Practical Lighting on *Toy Story 4*

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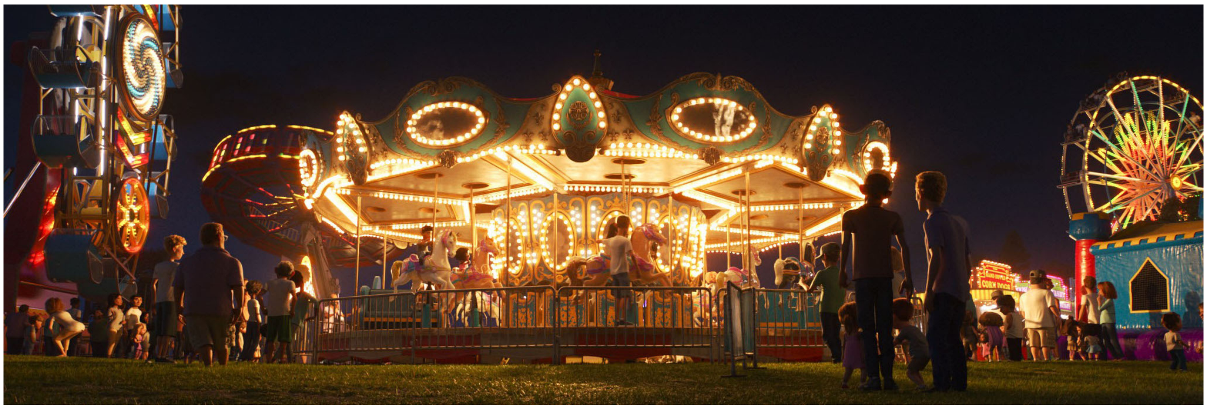

Figure 1: Nighttime carnival scene from Pixar's *Toy Story 4* ©Disney/Pixar.

ABSTRACT

Since the adoption of Global Illumination on *Monsters University* and Renderman RIS on *Finding Dory*, Pixar has pushed closer and closer to photorealism with physically-based lighting and shading. With each show, Lighting artists have needed to create, organize, and creatively balance more and more light sources of increasing complexity. Because Pixar has also traditionally worked with a "fixed" camera exposure, the light colors and intensities chosen by the artist would also drive the overall brightness of the final image.

Toy Story 4, which takes place in both an antiques mall and a traveling carnival, was a challenge to this workflow. The large variety of light sources in the antiques mall would be difficult to group into uniform categories; complex light animation on carnival rides required light intensities driven by upstream assets; and seeing the same lights under day and night illumination meant that production-wide choices for light intensities could not be made under a single, fixed exposure. We needed assets that behaved like in the real world and *just worked* when placed together in a scene.

We developed a method on *Toy Story 4* for tagging modeled assets with physical light properties that would automatically be converted into functioning light sources in a shot by a script called Bakelite. This pipeline gave the Lighting department more time for creative iteration with minimal setup, allowed pre-lighting visualization of shots by upstream departments, and ensured a final image that was both rich in surface detail and also accurate in HDR.

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CCS CONCEPTS

• **Computing methodologies → Rendering**.

KEYWORDS

lighting, light instancing, shading, procedural animation, HDR

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1 ASSET CREATION

To achieve consistency in our lighting assets, models that were targeted as future light sources had to adhere to strict naming and tagging standards, as these would later be fed into the Bakelite script for auto-conversion. All geometry was named BulbLightSource (sphere-like bulb object) or GlobeLightSource (irregular shape with an implied embedded bulb) and was tagged with primvars (primitive variables) for on/off, lumens, temperature, color, and surface area. The gprimPivot of the geometry in Maya was set to the location of the theoretical "filament," and this drove both the constraint target of the converted light source and the visual "core" of the geometry's shaded glow. Model hygiene scripts were run to check for proper tagging, and nightly diagnostic renders were used as visual checks.

We chose to decouple the shaded in-camera glow of the geometric surface with the indirect light cast from its corresponding light source as a rendering optimization to take advantage of Renderman light sampling. This choice also allowed more freedom to the Shading artist to use camera-dependent shading tricks for shaping glow falloff without affecting light cast. Despite this decoupling, it was important to preserve the intensity relationship between the asset and its light source so that they appeared in sync for any given camera exposure. To do so, we calibrated the exact glow colors with the colors output by

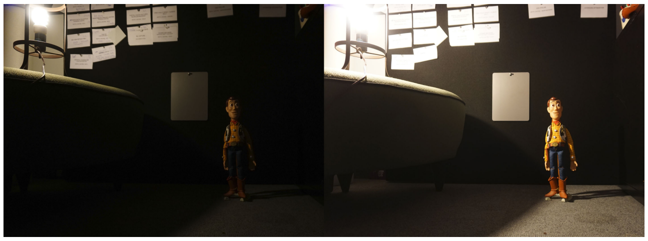

Figure 2: Reference photos of Woody lit by a 60 watt bulb under various exposures. ©Disney/Pixar.

Renderman light sources, as well as amended lighting tools to update primvars on modeled assets when their corresponding lights were updated. The final glow values were far brighter than Pixar typically used for glow, but they increased the visual realism of the lights in *Toy Story 4* and behaved more accurately in HDR than any previous Pixar film.

2 BAKELITE

The standard Pixar pipeline has a shot conversion stage where all the asset and animation data for a shot is baked down from our animation tool Presto into a set of USD files for consumption by Katana and Renderman. Bakelite is a post-process step to this shot conversion that creates a sidecar USD file containing all the position, orientation, scope, and primvar data for every practical light source in the shot. Baking reduces render startup time by removing the step of analyzing the scene for practical light data, and it also provides a useful diagnostic tool.

Bakelite works by matching regular expressions against the scopes and names of light-related geometric primitives in the shot, which have been standardized according to the asset naming conventions described above. The sidecar USD file generated by Bakelite is used by a set of Katana Ops to autogenerate all practical lights in the scene. The resulting lights have been pre-categorized into multiple collections to distinguish between different types of lights (such as ferris wheel lights vs ceiling fluorescents) that may use different instance masters (such as sphere lights with an IES profile vs tube lights). Each collection becomes a separate light array in Katana.

3 LIGHT ANIMATION

The data consumed by Bakelite is presented in USD format, and hence can be authored by any software capable of authoring USD. We used this capability for procedurally animating carnival lights in Houdini. Light bulb geometries were brought into Houdini as a usd point instancer, split into multiple groups, and given point attributes *local_id*, *local_u*, and *group_id* for procedural animation. A Houdini VEX script was used to animate the usd primvars for on/off and color, with each light bulb receiving a randomized brightness when turned on and decay rate when turning off. Director Josh Cooley wanted the carnival to feel "old-timey," so instead of the rapidly blinking modern LED bulbs that display any motion and color, we opted for the slower motion and softer color palette of warm incandescent bulbs. For better realism, 3 percent of bulbs were perpetually "broken" and never turned on. In the end, 5-16 procedural animation variants were exported as USD files from Houdini and layered onto 12 carnival rides and 7 carnival booth models. To communicate the light animation to downstream departments, all animation variants had a low resolution proxy object for viewport display that correlated display size with light intensity.

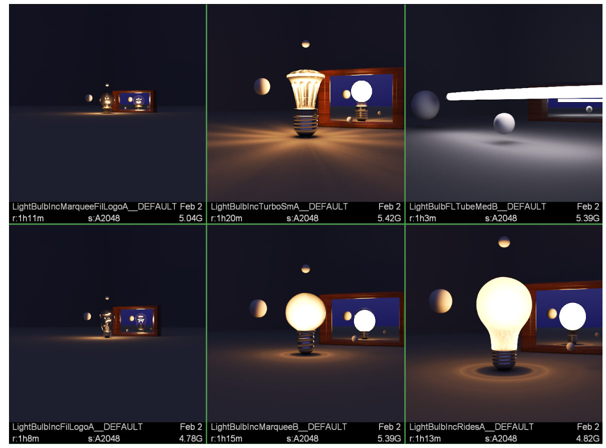

Figure 3: Example of nightly diagnostic light bulb renders. ©Disney/Pixar.

4 LIGHTING

Asset light sources manifest in Katana as light arrays, which are single scenegraph items that stand in for a large number of individual light instances. Lighting artists can use these arrays to make group-wide adjustments to attributes such as intensity, color, temperature, or size. Instance-specific adjustments can also be made using a "rod" object, which is parented under the light array and performs adjustments inside its spatial area of influence.

On previous films, light arrays could only contain light sources with identical attributes. This was amended on *Toy Story 4*, where per-instance attributes allowed us to group lights of varied size, shape, color, and intensity, dramatically reducing the number of distinct light arrays that were needed. About a dozen such groups were pre-defined at the production level, automatically dividing all the asset light sources into the same number of light arrays in each shot. These categories remained relatively unchanged across shots for the duration of production and simplified organizational complexity for Lighting artists.

Finally, the Lighting department on *Toy Story 4* chose to emphasize physically-correct camera exposure and light intensity. We took special care to ensure that our sun and sky illumination had physically-plausible illuminance values, so that the physically-plausible luminances chosen for the asset lights would look correct by comparison. This meant that the same assets and their lights would look sensible in both daytime and nighttime without any necessary readjustment to their intensities. This care vastly reduced setup time and eliminated lots of work to make lights look correct relative to each other. The result was an image that looked physically plausible, and it was especially vibrant and realistic when viewed in HDR.