Practical Multiple-Scattering Sheen Using Linearly Transformed Cosines

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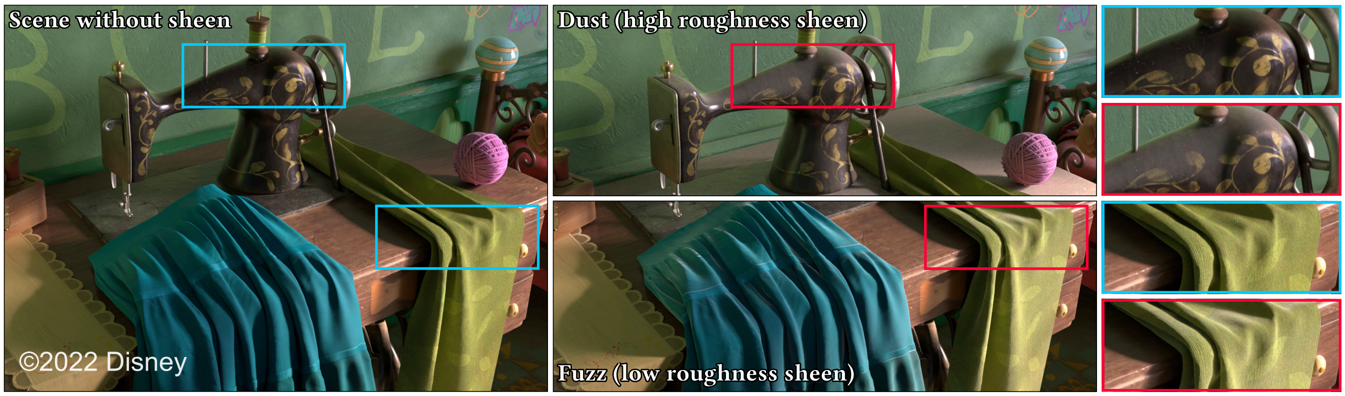

Figure 1: Illustration of our sheen model in a production setting. Low and high roughness values produce fuzzy or dusty appearances respectively as shown in the middle column.

ABSTRACT

We introduce a new volumetric sheen BRDF that approximates scattering observed in surfaces covered with normally-oriented fibers. Our previous sheen model was motivated by measured cloth reflectance, but lacked significant backward scattering. The model presented here allows a more realistic cloth appearance and can also approximate a dusty appearance. Our sheen model is implemented using a linearly transformed cosine (LTC) lobe fitted to a volumetric scattering layer. We detail the fitting process, and present and discuss our results.

CCS CONCEPTS

• **Computing methodologies → Reflectance modeling**.

KEYWORDS

rendering, ray tracing, appearance modeling, BRDF, sheen

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1 INTRODUCTION

A fabric sheen appearance can arise from fibers that protrude from the surface, either by construction as with velvet, or from stray fibers that have separated from their yarn. For the highest quality result, artists often distribute such fibers over the surface, adding considerable rendering overhead. These fibers typically add pronounced grazing reflectance in both the forward and backward scattering directions.

Our previous sheen model [Burley 2012] produced forward scattering but lacked backward scattering. Conty and Kulla [2017] introduced a microfacet-based sheen with a normal distribution approximating fibers distributed around the surface normal; while this model has significant backward scattering, it has only minimal forward scattering. Neither model produces results consistent with our explicit fiber simulation, see the comparison in Figure 2.

2 SHEEN MODEL

Following previous work on microflake theory [Jakob et al. 2010], a suitable far-field approximation of the desired appearance is a volumetric layer with a fiber-like SGGX phase function [Heitz et al. 2015] aligned with the surface normal. Its cross section parameter $\sigma \in [0, 1]$ further offers intuitive control to transition between both fuzzy and dusty surface appearances. For our purpose, the volume is assumed to be non-absorptive with unit density and thickness; these values produce plausible results, and artists did not find explicit control over their values to be useful.

Due to dominant multiple-scattering, evaluating such volumetric appearance models requires stochastic random walks [Dupuy et al. 2016] with unacceptably high variance for our production setting. We however found that the resulting BRDF can be surprisingly well

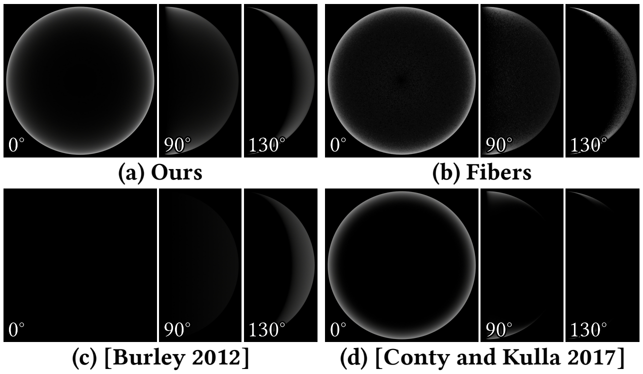

Figure 2: Spheres illuminated from the front (0°), side (90°), and back (130°). Our sheen (a) qualitatively matches the appearance of explicit fibers (b) while prior work (c & d) either lacks forward or backward scattering.

approximated with a simple LTC distribution [Heitz et al. 2016]:

$$f_r(\boldsymbol{\omega}_\mathrm{i}, \boldsymbol{\omega}_\mathrm{o}) \cos\theta_\mathrm{o} = C_\mathrm{sheen}\, R_\mathrm{i}\, D_\mathrm{o}\left(\frac{\mathbf{M}_\mathrm{i}^{-1}\boldsymbol{\omega}_\mathrm{o}}{||\mathbf{M}_\mathrm{i}^{-1}\boldsymbol{\omega}_\mathrm{o}||}\right)\frac{|\mathbf{M}_\mathrm{i}^{-1}|}{||\mathbf{M}_\mathrm{i}^{-1}\boldsymbol{\omega}_\mathrm{o}||^3}, \quad (1)$$

where D_o is a normalized clamped cosine distribution and C_sheen is an artist-specified RGB scale. The directional hemispherical reflectance $R_\mathrm{i} \in \mathbb{R}^+$ and the linear transform $\mathbf{M}_\mathrm{i}^{-1} \in \mathbb{R}^{3\mathrm{x}3}$ both depend on the incident elevation angle θ_i and an artist-specified *roughness* parameter $\alpha = \sqrt{\sigma}$.

Their values are fit to our fiber-like volume model[1] for a regular grid of 32 inputs for both α and $\cos\theta_\mathrm{i}$. For a good approximation, we found it sufficient to only use non-zero matrix elements $m_{1,1} = m_{2,2}, m_{1,3}$, and $m_{3,3} = 1$. This means all parameters (two matrix entries and R_i) fit into a single 32×32 three-channel texture which is linearly interpolated during BRDF evaluation and sampling.

The LTC representation enables efficient evaluation and perfect cosine-weighted importance sampling. Because the cosine is baked in (for sampling efficiency), the resulting BRDF is only approximately reciprocal, which we did not find problematic in practice.

We also experimented with an anisotropic version of the sheen with fibers tilted towards an artist-specified orientation, but we have not been able to achieve a good LTC fit. We would like to revisit this in the future however.

Even though we use the fitted BRDF directly in a production path tracer [Burley et al. 2018] we want to note that it could also be of interest in real-time applications that commonly use LTC distributions to enable real-time shading from polygonal area lights [Heitz et al. 2016].

3 RESULTS

The new sheen was added as an extra lobe on top of our production shading model [Burley 2012]. As a result, the intensity of existing BRDF lobes needs to be scaled down to still ensure energy conservation. This can be accomplished either based on the precomputed R_i reflectance table or by manually tuning a scale value. In the future,

[1] We could also have fit our LTC to a virtual BRDF capture of an explicit fiber simulation, but the SGGX volume provided comparable results with a more precise specification.

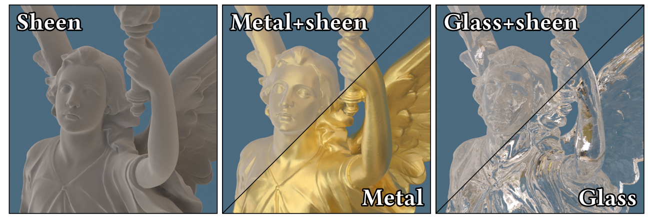

Figure 3: Sheen with a high roughness value (here $\alpha = 0.85$) resembles a thin dust layer when applied on top of materials.

we would also like to explore a physically accurate layering option, i.e. including directional blurring of the base material covered by the sheen layer.

Figure 1 shows our sheen used in the context of a production cloth asset. The new roughness control enables additional flexibility and can even transition to dusty appearances as illustrated in Figure 3.

We refer to the supplementary material for more comparisons of our sheen against prior work across different roughness levels. We also provide code for the fitting process and the resulting BRDF.

4 CONCLUSION

We proposed a new practical and flexible sheen model for physically based rendering of fuzzy or dusty materials. Compared to prior work, it is based on multiple-scattering in a thin volume layer of fiber-like particles. To avoid the computational expense of random walks, the resulting behaviour is summarized as a fitted LTC distribution that can be efficiently evaluated and sampled.

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REFERENCES

Brent Burley. 2012. Physically Based Shading at Disney. In *ACM SIGGRAPH 2012 Course Notes — Practical Physically-Based Shading in Film and Game Production.*

Brent Burley, David Adler, Matt Jen-Yuan Chiang, Hank Driskill, Ralf Habel, Patrick Kelly, Peter Kutz, Yining Karl Li, and Daniel Teece. 2018. The Design and Evolution of Disney's Hyperion Renderer. *ACM Transactions on Graphics* 37, 3, Article 33 (Aug. 2018). https://doi.org/10.1145/3182159

Alejandro Conty and Christopher Kulla. 2017. Production Friendly Microfacet Sheen BRDF. In *ACM SIGGRAPH 2017 Course Notes — Physically Based Shading in Theory and Practice.*

Jonathan Dupuy, Eric Heitz, and Eugene d'Eon. 2016. Additional Progress towards the Unification of Microfacet and Microflake Theories. In *Proceedings of the Eurographics Symposium on Rendering: Experimental Ideas & Implementations (EGSR '16).* 55–63. https://doi.org/10.2312/sre.20161210

Eric Heitz, Jonathan Dupuy, Cyril Crassin, and Carsten Dachsbacher. 2015. The SGGX Microflake Distribution. *ACM Transactions on Graphics (Proceedings of SIGGRAPH)* 34, 4 (jul 2015), 48:1–48:11. https://doi.org/10.1145/2766988

Eric Heitz, Jonathan Dupuy, Stephen Hill, and David Neubelt. 2016. Real-Time Polygonal-Light Shading with Linearly Transformed Cosines. *ACM Transactions on Graphics (Proceedings of SIGGRAPH)* 35, 4 (jul 2016), 41:1–41:8. https://doi.org/10.1145/2897824.2925895

Wenzel Jakob, Jonathan T. Moon, Adam Arbree, Kavita Bala, and Steve Marschner. 2010. A Radiative Transfer Framework for Rendering Materials with Anisotropic Structure. *ACM Transactions on Graphics (Proceedings of SIGGRAPH)* 29, 10 (July 2010), 53:1–53:13. https://doi.org/10.1145/1778765.1778790