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Material Modelling with Physical Constraints

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Abstract

The workflows and interfaces of commercial rendering software are currently designed for believable rendering purposes. However, for predictive rendering other approaches are needed; for example, the usual approach to describe a material or a colour is to use RGB values for diffuse and specular. Since these parameters do not have a physical meaning, these approaches are clearly not suitable for physically based rendering and in particular predictive rendering where we have to deal with complex BRDFs. An investigation is missing on how existing workflows have to be changed and expanded to make them suitable for predictive rendering without losing existing workflows.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction

In the last years, physically-based rendering became more and more popular in industrial applications as well as in the film and game industry [MHH*12]. Modern rendering programs are based on unbiased rendering algorithms and physically-based shading models. The advantages are obvious;

- The results look immediately correct since they are based on physical principles; lights do not have to be tweaked to get a realistic result, and if the light set-up is changed the materials still look plausible.
- Less parameters are needed to get the desired result, hence preparation time is reduced.
- Materials are consistent across different rendering algorithms, whether the rendering algorithm trys to solve the full rendering equation like a global illumination algorithm does or not (e.g. an OpenGL-based rasteriser) or is a gathering or shooting technique.

However, when switching from a non-physical environment to a physically-based, there are several drawbacks. Artists often have a hard time to adapt to the new concept, well-known existing workflows cannot be used anymore and shading models have to be adapted. Hence one of the big challenges industry currently faces is how to make use of the physically-based concept while preserving the look and feel as well as the flexibility artists are used to.

2. Background

BRDFs have to fulfill severals properties so that they can be used in the context of physically-based rendering. Firstly, they have to be energy conserving. This means that they are not allowed to reflect more energy than they receive. And secondly, the Helmholz reciprocity has to be fulfilled.

Traditionally, industrial shading models are restricted to a set of few simple BRDF models, i.e. the Lambert model for the diffuse component, (Blinn-) Phong or Cook-Torrance for glossy reflections and a Dirac impulse for perfect reflections and refractions. In modern rendering systems also a subsurface scattering component and a glossy refraction BRDF can be found quite often. Although each component might be more or less physically plausible, the combination of the BRDFs is often not, since the sum of the BRDFs are no longer energy conserving or reciprocity is violated. Especially when it comes to layering, verification of plausibility becomes hard. Simple tests like "is the sum of the diffuse and the specular colour smaller than 1" are misleading as soon as textures or other effects like layering come into play, since the original colour is manipulated by e.g. the values in the texture.

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3. Guaranteeing Physical Plausibility for Materials

Physically based rendering programs have mechanisms to guarantee energy conservation, but these mechanisms tend to change the appearance the result. For example, a popular choice is to use a weighting factor that favors the specular BRDF (this is e.g. done in iray [ira] or modo [lux]), but as it can be seen in figure 1, the material looks completely different afterwards. Hence more sophisticated solutions are needed that also take into account the appearance of the material.

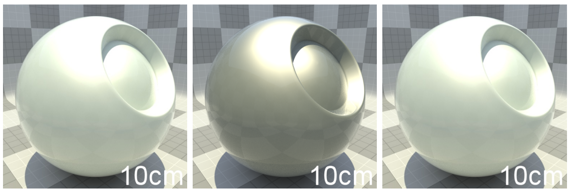

Figure 1: *Non-energy conserving material and its energy-conserving counterparts. In the middle the diffuse amount is reduced in a favour of the specular which leads to a completely different result. In the right image the appearance is taken into account. The result is much more similar.*

In contrast to the game and film industry our materials are not developed for a specific project and are discharged later, they have to live for many years in our products, they need to be stable and intuitively to use. When we started to switch from a believable rendering system to a physically based, we tried to enforce material plausibility based on the following design decisions:

- **Components**. Only BRDF components that are already physically plausible are available. We only use the normalised versions if both are available.
- **Layering** Since only a limited number of materials can be described with a fix compound BRDF, we introduced a layer-based material model in our new rendering environment. The idea is to reproduce nature as close as possible (and practicable) by modelling the individual layers of the material. We do this in a stacked system, thus taking all components into account and guaranteeing that the material components are treated in a natural and plausible way. If a specular and diffuse component is available in a single layer, we combine them so that their appearance is preserved.
- **Input Parameters.**We favoured physically based models like e.g. the Cook-Torrance model over empirical models like the Phong model. Parameters can be looked up in textbooks or measured and are consistent over different materials. Additionally, we restricted the input parameter ranges to sensible ranges; materials have a minimum reflectivity of 10 percent and a maximum of at about 80.

Although these mechanisms take care that the results do not violate the laws of physics, they do not guarantee that the material looks visually pleasing. We soon learned that although artists liked the materials in general and their realistic look, artists complained that they cannot manipulate materials how they want and are not able to achieve the same results they are used to get otherwise. For example, a common complaint was that materials like white pearlescent lacquer do not look bright enough. In a non-physically workflow the solution would be to set the reflectivity to a value larger than one, but with our new constraints this is not possible anymore. The new workflow requires to change the whole lighting setup which in turn changes the appearance of all other materials.

This taught us that in the future we have to have a deeper look on how we perceive materials and provide artists with better mechanisms to manipulate them. We think that our limitations are not in the underlying physical models, but in their practical application.

4. Conclusion

Physically-based material modelling and rendering has many advantages over non-physically based rendering. But although plenty of research exists that deal with the individual components, we still need to adapt our workflows and tools so that artists can use them in an intuitive and reliable way. One one side we need complex BRDF models that are able to capture real-life behaviour, but on the other side we also need the flexibility artistic models can give us.

References

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[lux] http://www.luxology.com/. 2

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