A Practical and Controllable Hair and Fur Model for Production Path Tracing

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Abstract

We present a novel BFSDF that is energy-conserving, efficient, and easy to control, reproducing a wide range of hair and fur with just a few intuitive parameters. This model is implemented in our production path-tracer and has achieved unprecedented richness in our characters.

1 Efficiency

Near-Field Solution A BCSDF is commonly used to describe hair reflectance models [Marschner et al. 2003]. Such models lack near-field accuracy. More importantly, averaging the scattering over all fiber offsets, h, lacks closed-form solutions if azimuthal roughness is considered, and requires expensive numerical quadrature [d'Eon et al. 2011]. Instead, we opt for a near-field BFSDF approximated by a position-dependent BSDF [Zinke and Weber 2007], using the true fiber offset h of the ray-fiber intersection. Compared to previous factored reflectance models [d'Eon et al. 2011], we delegate the integral over h to the renderer and solve it with Monte Carlo integration instead of quadrature. This simplicity and accuracy makes our model particularly well suited to path tracing.

Energy Conservation A factored reflectance model [Marschner et al. 2003] categorizes the total hair reflectance into separate path segments (lobes) inside an assumed smooth dielectric fiber. [d'Eon et al. 2011] proposed a framework to explicitly account for *all* possible lobes to achieve true energy conservation. However, based on our observation the unique characteristics of azimuthal distribution are largely maintained in the first few lobes $p \in \{R, TT, TRT\}$ for moderate roughness. As an approximation, we use an isotropic fourth lobe to capture the azimuthal distribution beyond TRT. The associated attenuation term A of this fourth lobe represents the total remaining energy. It can be derived as the sum of an infinite series $\sum_{p=TRRT}^{\infty} A_p = \frac{(1-f)^2 f^2 T^3}{1-fT}$, where f and T are the Fresnel and absorption term respectively.

Roughened Azimuthal Distribution [d'Eon et al. 2011] approximated azimuthal roughness using a wrapped Gaussian distribution. Instead, we use the *Logistic Distribution* which has a similar shape but, unlike Gaussian, has an invertible and closed form CDF over arbitrary finite range. Hence it can be perfectly sampled and evaluated over the azimuthal circle to ensure energy conservation. Instead of letting the artists control the scale of the logistic distribution s directly, we remapped it to azimuthal roughness β, ranging from 0 (directional) to 1 (isotropic) with perceptually linear behavior. The mapping we choose is $s = 0.265\beta + 1.194\beta^2 + 5.372\beta^{22}$.

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Figure 1: *Hair (left) and fur under different illumation (right) rendered with our unified shader.*

2 Controllability

Albedo Inversion It can be difficult to meet art direction using non-intuitive physically based parameters such as single-fiber absorption coefficients or pigment concentrations. Instead, our artists specify the desired multiple-scattering albedo α and our model infers the absorption coefficient σ_a. We precomputed our inverse mapping by simulating scattering on a dense block of fibers and performing least squares fitting to such set of (α, σ_a) data. In addition, azimuthal roughness β, behaving like the phase function of a hair or fur *volume*, not only changes the translucency of the look but also greatly affects the multiple-scattering albedo. Thus, we found it necessary to make the mapping dependent on azimuthal roughness. The result we arrive at is $\sigma_a = (\ln \alpha / (5.969 - 0.215\beta + 2.532\beta^2 - 10.73\beta^3 + 5.574\beta^4 + 0.245\beta^5))^2$.

Species Differenciation Human hair and animal fur are compositionally similar but there are structural differences among species. One key difference is the *medullary index*: animal fur usually has a much thicker inner core (medulla) which scatters light much more diffusely than human hair. Thus, in additional to multiple-scattering albedo, index of refraction, cuticle angle, and longitudinal and azimuthal roughness, we provide an additional roughness scale factor for the primary reflection lobe to differentiate it from the other lobes potentially deflected by medulla. With these six parameters we are able to reproduce a wide variety of species.

References

D'EON, E., FRANCOIS, G., HILL, M., LETTERI, J., AND AUBRY, J.-M. 2011. An energy-conserving hair reflectance model. In *Proceedings of the Twenty-second Eurographics Conference on Rendering*, Eurographics Association, Aire-la-Ville, Switzerland, Switzerland, EGSR '11, 1181–1187.

MARSCHNER, S. R., JENSEN, H. W., CAMMARANO, M., WORLEY, S., AND HANRAHAN, P. 2003. Light scattering from human hair fibers. *ACM Trans. Graph. 22*, 3 (July), 780–791.

ZINKE, A., AND WEBER, A. 2007. Light scattering from filaments. *IEEE Transactions on Visualization and Computer Graphics 13*, 2 (Mar.), 342–356.