An Empirical Fur Shader

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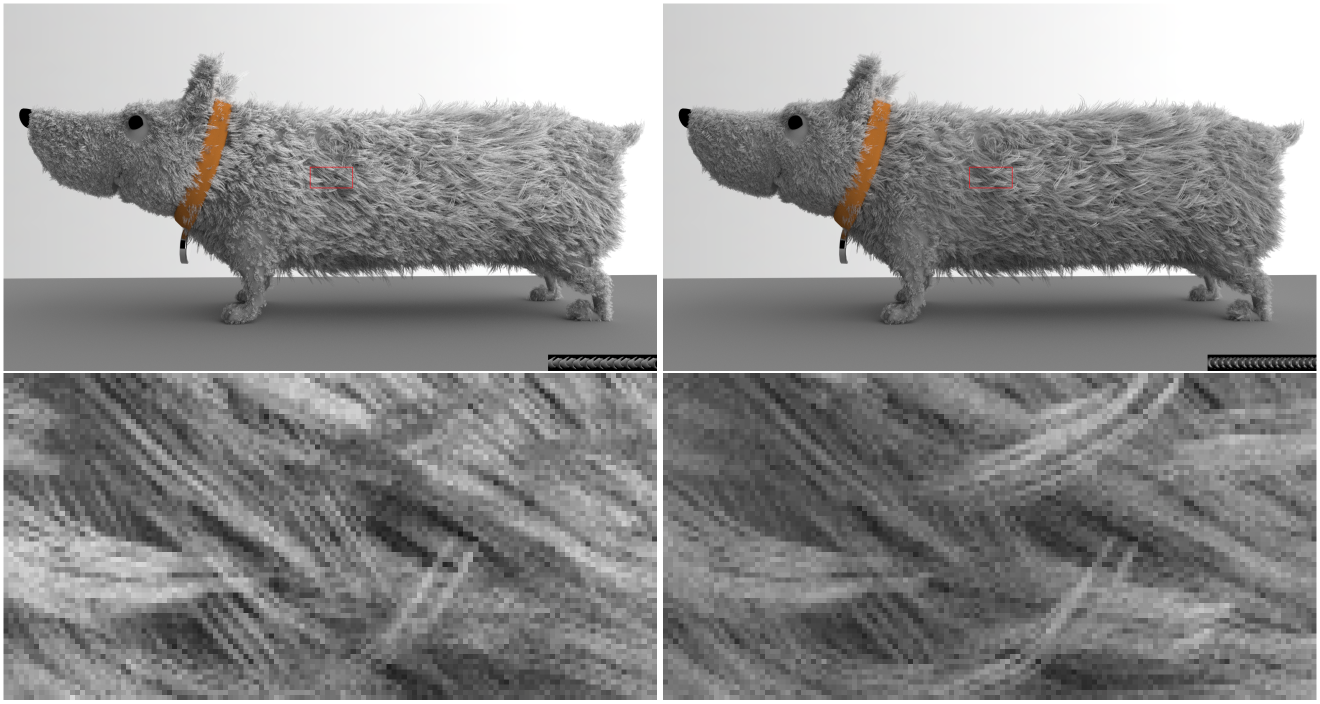

Figure 1: *Top: two different types of synthetic animal furs. The rendering time is 10 minutes 10 seconds for both images (1920x1080 pixels). Bottom: closeups of the red rectangle regions. All images were rendered on a dual Xeon W5590 system.*

1 Introduction

Many shading models have been proposed for human hair fibers (see, for example, [Marschner et al. 2003]) and they are used successfully in film productions. Not much attention, however, has been paid to animal furs. The models developed for human hair fibers may not be suitable for animal fur since the scale patterns, medullary types, and pigments are different from those of humans, and greatly different between animals [Deedrick and Koch 2004b]. In this paper we propose an empirical shader to reproduce the detailed appearance of animal fur.

2 Our Method

Fur consists of mainly three parts: the cuticle, medulla, and cortex. See detail [Deedrick and Koch 2004a]. The fur structure can be modeled with 3D software such as Maya, or by procedural methods as shown in Figure 2. Designers may apply an arbitrary material to each part.

The scattering integral is given as

$$L_o(\omega_o) = \int_\Omega S(\omega_i, \omega_o) L_i(\omega_i) cos(\theta_i) d\omega_i, \tag{1}$$

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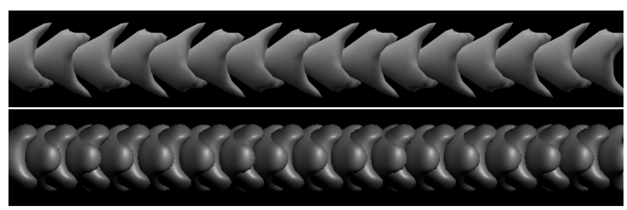

Figure 2: *Modeled fur examples*

where L_i and L_o are the incoming and outgoing radiances; ω_i and ω_o are the corresponding directions, respectively; and θ_i is the inclination of ω_i w.r.t the plane perpendicular to the fur tangent vector. The notations are borrowed from [Marschner et al. 2003]. It can be rewritten with a discretized version of the scattering function S as

$$L_o(\omega_o) = \sum_{j=0}^{N-1} \int_\Omega S_j(\omega_i, \omega_o) L_i(\omega_i) cos(\theta_i) d\omega_i, \tag{2}$$

where

$$S_j(\omega_i, \omega_o) = \mathbf{1}_{\left(j=\left[N\frac{acos(<\omega_i, fur\_tangent>)}{\pi}\right]\right)} S(\omega_i, \omega_o). \tag{3}$$

Here $[]$ is the floor function and $\mathbf{1}_{()}$ is an indicator function, whose value is one if the argument is true, and zero otherwise. In order to create S, we adopt the photon casting technique as in [Donner et al. 2009]. Fluxes of scattered photons are stored in a unicube map [Ho

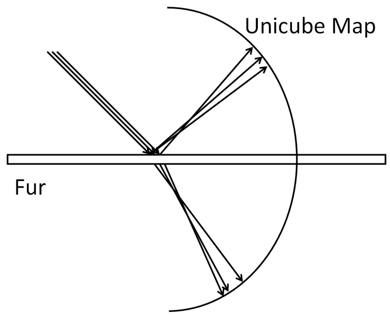

Figure 3: *Generation of S*

et al. 2009] as illustrated in Figure 3. Unicube mapping has desirable properties for our purpose. It uniformly samples the spherical surface and the texels are rectilinear. The scattering function S is originally four dimensional. It is decreased by one, however, under the assumption that fur is not eccentric. This is reasonable since we normally render not a single strand but rather a bundle of furs, and it reveals non-eccentricity as a whole even when furs are eccentric. In our system, S is discretized into 16x(6x64x64) grids. To be more precise, sixteen unicube maps are used to account for the angle between incoming ray direction and fur tangent ($N = 16$), and every face of a unicube map is divided into 64x64 pixels. We use more than one billion photons to create a high quality scattering function. They are cast from every direction and traced to a maximum of sixteen reflections or refractions. For efficient rendering, we use the quasi-random sampling importance resampling technique [C.J. Perez 2005] in a way reminiscent of [Talbot 2005]. A product of the luminance of an environment map and a scattering function is used as a *pdf* to determine the direction of scattered rays.

3 Result

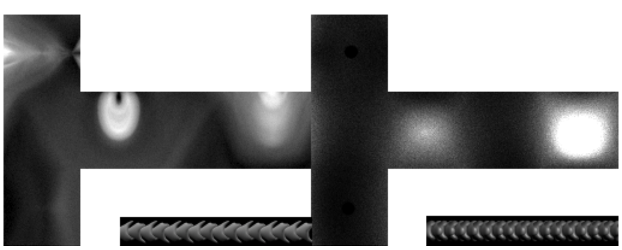

Figure 4: *Scattering function examples at a* 45 *degree incident angle.*

We implemented the described method in our path tracer. Figure 1 shows the results of our method. Our algorithm is able to render the difference between fur structures. The rendering times are the same for all the images. Two examples of discretized scattering functions are given as Figure 4. It takes roughly two minutes to create a scattering function on a dual Xeon W5590 system. By generating a scattering function with a cylinder whose refractive index is about 1.5, human hair fibers can also be rendered in the same framework as shown in Figure 5.

4 Conclusion and Future Work

In this paper, we introduced an empirical fur shader. It covers a vast range of fur structures due to its flexibility. Currently generating a scattering function is time-consuming since we have not established a method to design a fur structure to obtain a certain look. Therefore providing both interactive feedback and a fur structure library will be helpful for a rapid design process. We would like to extend this method to handle more complex optical effects including structural color, and find a suitable domain where a sparse representation of acquired data is possible.

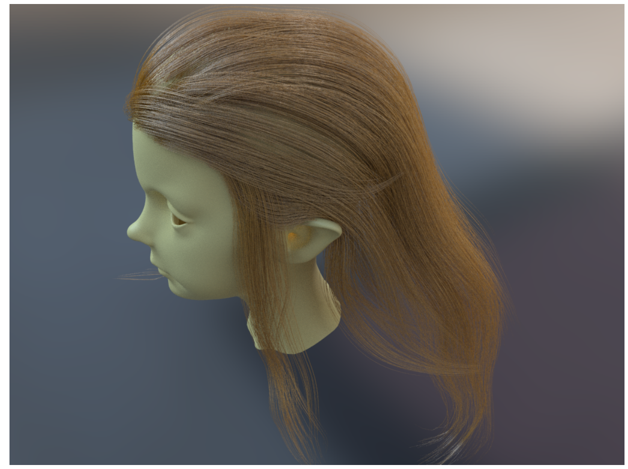

Figure 5: *An example of human hair fibers. Rendering time is 2 minutes 30 seconds on a dual Xeon W5590 system(1024x768 pixels).*

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