a case study, we show how this can be used for automatic integration of synthetic elements into plates throughout the visual effects review process, from layout to interactive lighting. Auxiliary channels allow a compositor to perform several post-render adjustments, including rebalancing lighting on live-action elements.

CCS CONCEPTS

• **Computing methodologies → Ray tracing**; **Image-based rendering**;

KEYWORDS

path tracing, image-based lighting, VFX workflow

ACM Reference Format:

Steve Agland, Matthew Reid, and Daniel Heckenberg. 2018. Prelit Materials: Light Transport for Live-Action Elements in Production Rendering. In *Proceedings of SIGGRAPH '18 Talks.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3214745.3214746

SIGGRAPH '18 Talks, August 12-16, 2018, Vancouver, BC, Canada

ACM ISBN 978-1-4503-5820-0/18/08.
https://doi.org/10.1145/3214745.3214746

1 INTRODUCTION

VFX work requires rendering synthetic objects and integrating them into live-action plates (e.g. Fig. 1a). Additional data from the film set is typically collected, such as LIDAR scans of the set, HDR light probes, and camera settings. More data is derived later, such as camera motion and rotomation. Together these allow for very realistic integration, but the simulation of light transport between synthetic and live-action objects has not advanced in step with recent developments in rendering technology.

Techniques for automatically integrating synthetic objects into photographs have been explored for at least 20 years[Debevec 1998], but the visual effects industry has largely relied on shadow "catcher" materials, which often produce a semi-transparent image intended to be composited over the plate later. The feature set has evolved piecemeal to include reflections, indirect light and extra illumination, but the technique began when production renderers had limited support for global illumination. These catcher objects can be difficult to manage if they self-shadow or cast significant indirect light, and often require manual compositing work to finesse lighting integration. Modern production pathtracers and high-dynamic range digital plates open the possibility to generalise these requirements into a single concept.

2 RENDERING *PRELIT* OBJECTS

We observe that the general problem is to compute the change in illumination to the live-action elements, such as the environment or rotomated actors. We project HDR shot plates and light probes onto proxy geometry (Fig. 1b) and treat these objects as first-class members of the light transport simulation. We call them *prelit*, because their materials have the real-world lighting "baked in". We also extend the scene description by defining two overlapping subsets: the *prelit scene*: geometry and light sources that represent the scene as photographed (the ground surface, light probes, etc); and the *relit scene*: synthetic geometry and lights, and those parts of the prelit scene which interact with these synthetic objects in terms of light transport.

When shading prelit materials, our pathtracer samples the irradiance from both the relit (L_{Ri}) and the prelit (L_{Pi}) scenes (Fig. 1c). By assuming the projected photographic imagery is the prelit radiance (L_{Po}), the relit radiance (L_{Ro}) is computed,

$$L_{Ro}(x, \omega_o) = \int_{\Omega} L_{Ri}(x, \omega_i) \frac{L_{Po}(x)}{L_{Pi}(x, \omega_i)} (\omega_i \cdot n) \mathrm{d}\omega_i \tag{1}$$

where x and n are the surface position and normal, and ω_i and ω_o are incoming and outgoing light vectors over the unit hemisphere Ω. Note that $\frac{L_{Po}(x)}{L_{Pi}(x,\omega_i)}$ can be considered an albedo estimate.

This effectively relights the plate at both primary and indirect ray hits, with several desirable properties. Light and shadow are cast onto plates from synthetic objects with realistic color and density, assuming the on-set lighting is reproduced accurately. If incorrect, lights can be tweaked interactively until phenomena like shadow density match. The indirect light cast from the live-action elements onto synthetic objects is locally correct, particularly where they are very close, due to the recursive simulation of shadow and light. This effect is difficult to achieve without a holistic solution to live-action light transport. It is also possible to relight the live-action elements, by removing on-set light sources or adding new ones.

By accumulating samples of L_{Ro}, an image I_R approximating a final composite is generated in a single pass (Fig. 1d). It is also useful to also accumulate L_{Po} in an auxillary channel I_P, and to filter samples to extra channels based on their light paths.

3 COMPOSITING WITH *PRELIT* RENDERS

By accumulating samples into n disjoint subsets based on light path, I_{Rj} and I_{Pj} (for $j \in \{1 \ldots n\}$) (Fig. 1e), it is possible to adjust the lighting as a compositing operation, while leaving non-relit parts of the plate unaffected,

$$I_R{}' = I_P \frac{\sum_{j=1}^{n} g_j I_{Rj}}{\sum_{j=1}^{n} g_j I_{Pj}} \tag{2}$$

where $I_R{}'$ is the rebalanced beauty render, and g_j is the gain applied to light path j. This can be used to fine-tune shadow color, for example. The live-action plate can be divided out of the beauty render to yield a "relighting multiplier" $I_M = \frac{I_R}{I_P}$ (Fig. 1f), which can be re-applied to an unfiltered plate.

4 THROUGHOUT THE PIPELINE

The *Peter Rabbit* film had over 1100 shots requiring integration of synthetic characters. For the project we established automated review renders using prelit materials for several departments, including Layout, Animation and FX. Render scenes were built automatically using the latest assets, prelit materials, and spherical light probes that had been automatically matched to shots.[Heckenberg et al. 2017] This meant each department received fast near-final-looking renders of their work, with realistic lighting and live-action integration to help review layout and animation choices in context (Fig. 2). These renders could also be used in Editorial before Lighting or Compositing had begun work on a shot.

Figure 2: On *Peter Rabbit*, automated dailies renders for Animation, Layout and other departments used prelit materials, the shot plate, and a single spherical light probe.

5 LIMITATIONS AND FUTURE WORK

Despite overall succcess on *Peter Rabbit*, prelit materials couldn't solve all live-action integration challenges. Our implementation of prelit materials currently only models Lambertian diffuse surfaces, and we are exploring extending this to arbitrary BRDFs, without which separate reflection passes are required. Variance from the albedo esimate in Eq. (1) could be reduced by integrating L_{Ri} and L_{Pi} over the hemisphere separately before computing their ratio, but would require a more significant change to the pathtracer.

For prelit materials to work, all lights from the prelit scene must be present, and effectiveness strongly depends on the accuracy of input data. Care must be taken to handle near-zero values of L_{Po} or L_{Pi}. Our simple approach of projecting the shot plate and a single light probe onto the prelit materials was at times inadequate when the backfacing side of an object cast incorrect indirect light onto the scene beyond.

However, prelit materials have proven useful for reviewing work in context prior to shot lighting, and reducing the time spent on plate integration in Lighting and Compositing. We hope that this or an improved technique might find wider adoption in the industry. We also plan to explore using a similar approach for "delighting" photographic assets to extract albedo maps.

ACKNOWLEDGMENTS

Thanks to Narendra Kumar Vadapalli for the pipeline implementation; and Francesco Sansoni, the lighting crew, and the supervision team on *Peter Rabbit* for their patience and valuable feedback.

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