Workshop on Material Appearance Modeling (2013)
H. Rushmeier and R. Klein (Editors)

Towards a Practical Gamut of Appearance Acquisition

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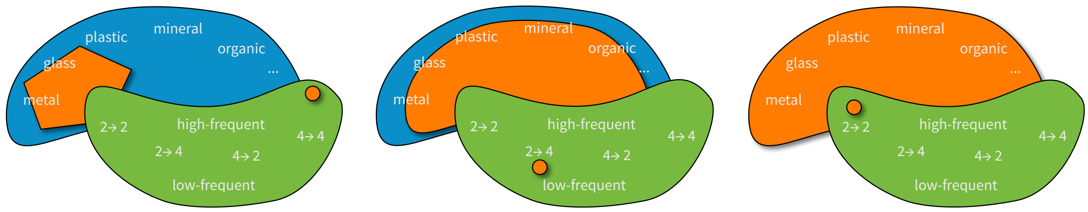

Figure 1: *Sketches of envisioned appearance processing gamut visualizations (material types and their arrangement are intended only to be seen as placeholders). In order to assess the gamut of an appearance acquisition and processing pipeline, one needs to consider both the materials the process supports and the illumination interaction which is possible. For instance, a parametric BRDF model may support a small set of material types, but provide for general light transport interaction, so that the effect of any 4D incident light field may be described for a 4D outgoing light field in dense sampling. A recorded BTF might only work for a (2D) distant light with a low frequent or sparse sampling, but cover considerably more material types, while, finally, a densely sampled reflectance field in image space covers almost any material type, but only simulates a 2D camera for a 2D incident distribution of light.*

Abstract

We propose discussing the performance of appearance modeling in terms of supported material and illumination gamut. While we have a precise understanding of the cost of any given appearance modeling method, performance is intrinsically hard to express without standardized material and illumination test scenarios. This lack of vocabulary hampers comparability between alternative approaches as well as the communication with community outsiders.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism —Color, shading, shadowing, and texture I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture—Reflectance

1. Introduction

Recent successes in appearance modeling are impressive, and have enabled computer graphics researchers to establish appearance fabrication as an emerging subject [HIH*13]. The underlying appearance models are applicable because of sophisticated acquisition protocols which are most diverse and vary greatly with the model employed or the application in mind [WLL*08].

While this diversity forms a creative environment for basic research, we need standardized tests. The lack of comparability forms an obstacle which may have consequences for communication with the outside of the research community, and should be addressed. In this position paper, we discuss why defining such standards is challenging and worthwhile.

2. Goals for appearance modeling and acquisition

Material appearance may be understood as the interaction of light with surfaces or volumes. Acquisition techniques fol-

DOI: 10.2312/MAM.MAM2013.021-023

low a pipeline of exposing a material sample to controlled (or at the least, precisely known) illumination, and measuring the scattered light. This observation then drives a model, which can be analytical and compact [War92], or defined in a general function space, as is common for data driven models [MMS*04]. At the end of this pipeline stands either a rendered picture for a user-defined camera configuration and illumination conditions or a physically fabricated object which recreates the appearance of the input material. Either way, the quality of the rendering or synthesized object becomes only apparent through varying illumination.

3. Criteria for success

Modern appearance models, especially data driven ones, scale quality monotonically with cost. Increasing the number of input pictures, storage space, rendering time and so forth increases quality, and most data-driven approaches would asymptotically approach perfect rendition. Still, naïve recording of an 8D reflectance field [DHT*00] – or an equivalent comprehensive appearance representation – will remain infeasible for useful resolutions in the foreseeable future.

Creative solutions are required, and they all introduce their individual trade-offs. This space can be navigated along different dimensions. We believe that **process cost** and **process gamut** are good criteria for their evaluation. So far, we are very precise in quantifying the former – for each result we present, we can specify the invested effort in the measurement setup design and construction, the number of pictures we acquired, the storage we used and the rendering time we needed, which for a commercial application would directly translate to costs.

A process gamut should provide a means to express how well a method is able to reproduce real-world appearance. This is difficult to realize, as two aspects interconnect:

3.1. Illumination gamut

In order to create realistic images, appearance models must account for a wide range of possible illumination conditions and camera settings. Some models work for certain types of illumination (distant lights for BTFs [MMS*04]) or constrained observers (fixed camera for image space reflectance fields [DHT*00]), which renders them difficult to compare. Others are more general, but are limited by sampling densities that map to different linear spaces in their implementation [MMS*04].

Ngan et al. [NDM06] have proposed to navigate the space of BRDFs according to an image-space metric for a test sphere rendered in a representative illumination. In a similar respect, the measurement of the rendering performance of an appearance modeling approach would be possible with a representative data set of illumination and observer conditions to be tested against. This presents a considerable challenge, though – during the rendering of scenes, almost arbitrary local illumination conditions can occur due to direct illumination, cast shadows or caustics.

3.2. Material gamut

Conversely, the performance of analytical models is largely unaffected by illumination concerns. However, they have a limited gamut of materials they can faithfully represent. In order to quantify the expressiveness of an appearance model, we would require a representative set of real-world material samples to test against. Ren et al. [RWS*11] have presented a step towards this by generalizing the concept of a color checker to BRDF material samples.

In addition to surface material, though, appearance arises to a large part from the *geometry* of interacting surfaces, especially for non-smooth materials which are usually modeled by BTFs. So far, we only know how to make things arbitrarily difficult (for instance, by inserting geometric detail into a surface which causes distant shadows to be cast) but can not provide a meaningful numerical measure for the distance of a method under consideration to the optimum, nor quantitatively compare two competing approaches.

4. Challenges in the realization

While Figure 1 shows a mock-up of what a visualization for a combined process gamut comprising both material and illumination expressivity might look like, it also demonstrates some of the challenges we will face in its definition. On the illumination side, we can classify techniques according to the light interaction space they can provide [HIH*13] along one axis, and separately express for which sample rates appearance is modeled faithfully. However, this simplified view would not differentiate approaches which have similar sampling rates, but record in different bases (such as point illumination vs. extended light sources vs. spherical harmonics vs. compressive sensing ...).

The definition of the material gamut component is considerably more difficult even; aside from the definition of relevant material classes (what is the space of all materials?), their arrangement in a fashion which is both compact for existing techniques, but also leads to understandable, meaningful visualizations creates a most challenging puzzle.

5. Benefits for the research community

While the definition of a combined gamut for both illumination and materials creates a challenging task, the identification of the effective gamut of a material acquisition system by testing it against illumination and material standards would bring large benefits to the research community. With the current state of the art, the diversity and complexity of possible acquisition setups make a useful comparison between two different approaches prohibitively costly. With representative test conditions, they could be evaluated individually and fairly ranked.

Another advantage of standardized evaluation lies in the opening of research opportunities towards *appearance engineering*, by documenting that proposed techniques would cover a specified percentage of previously unavailable materials or would support a fixed fraction of standard illumination conditions.

6. Benefits for technology transfer

Both when giving advice on an industrial process and when instigating collaborative efforts with industrial partners, the responsibility to facilitate the communication lies with the research community. In our experience with a recently completed technology transfer project, there were difficulties to overcome which in the future could be lessened by standardized performance measures.

One of the main problems lies with lacking terminology. Our partners are well aware of the specific problems in their application domain – they can precisely state their needs, in particular, regarding the business processes the technology needs to integrate with; they express demand for integrated marketing communication techniques which enables them to address high-definition print and movie production pipelines as well as web and mobile applications with a unified approach.

Unlike color processing pipelines, however, where the gamut of preservable appearance is established and well defined, we are hindered in talking about appearance modeling as we cannot define our abilities concisely. In practice, this requires us to spend large amounts of time on iterative prototyping and testing until satisfaction is reached.

Worse, we cannot create an awareness for the abilities of modern appearance modeling technologies. Given the wariness of large-scale industry towards potentially disruptive technology, we see it as the duty of the research community to pave the road from currently established color matching pipelines up to appearance matching. For this, measures for quantifiable performance of appearance technologies would be an important next step.

7. Outlook

For the reasons put forth above, we propose to look into the problem of establishing a consensus on how to assess the effective gamut of material modeling and acquisition techniques – and look forward to fruitful discussions.

8. Acknowledgements

This article was in part supported by "Kooperatives Promotionskolleg Digital Media" at Stuttgart Media University and the University of Stuttgart.

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