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Interactive Appearance Design in the Presence of Optically Complex Materials

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Figure 1: *Rendering different material variations using Lagoa cloud rendering. During appearance design, it is essential to be able to easily switch between different materials, edit their parameters and get a fast visual feedback. Classical analytical models combined with layering or mixing techniques are quick to evaluate and yield physically plausible results for a wide range of materials. However, predicting the appearance of materials with complex micro structure, such as cloth, wood or sand is still challenging.*

Abstract

In this position paper, we discuss the usability of different material representations for interactive appearance design in the context of visual prototyping. We emphasize the importance of methods explicitly considering micro-geometry, particularly when combined with efficient volumetric representations. Decoupling of small-scale geometric structure and optical properties allows for the most comprehensive edits while still achieving physically plausible results, even for optically complex materials such as cloth.

1. Introduction

State-of-the art computer generated image synthesis has reached a remarkable level of photo-realism. Light transport can be computed efficiently enough for many applications and recently much effort has went into the reproduction of even fine visual detail.

Appearance models essentially describe the look of a material, invariant to a specific lighting situation, allowing for predictions of appearance under arbitrary lighting conditions. In an ideal world these models would be directly related to structure and first principles. However, even though highly desirable, such a representation is commonly available only for few material types.

Being able to predict the appearance of objects is useful in many applications. One of them is product design. Previously, many decisions could only be made by constructing several different real prototypes. Nowadays, some of these prototypes can be replaced by purely virtual prototypes through the application of physically-based rendering methods.

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Figure 2: *Sand rendering (Lagoa cloud rendering) using a dedicated particle scattering function together with brute-force path tracing. The model accounts for volumetric absorption, volumetric scattering, refraction, internal scattering and Fresnel attenuation.*

In the context of design, we are not only interested in the quality of material depiction in final beauty shots of a product, but also during the interactive creation process. Using cloud-based services such as Lagoa, people can nowadays collaborate on designs, change material properties and tweak lighting setups without even being in the same office or city. This is made possible by rendering servers, which stream progressive renderings immediately to multiple users at the same time, which are logged into the same online platform with their browser. Even if an efficient rendering system is used and even though computing power can be scaled as needed in the cloud, images still need some time to converge before the result can be regarded as a "correct" answer. This time highly depends on the complexity of a material and how it is represented.

Given this application, we have identified five key goals for a material representation and rendering system:

- First, it should allow for predictive rendering.
- Second, we would like to have interactive feedback, at a quality level sufficient for evaluating the appearance.
- Third, we prefer generic material descriptions to be able to design different material types while keeping the system architecture as simple as possible.
- Forth, the material representation should be dynamic in a sense that it is possible to create different variations of a material using intuitive parameters.
- Fifth, it is desirable to restrict editing in a way that physical realizations of the edited appearance are possible. Ideally, a decoupling of geometric (microscopic) shape and structure as well as optical material properties would be possible.

In the following we discuss how common material representations fit for the use in such a system.

2. Interactive Design and Rendering of Materials

To predict the appearance of an object in different scenarios, we not only need its basic geometry but also an exact representation of the optical properties of its materials. Several approaches have been proposed for the acquisition and representation of optical properties of real world materials.

2.1. Related Work

Often, measurements of reflectance data are used directly during rendering, such as for image-based representations like Bidirectional Texture Functions (BTFs) [DvGNK99, MMS*05, HF11]. This approach is quite effective if existing materials need to be reproduced virtually. Moreover, efficient techniques for interactive streaming and rendering of BTFs have been presented. However, the material description is static and it is difficult to edit such representations since structure (micro-geometry) and optical properties cannot be easily decoupled. Finally, certain visually relevant features, including light diffusion, silhouette edges and translucency, are not covered. Because storage requirements for image-based representations are commonly large and editing is difficult, compact analytical models describing surface-reflectance for certain types of materials are widely used instead (examples are shown in Figure 1). While these models can often be rendered efficiently, their use in virtual prototyping is not always possible: When rendering is performed based on ad-hoc parameters it is not guaranteed that appearance prediction is possible. Moreover, it remains unclear how parameters can be mapped to measurable quantities. On the other hand, even with physically accurate models for simple materials like glass or conductors rendering can be very challenging due to complex micro geometry (see Figure 2).

2.2. Micro-Geometry Based Rendering

Westin et al. [WAT92] were the first to propose a system that simulates surface reflectance based on computation of light transport for micro-geometry. Ashikmin et al. [APS00] describe how different BRDFs can be generated from 2D microfacet orientation distributions. Even more flexibility can be obtained by dividing the representation in one part describing micro-geometry and another one describing the optical properties of this geometry. Wu et al. [WDR11] have presented an elegant system to design large scale appearance based on a bi-scale design framework, which allows to edit both small-scale geometry and BRDFs of this geometry. The system is highly interactive, but unfortunately it does not support global illumination and sub-surface scattering, which are important for many types of materials. Iwasaki et al. [IDN12] have extended the basic framework to support

highly glossy materials.
Micro-geometry can also be measured directly. For certain materials, purely surface-based measurements can already give the most important features of a material. This can be done using laser-range scanners, structured-light setups or specialized systems [JCR*11]. Ruiters et al. [RSK13] have separated measured BTFs together with measurements of small scale geometry into a heightfield component and a parallax compensated BTF, enabling material design based on interpolation and texture synthesis.
However, for some types of materials, such as cloth [SZZ12], volumetric measurements are required to obtain an exact representation of the micro-geometry. Zhao et al. propose to build a database of small measured cloth samples using Micro-CT scanners, which can serve as building blocks for larger pieces of cloth using structure aware synthesis [ZJMB11, ZJMB12]. Rendering can then either be performed directly using a detailed volumetric description of the micro-geometry based on micro-flake models and anisotropic volumetric rendering [JAM*10] or based on a Gaussian distribution of fiber orientation and density [SKZ11] (see Figure 3).

Full global illumination computation is used to predict the appearance of the material. If bidirectional curve scattering functions (BCSDFs) [ZW07] can be used to describe the optical properties of the fibers (as in [SKZ11]), properties of fibers can be measured and edited independently of the arrangement of fibers. This flexibility is hardly possible with aggregate representations of reflectance.

3. Conclusion

We believe that explicit or statistical representations of micro-geometry together with simulations of material-internal light transport offer the amount of flexibility required for visual prototyping of complex materials. The decoupling of small-scale geometric structure and optical properties allow for the most comprehensive edits while still achieving physically plausible results. However, even though so far mainly domain specific applications have been presented in the literature, we think that the general ideas are applicable to a wider range of materials.

4. Future Work

Major challenges to be solved are the expressiveness of models and the speed of computation. While any common rendering algorithm can be applied to micro-geometry rendering in principle, not all of them are suited well for this task. Common techniques to accelerate the computation of global illumination such as photon mapping and virtual point lights rely on assumptions of sparsity of geometry and low frequency effects of lighting. However, in the context of micro-geometry rendering these are often not fulfilled. For example in cloth rendering, multiple scattering has to be computed in the presence of dense fiber assemblies. These fibers are often highly specular and combined they lead to complex anisotropic effects. As fibers of neighboring yarns and even fibers within some special yarns can have completely different colors, high frequency effects dominate the appearance. Therefore, the most common approach for rendering micro-geometry is still brute-force path tracing. While brute-force

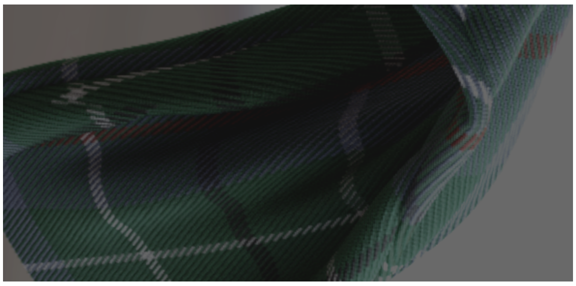

Figure 3: *Volumetric cloth. The appearance is linked directly to optical properties of fibers and their geometrical arrangement through yarns and the weave pattern, allowing for intuitive editing.*

path tracing can be performed relatively efficiently nowadays and cloud computing and parallel computing architectures currently develop fast, early images computed during progressive rendering with low sampling rates can still show much noise if complex sub-surface scattering has to be computed.
However, during product design, noise can be a major problem as different noise characteristics can drastically change the look and feel of materials. For example in the context of visual perception of materials it can be observed [GZ11] that a higher noise level often leads to a softer impression of a sample.
Different solutions can be imagined to avoid this kind of noise. First, in the context of micro-geometry rendering, more efficient biased rendering algorithms could be employed [Jen01, WFA*05, KGPB05, HOJ08]. However, these can lead to other artifacts such as color banding or color shifts. We believe that more research is needed to study the effects on material perception – in any case some biased rendering approaches may add a level of uncertainty, which may not be tolerable. Also, as mentioned above, these rendering algorithms should be specifically designed for or at least tested in this special context.
Second, image filtering techniques and image reconstruction filters can be used to reduce the perceived noise as a post-process [McC99, ODR09, RKZ11, SD11, RKZ12, SKZ13]. Similarly, more research is needed to be able to judge their effect on the look and feel of materials.
A third option to accelerate rendering is the use of precomputation (at the cost of restricting editing operations). This can be done by holding some elements fixed and focusing on single aspects such as relighting ([PVL*05, HPB06]).

Another possibility is to simulate BTFs based on microgeometry [SKZ13] and use these during rendering. Also volumetric rendering based on instances of a few blocks can be accelerated by precomputing flux transfer within and among these blocks [ZHRB13].

Ou et al. [OKKP12] have studied how humans judge the output of different progressive rendering algorithms in the context of appearance design. They have found that for their examples the noise of Monte Carlo path-tracing is preferred over artifacts produced by virtual point light rendering and photon mapping. However, in these examples, the noise mainly comes from light transport and scattering due to coarse geometry. It would be interesting to evaluate if the results still hold when the focus is more on the interactive design of optically complex materials where the noise also comes from sub-surface scattering.

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