Attribute-preserving gamut mapping of measured BRDFs

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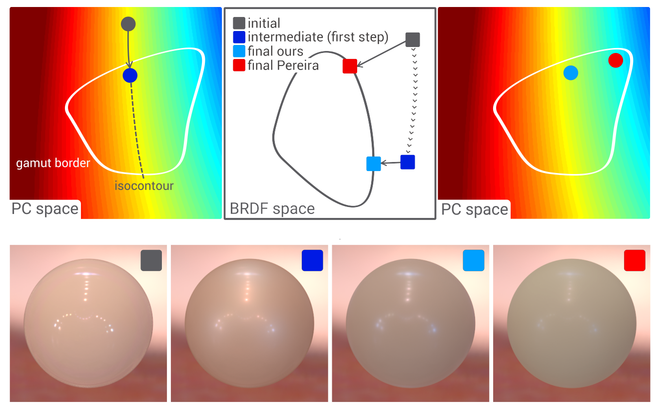

Figure 1: Overview of our two-step gamut mapping method. Top-left: We first push the original BRDF (gray) into gamut (intermediate BRDF, dark blue) in PC space. Isocontours indicate the same value of a given perceptual attribute. Top-middle: Back in the original BRDF space, we apply an image-based optimization (final BRDF, light blue). The red dot represents the result of applying a single step based on image optimization [Pereira and Rusinkiewicz 2012]. Top-right: We move back to PC space to show the final BRDFs with both methods; ours lies closer to the intended attribute value than the single-step method. Bottom: Real results with the *alumina oxide* BRDF from the MERL database. From left to right: original; our intermediate BRDF; our final result; single-step image-based optimization. Our result preserves highlights better, while exhibiting less color shift.

ABSTRACT

Real-world materials present a wide variety of appearances, commonly described in computer graphics with the bidirectional reflectance distribution function (BRDF). Printers, on the other hand, have a predefined set of only a few inks, which defines the printer's gamut. As a consequence of this limitation, many materials cannot be exactly reproduced by the printer, creating distortions in the printed appearance that are hard to control. Finding the best approximation of the input BRDF that falls within the printer's gamut while minimizing such distortions as much as possible is the problem known as gamut mapping. We present a novel two-step gamut mapping algorithm that allows users to specify which perceptual attribute of the original material they want to preserve. In the first step, we work in the low-dimensional intuitive appearance space recently proposed by Serrano et al. [Serrano et al. 2016], and adjust achromatic reflectance via an objective function that strives to preserve certain attributes. From such intermediate representation, we then perform an image-based optimization including color information, to bring the BRDF into gamut. We show how our method yields superior results compared to the state of the art, with the additional advantage that the user can specify which visual attributes need to be preserved. For more details we refer to the reader to the full paper [Sun et al. 2017].

CCS CONCEPTS

•Computing methodologies → Reflectance modeling;

KEYWORDS

Perceptual appearance, gamut mapping

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1 OUR METHOD

In the first step, we leverage recent works on material acquisition [Nielsen et al. 2015] and editing [Serrano et al. 2016]. In these works, Nielsen et al. first built a five-dimensional PC space based on PCA decomposition which serves as a basis for each BRDF, then Serrano et al. learnt functionals mapping the space of principal components to higher level perceptual attributes defined for achromatic reflectance; these functionals define an intuitive control space for appearance. We use these mappings in PC space to follow the path that brings the luminance into gamut in PC space, while preserving the desired attribute. However, adding the color information to the remapped luminance leads to a BRDF that will likely still be out of gamut. We thus complete the gamut mapping process with our second step, which consists on an image-based optimization, inspired by other recent works [Pereira and Rusinkiewicz 2012].

Figure 1 presents an overview of our method. First (Figure 1, top-left), working in PC space, we follow the isocontour of a given functional to bring into gamut the initial BRDF; these isocontours represent the same value of a given attribute (please refer to [Serrano et al. 2016] for details). Note that in this space we only work with luminance values; color will be handled in a second step. This

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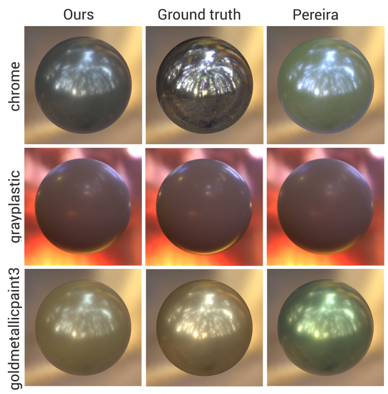

Figure 2: Comparison of our results and the state of the art [Pereira and Rusinkiewicz 2012]. Our method minimizes color shifts (*chrome* and *goldmetallicpaint3*), while better preserving specular behavior (*grayplastic*).

yields an intermediate BRDF which, although it preserves the desired perceptual attribute, cannot be guaranteed to fall within the gamut defined by the inks in the original BRDF space.

In our second step, we bring the intermediate BRDF into gamut using an image-based optimization (Figure 1, top-center). Figure 1, top-right, shows the final BRDF using our method, compared to a single-step, image-optimization method (such as Pereira's state of the art algorithm [Pereira and Rusinkiewicz 2012]). It can be seen how our result better preserves the intended attribute in this space, since it is never explicitly taken into account in existing single-step methods. Figure 1, bottom, shows real examples produced with our method, and Pereira's [Pereira and Rusinkiewicz 2012]. Although obvious differences exist in both results with respect to the original BRDF, given the limited ink gamut, our method maintains stronger highlights and exhibits significantly less color shift.

2 RESULTS

We validate our technique on the BRDFs from the MERL database [Matusik et al. 2003], using a gamut formed by real measured inks [Matusik et al. 2009]. We compare our results with those from Pereira [Pereira and Rusinkiewicz 2012]. Our proposed method allows certain interactivity (although it is not a requirement), the user can choose which attribute(s) to preserve; in this case we always fix the same two attributes (*metallic* and *brightness*), in order to provide a fair comparison. Some representative results rendered with different environment maps are shown in Figure 2.

We have carried out a perceptual study to evaluate the results of our gamut mapping algorithm. We used a subset of 50 out-of-gamut BRDFs from the MERL dataset. We presented our materials on a sphere rendered under the *Eucalyptus* environment map. The user is presented with a reference image (center), and two different results (Pereira and ours), one at each side, and is asked to select which of the two alternatives shown is more visually similar to the reference image. Twenty-two of the tested BRDFs showed significant differences in the results (χ^2 test, $p < 0.05$); among these 77.6% of the time, our result was chosen over the state of the art method. Agreement between users was high, with 81.3% users on average agreeing with the majority on a given choice.

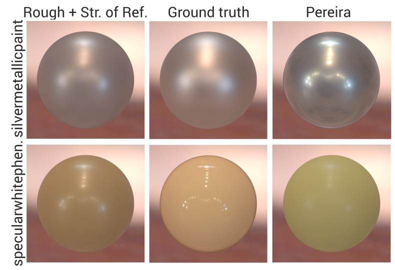

Figure 3: Results computed preserving the *roughness* and *strength of reflections* attributes in the first step of the method compared to the state of the art [Pereira and Rusinkiewicz 2012]. This particular combination of attributes aims to better preserve the appearance of the reflections.

Finally, we present additional gamut mapping results preserving different combinations of attributes during the optimization along isocontours in our first step. In Figure 3 we show results preserving the attributes *roughness* and *strength of reflections*. Note that this combination of attributes performs particularly well at preserving the look of the reflections.

3 CONCLUSION

We have proposed a new two-step method for BRDF gamut mapping. In the first step we work in PC space, and use some previously proposed functionals that map this space to higher-level intuitive attributes to preserve the appearance of any of such attributes. The output of this first step, which only optimizes achromatic reflectance, is then used as input to an image-space optimization which brings the final BRDF into the ink gamut by expressing it as a convex combination of the available inks. We perform better than the state of the art, although some cases where the initial BRDF is very far away from the gamut remain a challenge.

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