VOLUMETRIC LIGHTING

TNCG13 - RENDERING TECHNIQUES (REPORT 2)

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Abstract

In this paper I will concentrate and focus on a specific method for artistic volumetric lighting presented by Nowrouzezahrai et al. [3] in their paper **"A Programmable System for Artistic Volumetric lighting"**. The method is inspired by Kerr et al. [2] and their paper **"BendyLights: Artistic Control of Direct Illumination by Curving Light Rays"** and incorporate the non-linear lighting where each photon beam can be seen as a volumetric generalization of *BendyLight*. Beams are well suited when it comes to wispy effects, which has been difficult to model in the past (using either point primitives or density grids).

1 Introduction

The system presented by Nowrouzezahrai et al. [3] for generating target stylizations of volume effects imitates the way professional artists hand draw these effects. The method is based on the approach made by Jarosz et al. [1] on *photon beams* which provide physically-based rendering of participating media.

The framework by Nowrouzezahrai et al. [3] allows for art-directed and programmatic injection of source terms into physically-based volumetric light transport.

2 Volumetric lighting

The term "volumetric lighting" simply refers to lighting that is more uniform throughout the entire volume and less directional. Volumetric lighting illuminate the entirety of the interior which results in a better balance of luminance throughout the visual field. Using volumetric lighting when rendering a room, the room feels brighter, larger and more relaxing. Facial rendering seems more natural, consistent and complimentary. Also, shadows tend to be softer and less pronounced which is important.

A common artistic goal is to induce a desired color gradient across the media's volume. Compared to physically-based rendering, where the artist has to manipulate the σ parameters themselves, Nowrouzezahrai et al. [3] provides a system that allows the artists to directly specify a desired color gradient.

The technique that is used incorporates non-linear lighting which is inspired by Kerr et al. [2] and their paper **"BendyLights: Artistic Control of Direct Illumination by Curving Light Rays"**. *BendyLights* (discussed in section 4) is a non-linear spotlight for controlling lighting and shadows. When Nowrouzezahrai et al. [3] incorporate the non-linear lighting, each photon beam can be seen as a volumetric generalization of a *BendyLight*.

2.1 Design Requirements

Nowrouzezahrai et al. [3] gathered a few core principles of great importance for the artists:

- the model should mimic the abstractions that artists normally use when thinking about volume effects,
- results spanning the entire gamut of believability should be generated, from physically accurate to completely art-directed,
- the integration of the system must result in a seamlessly transformation into the existing production pipline, and
- the flexibility should be exposed through programmability.

The most important requirement is the first principle listed - the way artists conceptualize volumetric

Figure 1: The method presented by Nowrouzezahrai et al. [3] was used for the movie *Tangled*. Their technique's ability to produce curving light beams (to author artistic volumetric effects) was used to match the organic artistic style of the movie.

effects influences the way they reason about digitalized replicas. The biggest problem for artists is that volumes is not intuitive like surfaces and the lack of geometric models makes them very difficult to get a hang of. Nowrouzezahrai et al. [3] solves this problem by using photon beams. This allows the artists to think about light in a volume of its own geometric entity. The lighting volumetric effects is reduced to modeling and shading problems.

Artists have their own special way of drawing volumetric effects which consists of a two-stage procedure as seen in figure 5. The solution provided by Nowrouzezahrai et al. [3] generalizes the photon beams algorithm, where both the process of generating and shading beams can be performed using physically-accurate or non-physical, art-directable procedures.

3 Theoretical Foundation

3.1 General Light Transport

Light at a point x (e.g. the camera) from direction w is expressed as

$$L(x,w) = L_s(x,w) + L_m(x,w) \tag{1}$$

where the surface radiance (potentially undermined by the media), L_s, is governed by the rendering equation and the second term, L_m, is the radiance due to the participating media,

$$L_m(x,w) = \sigma_s \int_0^d e^{-\sigma_t z} \int_{\Omega_{4\pi}} \rho(\theta_z) L(w_z, w_z) dw_z dz \tag{2}$$

The equation accumulates light at points x_z along the eye ray. When a ray hits a surface d units away, the accumulation stops. This light recursively depends on radiance arriving at x_z from directions w_z over the sphere $\Omega_{4\pi}$. When $cos\theta_z = w \cdot w_z$, the phase function is denoted ρ.

To simplify equation 2, the case for homogeneous media is described with three different coefficients - absorption (σ_s), scattering (σ_a) and extincion ($\sigma_t = \sigma_s + \sigma_a$).

3.2 Photon Beams for Physically Accurate Rendering

There is a difference between *photon mapping methods* and the *photon beams method* (presented by Nowrouzezahrai et al. [3]) when computing equation 1.

Photon mapping methods compute equation 1 in two steps. The key features of the photon mapping algorithm are the use of photon tracing and the photon map. In the first step, during precomputation, a collection of photons are traced through the scene and stored at points x_p. In the second step, during the rendering, a *shading pass* queries the data and applies a physically accurate shading model to compute final radiance towards the eye.

In the **photon beams method** the first method pass remains. In this method each photon beam is treated as a beam of light and instead of using photon points (fig. 2a) to estimate the density this method uses the beams. Jarosz et a. [1] derived a "Beam x Beam (1D)" (fig. 2b) estimate for computing L_m along the camera rays given a collection of beams.

The quality of radiance estimation is increased by photon beams since the space is fulled more densly. The blue search region overlaps two photon beams but does not overlap any photon point as can be seen in figure 2a.

$$L_m(x,w) = \sigma_s \sum_p k_r(u) e^{-\sigma_t z} \rho(\theta_p) e - sigma_t v \frac{\Phi_p}{sin\theta_p} \tag{3}$$

The summation in the equation above (eq. 3) loops over all beams and evaluates the terms at the intersection of the camera ray with each photon beam

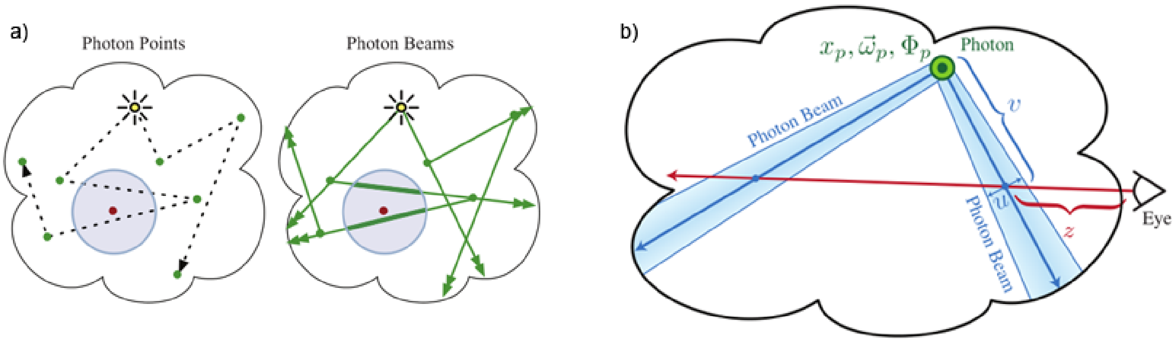

Figure 2: a) "Photon Points" - volumetric photon mapping stores scattering events at points (green) and performs density estimation. With "Photon Beams" the full trajectory of each photon is stored and density estimation is performed on line segments. b) Geometry for the *Beam x Beam 1D* of equation 3.

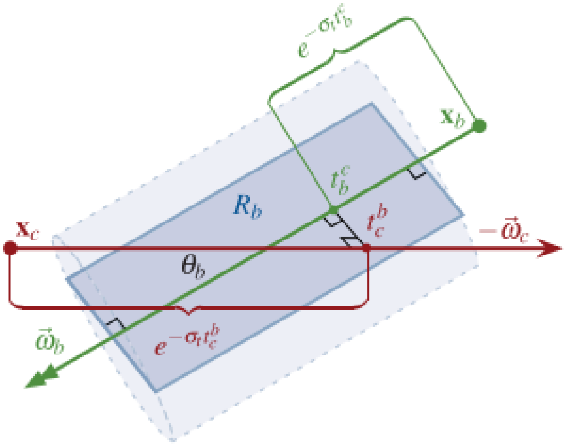

Figure 3: The estimator simplifies the photon beams to a 1D blur by compressing the cylinder into a camera-aligned rectangle.

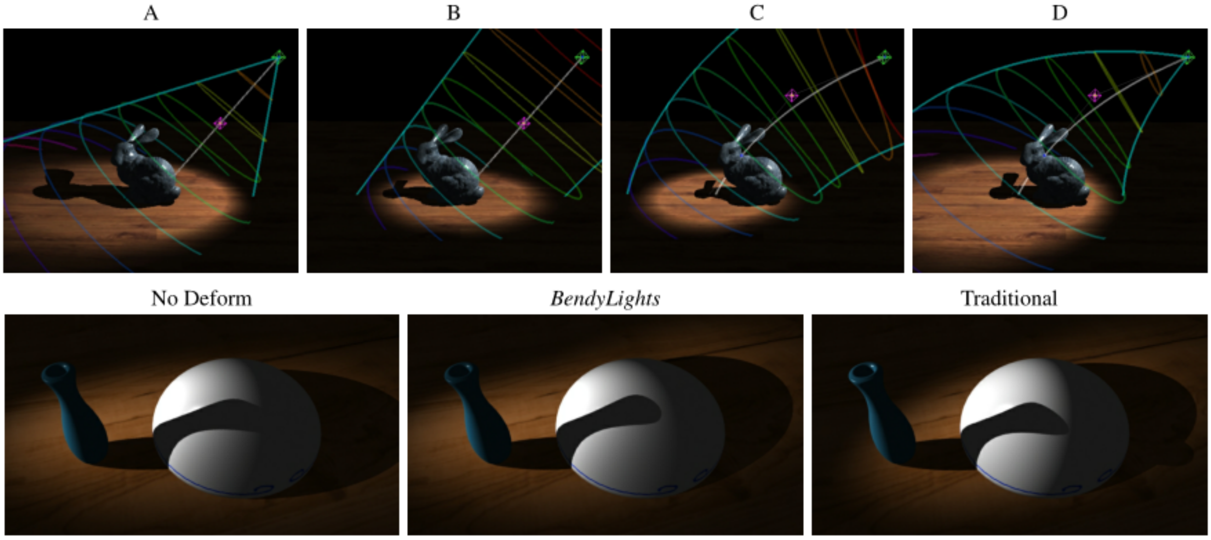

Figure 4: Row 1: An example of basic *BendyLights* operations. (A) Non-deformed spotlight. (B) Setting a constant radius. (C) Bending light rays from B. (D) Bend from C with the radii of A. Row 2: *BendyLight* example which is not using traditional linear lighting techniques. Shown is a spotlight before deformation, the resulting edit with *BendyLights*, and Kerr et al. [2] best approximation of this edit with traditional linked linear lights.

(fig. 2b). Each beam has a finite width and the endpoints of the photon beams are surface photons which are used when to estimate the density.

4 Bendy Lights

Even though cinematic lighting models provides artists with non-physical controls and are quite powerful, this is not enough. Artists finds it necessary to achieve many desired effects which are not possible with cinematic lighting.

BendyLights is a spotlight-based lighting model for artistic control where light travels along nonlinear paths from a point source. *BendyLights* have the following advantages compared to traditional light lining and cinematic light [2]:

- by using only a single light, lighting effects, where shadows and highlights are included, can be adjusted independently at different spatial locations.
- smooth spatial consistency of the non-physical lighting effects is maintained across surfaces.
- by using familiar spline editing tools light paths can be easily controlled.
- artists can drag shadows, highlights and hotspots while the interface provided by Kerr et al. [2] appropriately deforms the spline.
- lighting effects made by *BendyLight* can be animated by keyframing the spline control points.
- the *BendyLight* method can easily be integrated in production renderers and can be rendered in real-time on GPUs.
- *BendyLight* works with global illumination.

Figure 4 shows a few basic examples of *BendyLights*.

4.1 Curved Beams

When having physically accurate light transport the frustra has the shape of a perfect cone. It is, however, possible to have a curved, warped frustra using procedurally generated beams. Another way to look at a photon beam is as a spatially-varying volume of light.

> "Each curved photon beam induces *volumetric* a bendy light, albeit with a more flexible, art-directable spatial and angular radiance distribution." Nowrouzezahrai et al. [3]

5 Photon Beams

Photon beams can be described as small spotlights which are attenuated volumetrically along their x axis. By storing the entire path of a photon instead of just the scattering location, volumetric photon mapping is generalized through photon beams. Each photon beam represents a truncated conical beam of light through the medium.

5.1 Deducing Scattering Parameters

5.1.1 Determining σ given Beam Power

Nowrouzezahrai et al. [3] allows the user to specify two target colors, C_1 and C_2. C_1 is the color at the beginning of the beam and C_2 is the color at a canonical distance which is assumed to be 1 along the beam. This is because the arbitrary distance for C_2 results in uniform scaling of $\sigma = \{\sigma_s, \sigma_a, \sigma_t\}$.

The following equation (eq. 4) shows the behavior along the length of the beam if the beam is perpendicular to the view at some canonical distance z.

$$L_m(v) = \sigma_s \Phi_p e\ -\sigma_t z e^{-\sigma_t v} \tag{4}$$

When the color and the power, Φ_p, of the beam correspond to a fixed light source color in single-scattering, the parameters σ_s and σ_t are obtained under the constraints imposed by C_1 and C_2 according to Nowrouzezahrai et al. [3].

$$\begin{aligned} C_1 &= \sigma_s \Phi_p e\ -\sigma_t z \\ C_2 &= \sigma_s \Phi_p e\ -\sigma_t z e^{-\sigma_t} \end{aligned} \tag{5}$$

The following solutions for σ_t and σ_s are obtained by dividing the equations in (5). This division provides an estimate for σ_t which is then plugged back into the equations. The solution below, however, is physically meaningful only if $\sigma_s \leq \sigma_t$ which can be satisfied if $C_2 < C_1$ in all color channels.

$$\begin{aligned} \sigma_t &= -log\left(\frac{C_2}{C_1}\right) \\ \sigma_s &= \left(\frac{C_1}{\Phi_p}\right)\left(\frac{C_1}{C_2}\right)^z \end{aligned} \tag{6}$$

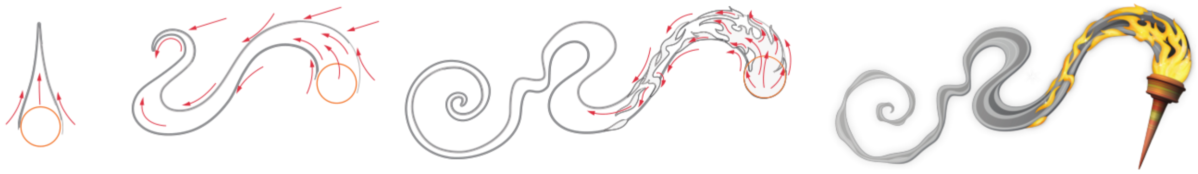

Figure 5: Left to right: the first step to draw a volumetric effect is for the artist to sketch a coarse high-level outline of the media. The second step is to progressively refine the sketch to include increased levels of detail and dynamics before "rendering" the final image in the third step.

5.1.2 Solving for All Photon Beam Parameters

By using the gradient specification, Nowrouzezahrai et al. [3], provide the ability to specify all the parameters for photon beams.

A complication is that the space is overcomplete[1]. To address this problem Nowrouzezahrai et al. [3] substitute $\sigma_s = \alpha\sigma_t$ in equation 6 to obtain

$$\sigma_s = -\alpha log\left(\frac{C_2}{C_1}\right) \quad (7)$$
$$\Phi_p = \left(\frac{C_1}{\sigma_s}\right)\left(\frac{C_1}{C_2}\right)^z$$

By observing the derivations, it is shown that either the albedo or the light's power are irrelevant to the final image color.

5.2 Procedural Shading of Photon Beams

As can be seen in figure 2b, there are a few high-level parameters: the distances along and across the beam (v and u), the distance to the camera (z) and the angle between the eye ray and the beam (θ_p). Nowrouzezahrai et al. [3] noticed that, when they were given a collection of photon beams, the radiance on the image was influenced by these parameters. The parameters influenced the observed radiance through four physical processes, each associated with a function below:

- $f_b(v)$ - color change due to attenuation along the beam.
- $f_e(z)$ - color change due to attenuation towards the eye.
- $f_f(\theta_p)$ - shading depends on the viewing angle.
- $f_t(u)$ - shading is influenced by the photon beam's thickness.

By combining the four physical processes, the high-level parameters and the media parameters (σ_s, σ_a and σ_t), physically accurate shading as well as arbitrary non-physical shading behavior were fully described.

Nowrouzezahrai et al. [3] art-directable radiance estimate replaces equation 3 with the following expression

$$L_m(x, u, v, z, \theta_p) = \sum_p f_t(u) f_b(v) f_e(z) f_f(\theta_p) \quad (8)$$

The advantage of this generalized model is that it can be used for art-directable shading as well as for replicating physically shading by using the following terms

$$f_t = \phi k_r(u) \quad (9)$$
$$f_f = \sigma_s \frac{\rho(\theta_p)}{sin\theta_p}$$
$$f_c = e^{-\sigma_t z}$$
$$f_b = e^{\sigma_t v}$$

The terms above satisfies the requirement in equation 3 which denighes "generating physically-accurate to completely art-directable results", Nowrouzezahrai et al. [3].

5.3 Procedural Photon Beam Generation

The volume's *lit shape* is explicitly defined by the beams in a scene which are geometric lighting primitives (section 3).

The method provided by Nowrouzezahrai et al. [3] allows the artist to think of sculpting a volume as if it were a geometric entity which is a natural 3D extension of the process of hand sketching a 2D volumetric effect (fig. 5).

To deposit and evolve beams over time, procedural geometric modeling is used. One advantage is that

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[1] This means that an infinite number of parameter choices can lead to identical results.

it allows the artist to focus on directly creating volumetric appearance. By allowing this, there is no need to use physical simulation combined with volumetric shaders to get less desirable results.

6 Summary

Giving the artist the possibility to create on paper and then implement the outline as curves in Houdini^{TM} opens a new world for artistic volumetric lighting. This is exactly what was done in the movie *Tangled*. In figure 1, curvy beams from the girls chest slowly fill a room, creating intricate, non-physical lighting both indirectly and volumetric on surfaces. For this scene, the artist designed and drew spiral and flower shapes on a paper, implemented them as curves in Houdini^{TM} and used then them as both target shapes and paths for beams. This would not have been possible without the technique provided by Nowrouzezahrai et al. [3]. Another great thing about beams is that they naturally can be sampled as light sources for surface shading. Also, as seen in figure 1, the beams cast light on the characters faces as well as being reflected in the environment.

As mentioned before, the system by Nowrouzezahrai et al. [3] enhanced the creativity and creative freedom of the artists compared to previous ad-hoc techniques. The system also improves the workflow (both intuitively and efficiently) since beams are a "closer analogy" to the volumetric light.

Beams are well suited when it comes to wispy effects which has been difficult to model in the past (using either point primitives or density grids).

When studying these papers I have realized that the artists decides the future in lighting, whether it is artistic volumetric lighting or not. The physically-accurate photon beams approach is the closest to what the artists want - being able to draw volumetric effects by hand. Nowrouzezahrai et al. [3] are able to expose an intuitive programmable model for design volumetric effects by generalizing this approach and tying it to a geometric interpretation for volumes and the lighting within them.

References

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