Workshop on Material Appearance Modeling (2017)
H. Rushmeier and R. Klein (Editors)

Image-based remapping of material appearance

A. Sztrajman[1], J. Křivánek[2], A. Wilkie[2], T. Weyrich[1]

[1]University College London, United Kingdom.
[2]Charles University, Czech Republic.

Abstract

Digital 3D content creation requires the ability to exchange assets across multiple software applications. For many 3D asset types, standard formats and interchange conventions are available. For material definitions, however, inter-application exchange is still hampered by different software packages supporting different BRDF models. To make matters worse, even if nominally identical BRDF models are supported, these often differ in their implementation, due to optimisations and safeguards in individual renderers. To facilitate appearance-preserving translation between different BRDF models whose precise implementation is not known (arguably the standard case with commercial systems), we propose a robust translation scheme which leaves BRDF evaluation to the targeted rendering system, and which expresses BRDF similarity in image space. As we will show, even naïve applications of a nonlinear fit which uses such an image space residual metric work well in some cases; however, it does suffer from instabilities for certain material parameters. We propose strategies to mitigate these instabilities and perform reliable parameter remappings between differing BRDF definitions. We report on experiences with this remapping scheme, both with respect to robustness and visual differences of the fits.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Introduction

The workflow of 3D modelling commonly involves a broad range of modelling and rendering tools, each targeting different goals and requirements [SDSG13]. However, the exchange of data between these tools is very limited, and existing model assets often have to be redesigned to be used in other software, which results in large modelling overheads. This is particularly true in the case of material models. So far a great number of BRDF models has been developed for appearance representation, but only few have been widely adopted in the graphics software pipeline, and the exchange of materials between applications has been handicapped for the lack of a standardisation even at implementation level.

The current abundance of BRDF models responds to the fact that no single model is able to realistically reproduce the full range of available measured materials [GGG*16]. However, for a given material represented using one model, it is often possible to find a new set of parameters which match its appearance in a different one. This process, which we call a *remapping* of the material parameters, is used by rendering systems to deal with the incompatibility between models. Current attempts include manually finding approximate relations between the functional shapes of the models, which requires access to the model implementations, or incurs in oversimplifications by assuming one-to-one correspondence between individual parameters of both models.

An automatic solution to this problem needs to consider the constraints of the real-world scenario where a material is exported from one software to an external renderer. In this situation, we do not have access to the implementation of the shaders, only to the model parameters and the resulting renderings. We present an image-based method for the remapping of BRDFs which works under these conditions, assuming no knowledge of the model implementations. We analyse the robustness of the method applied to a set of BRDF models, and we discuss common issues and strategies to improve the stability of the method in different types of materials.

2. BRDF Fitting Strategies

The process of BRDF remapping is similar in structure to the fitting of BRDFs, where we start with a target BRDF model and an initial guess of the parameters, and we want to fit reflectance data, generally measured from a real-world material. This involves the minimisation of the difference between the appearances of the BRDF and the data, performed through nonlinear optimisation of the parameters of the BRDF model (Figure 1).

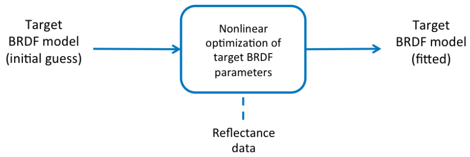

Figure 1: *Basic scheme for BRDF fitting.*

In the case of BRDF remapping (Figure 2) the scheme is analogous —however, instead of using measured data we are now matching the appearance of the target BRDF model with another *source* BRDF model.

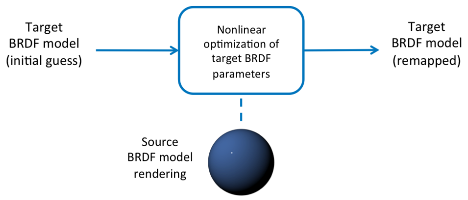

Figure 2: *BRDF remapping scheme.*

In this scheme we assume no direct access to the implementation or reflectance values of the BRDF models. In particular, the target model is assumed to belong to an external renderer in a typical usage scenario of our technique. In order to perform an appearance comparison under these conditions, we will measure the difference in image space, by comparing rendered images of a single scene using each of the two BRDF models. Thus, in each step of the optimisation we only need to be able to generate new renders of this scene with the target BRDF. The image difference is then computed with an L_2 metric in colour space, which is common practice in the context of BRDF fitting [NDM05].

2.1. Optimisation schemes

A simple optimisation scheme which attempts to fit all model parameters at once (as shown in Figure 2) often leads to local minima during the optimisation. In Section 3 we provide a systematic analysis of the stability of the remapping scheme. In order to improve the stability of the optimisation we test the following two variants of our remapping scheme.

Two-stage remapping

In this scheme the diffuse and specular terms are remapped independently. The appearance comparison during each optimisation requires a source render with a single term. In the end we obtain remapped versions of each term which are merged in the remapped target BRDF model.

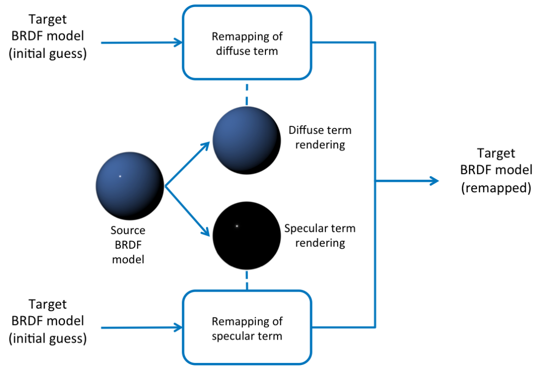

Figure 3: *BRDF remapping scheme in two stages. Diffuse and specular components are remapped independently.*

Three-stage remapping

The two-stage remapping assumes an independence of diffuse and specular terms that might not hold true for some layered materials. The three-stage scheme recovers the coupling between both terms by using the results of the two-stage scheme as a good starting guess for a subsequent simple remapping that optimises all parameters together, reducing the chance of falling into local minima.

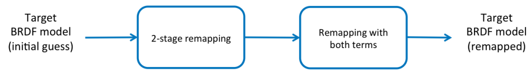

Figure 4: *BRDF remapping scheme in three stages.*

3. Results

We performed a systematic study of the remapping schemes through the analysis of the robustness of the transformation linking the parameters of the models, using multiple combinations of BRDF models available in Mitsuba [Jak10] (Ashikhmin-Shirley, Beckmann, GGX, Phong, Ward). We focus here on a few of these to analyse the common problems encountered when dealing with the remapping between different BRDF implementations. For the image-based appearance comparison a simple scene was used, with a sphere of radius 2 at the origin, and a point light source shifted from the view direction ($r_v = 3$, $\theta_v = 0$, $r_l = 5.2$, $\theta_l = 45°$, $\phi_l = 125°$, fov$= 40°$) to avoid a symmetrical sampling of the angular domain which is redundant for isotropic materials. The renderings were generated as colour space HDR images (512×512), and the nonlinear optimisation was performed using the Trusted Region Reflective method, and enforcing positive values on the remapped parameters.

3.1. Conductors

Our analysis of the remapping of conductors includes 60 materials from Mitsuba's database. In Figure 5 we show the results for a remapping from Ashikhmin-Shirley (source) to Ward (target). In these implementations the specular terms in both models are described by an RGB specular parameter and a single-channel roughness, essentially characterising the intensity and the spread of the lobes (The information provided by the index of refraction in the standard BRDF interface in Mitsuba is here condensed into the reflectivity). We show the remapping of a specular parameter in Ashikhmin-Shirley to an analogous parameter in Ward (both single-channel), for multiple fixed values of roughness.

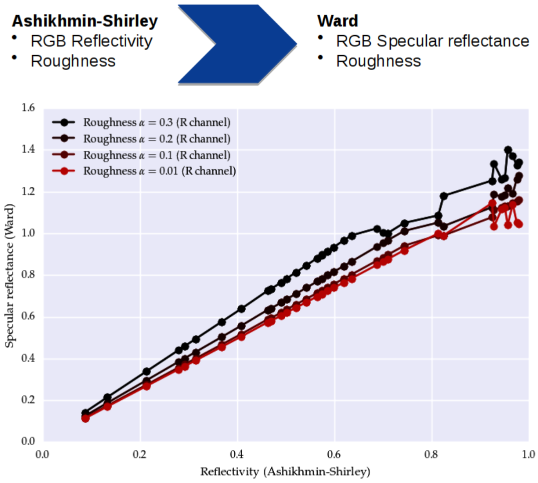

Figure 5: *Remapping of conductors from Ashikhmin-Shirley to Ward. Detail of parameters in Mitsuba, and plot of Specular reflectance (Ward) vs Reflectivity (AS).*

The expected output of the remapping is a smoothly varying relation between source and target parmeters. In a typical usage case of the method for material interchange, this would be the behaviour expected by the user: small changes in the source material should correspond to small changes in the exported appearance. We will show that a deviation from this behaviour usually signals a decreasing capacity of the target model to match the source, or the occurrence of local minima during the optimisation.

In Figure 5 the transformation shows a smooth behaviour for most materials but displays instabilities for parameters which are remapped to specular reflectance > 1. These can be traced back to our implementation of Ward, where the values of specular reflectance are trimmed to avoid energy loss, and is an example of the implementation-dependent behaviour that we may find in renderers. Most of the instabilities found during our study shared this behaviour, defining well-located regions in parameter space where the remapping becomes unreliable. In Section 3.2 we analyse cases where the instabilities are widespread across the parameter space and are not related to implementation differences.

After filtering the unstable cases from Figure 5, we present in Figure 6 the results for a round-trip remapping, where we remapped back the parameters to the initial model Ashikhmin-Shirley. The result is a straight line of unitary slope, showing that the parameters go back to their original values after the two remappings. This speaks for the general robustness of the approach, and indicates that we can still recover the original appearance after a remapping takes place.

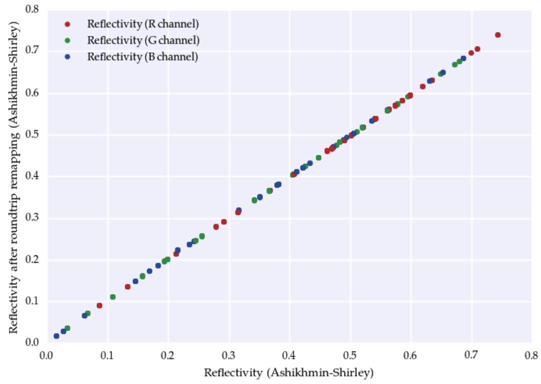

Figure 6: *Round-trip remapping of conductors from Ashikhmin-Shirley to Ward and then back to Ashikhmin-Shirley. Remapped reflectivity vs original Reflectivity.*

3.2. Dielectrics

The reflectance in dielectric materials includes an additional diffuse component. The specular component has a similar behaviour for all channels and is usually approximated with a single parameter (the index of refraction in Ashikhmin-Shirley). In Figure 7 we show the results of remapping from Ashikhmin-Shirley to Ward, using a simple optimisation with both diffuse and specular parameters. The plot corresponds to a parameter sweep of the IOR in Ashikhmin-Shirley for fixed diffuse and roughness parameters.

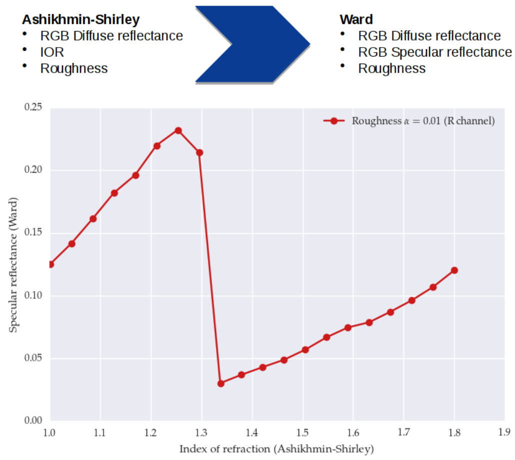

Figure 7: *Simple remapping of dielectrics from Ashikhmin-Shirley to Ward. Detail of parameters in Mitsuba for both models, and plot of Specular reflectance (Ward) vs IOR (AS).*

The instability here signals a change of behaviour in the remapping process. In Figure 8 we show the renderings corresponding to the points at both sides of the cliff in Figure 7.

In one case the remapping is working correctly and we obtain a similar appearance in both models. In the other we observe that the optimisation arrives at a local minimum and the remapping is unable to recover the characteristic highlight from the source.

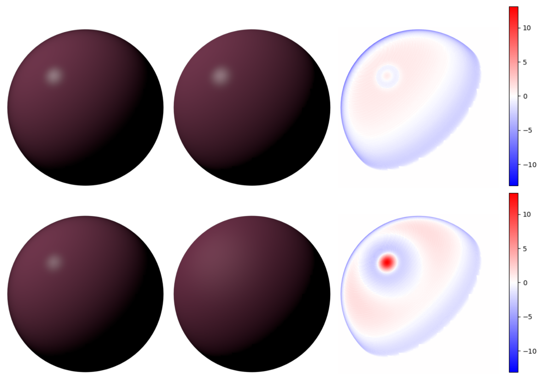

Figure 8: *Source model (left), remapped target (center) and percentage error (right), corresponding to* $IOR = 1.3$ *(up) and* $IOR = 1.34$ *(down) in Figure 7.*

In Figures 9 and 10 we show the results of the two- and three-stage approaches, developed to improve the stability of the remapping process. The two-stage approach effectively recovers a smooth relation between the parameters, by avoiding the coupling between the diffuse and specular terms. With the additional optimisation step of the three-stage approach, in some cases we were able to slightly reduce the optimisation error with respect to the two-stage approach, but unfortunately the coupling between diffuse and specular terms still causes several instabilities which make this second approach unreliable. In sum, in order to generate a robust remapping we need to avoid the coupling of the diffuse and specular components, by remapping each term independently (two-stage method).

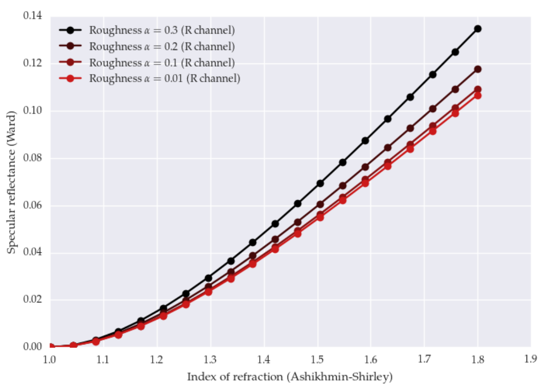

Figure 9: *Two-stage remapping of conductors from Ashikhmin-Shirley to Ward. Specular reflectance vs Reflectivity for multiple values of roughness.*

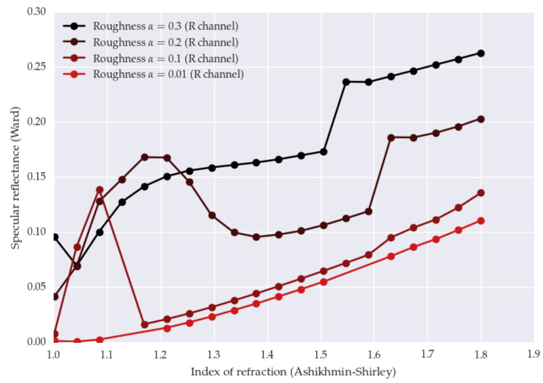

Figure 10: *Three-stage remapping of conductors from Ashikhmin-Shirley to Ward. Specular reflectance vs Reflectivity for multiple values of roughness.*

4. Conclusions

We presented an image-based scheme for automatic remapping of uniform BRDFs, which does not require access to the implementations of the models, and which is therefore compatible with the workflow of material interchange in commercial renderers. The remapping procedure was tested with both dielectric and conductor materials, overall resulting in a transformation that is robust in terms of parameter variations. In the cases where we find instabilities these are generally located in a well-defined area of parameter space. In addition, when dealing with materials with both diffuse and specular terms, they need to be remapped independently (two-stage method) to avoid local minima during the optimisation.

References

[GGG*16] GUARNERA D., GUARNERA G., GHOSH A., DENK C., GLENCROSS M.: Brdf representation and acquisition. *Comput. Graph. Forum 35*, 2 (May 2016), 625–650. 1

[Jak10] JAKOB W.: Mitsuba renderer, 2010. http://www.mitsuba-renderer.org. 2

[NDM05] NGAN A., DURAND F., MATUSIK W.: Experimental analysis of brdf models. In *Proceedings of the Sixteenth Eurographics Conference on Rendering Techniques* (Aire-la-Ville, Switzerland, Switzerland, 2005), EGSR '05, Eurographics Association, pp. 117–126. 2

[SDSG13] SCHREGLE R., DENK C., SLUSALLEK P., GLENCROSS M.: Grand Challenges: Material Models in the Automotive Industry. In *Eurographics Workshop on Material Appearance Modeling* (2013), Klein R., Rushmeier H., (Eds.), The Eurographics Association. 1

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 642841. We would like to thank Cyrille Damez from Allegorithmic for his support.