Physically Based Shading in Theory and Practice

SIGGRAPH 2013 COURSE NOTES

Course Organizers

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Presenters

HÅKAN "ZAP" ANDERSSON
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CHRISTOPHE HERY
Pixar

NATY HOFFMAN
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BRIAN KARIS
Epic Games

DIMITAR LAZAROV
Treyarch

ADAM MARTINEZ
Sony Pictures Imageworks

DAVID NEUBELT
Ready at Dawn Studios

MATT PETTINEO
Ready at Dawn Studios

RYUSUKE VILLEMIN
Pixar

Course Description

Physically based shading is transforming the way we approach production rendering, and simplifying the lives of artists in the process. By adhering to physically based, energy-conserving models, one can easily create realistic materials that maintain their properties under a variety of lighting conditions. In contrast, traditional "ad-hoc" models have required extensive tweaking to achieve the same result. Building upon previous incarnations of the course, we present further research and practical advice on the subject, from film and game production.

LEVEL OF DIFFICULTY: Intermediate

Intended Audience

Practitioners from the videogame, CG animation, and VFX fields, as well as researchers interested in shading models.

Prerequisites

An understanding of shading models and their use in film or game production.

Course Website

All course materials can be found at `http://selfshadow.com/publications/s2013-shading-course`

Contact

Address questions or comments to `s2013course@selfshadow.com`

About the Presenters

HÅKAN "ZAP" ANDERSSON is a rendering developer at Autodesk. He previously worked at mental images—where his official title was "Shader Wizard"—and created many of the most commonly used mental ray shaders in existence today. Zap is a native of Sweden, with an engineering degree in electronics and a CAD industry background. He wrote his first renderer around 1986 for the Swedish ABC80 computer, with a graphics card he hand-wired himself.

CHRISTOPHE HERY joined Pixar in June 2010, where he holds the position of Senior Scientist. He wrote new lighting models and rendering methods for *Monsters University* and *The Blue Umbrella*, and continues to spearhead research in the rendering arena. An alumnus of Industrial Light & Magic, Christophe previously served as a research and development lead, supporting the facility's shaders and providing rendering guidance. He was first hired by ILM in 1993 as a senior technical director. During his career at ILM, he received two Technical Achievement Awards from the Academy of Motion Pictures Arts and Sciences.

NATY HOFFMAN is Vice President of Technology at 2K. Previously he was employed at Activision (working on graphics R&D for various titles, including the Call of Duty series), SCEA Santa Monica Studio (coding graphics technology for *God of War III*), Naughty Dog (developing PS3 first-party libraries), Westwood Studios (leading graphics development on *Earth and Beyond*) and Intel (driving Pentium pipeline modifications and assisting the SSE / SSE2 instruction set definition).

BRIAN KARIS is a Senior Graphics Programmer at Epic Games, where he works on the renderer for Unreal Engine 4. Prior to joining Epic in 2012, he was employed at Human Head Studios and created the renderer for *Prey 2*, focusing on systems for virtual texturing, lighting and visibility.

DIMITAR LAZAROV is the Lead Graphics Engineer at Treyarch, where he worked on the *Call of Duty: Black Ops* and *Call of Duty: Black Ops II* titles. He has over a decade of experience in game development and has contributed to a diverse portfolio of games, ranging from kids friendly titles such as *Casper Spirit Dimensions* and *Kung Fu Panda*, to action blockbusters such as *Medal of Honor: European Assault*, *True Crime: New York City* and *Transformers: Revenge of the Fallen*. Dimitar's main expertise is graphics programming and performance optimizations, and he is often involved in system and core engineering, tools programming and other areas that need his attention to detail.

ADAM MARTINEZ is a Shader Writer for Sony Pictures Imageworks and a member of the Shading Department, which oversees all aspects of shader writing and production rendering at Imageworks. He is a pipeline developer, look development artist, and technical support liaison for productions at the studio. He was also one of the primary architects of Imageworks' rendering strategy behind *2012* and *Alice In Wonderland*.

DAVID NEUBELT has served as a Lead Graphics and Engine programmer at Ready at Dawn Studios since 2005, where he has shipped multiple PSP *God of War* titles, *Daxter*, and *God Of War: Origins Collection* for PS3. Most recently, he has helped shape their next-generation engine from its inception, contributing in many areas, including the development of production BRDFs and their 3D material scanning pipeline.

MATT PETTINEO is a Lead Graphics and Engine programmer at Ready at Dawn Studios, where he has worked since 2009, helping to develop a physically based shading model and material authoring pipeline for use in their upcoming title. He also focuses on hardware development and optimization for next-generation consoles.

RYUSUKE VILLEMIN began his career at BUF Compagnie in 2001, where he co-developed BUF's in-house raytracing renderer. He later moved to Japan at Square-Enix as a rendering lead to develop a full package of physically based shaders and lights for mental ray. After working freelance for several Japanese studios, he joined Pixar in 2011 as a TD.

Presentation Schedule

09:00–09:05 **Introduction** *(Hill)*

09:05–09:20 **Background: Physics and Math of Shading** *(Hoffman)*

09:20–09:40 **Getting More Physical in Call of Duty: Black Ops II** *(Lazarov)*

09:40–10:00 **Real Shading in Unreal Engine 4** *(Brian Karis)*

10:00–10:30 **Crafting a Next-Gen Material Pipeline** *(Neubelt and Pettineo)*

10:30–10:45 **Break**

10:45–11:10 **Everything You Always Wanted to Know About `mia_material`***
(* But Were Afraid to Ask) *(Andersson)*

11:10–11:35 **OSL The Great and Powerful** *(Martinez)*

11:35–12:15 **Physically Based Shading at Pixar** *(Hery and Villemin)*

Abstracts

Background: Physically-Based Shading

Naty Hoffman

We will go over the fundamentals behind physically based shading models, starting with a qualitative description of the underlying physics, followed by a quantitative description of the relevant mathematical models, and finally discussing how these mathematical models can be implemented for shading.

Getting More Physical in Call of Duty: Black Ops II

Dimitar Lazarov

This talk will cover a number of improvements and optimizations made to our physically based shading approach since *Call of Duty: Black Ops* (as presented at SIGGRAPH 2011). In particular, we derived a new environment map Fresnel formulation, that is significantly closer to ground truth ray-traced simulations. Additionally, we improved our environment map normalization strategy, which helped to ensure matching reflections across varying geometry and baked lighting representations.

We also implemented a new cosine-power-based environment map pre-filtering technique, which contributed to a more uniform gloss response between point lights and environment maps. Last but not least, we further optimized all of our physically based shading math, which resulted in a ten percent overall shader speedup.

Real Shading in Unreal Engine 4

Brian Karis

Unreal Engine 4 has always had the basics of physically based shading. Last year we felt that we could make major workflow and quality improvements in how we authored materials, by layering and blending pre-made materials from a library instead of authoring components separately and redundantly for every use (e.g. diffuse and specular textures). This in turn motivated a deeper review of our material and shading models, not only with the aim of increasing physical accuracy, but also to minimize the number of parameters without limiting expressiveness. The work Disney presented in this course last year provided the perfect starting point for our solution.

I will discuss how we reduced the number of material parameters of Disney's model and simplified it for real-time use in UE4. I will show how an importance-sampled IBL version of this shading model can be approximated using pre-filtering. I will also discuss our experiences, the limitations that either we or our licensees have encountered and the results we have achieved with it. Finally, I will present an energy-conserving analytical area light model and show how the concepts used can be expanded to other light shapes such as capsules and rectangles.

Crafting a Next-Gen Material Pipeline

David Neubelt and Matt Pettineo

Physically based shading has already made strong inroads into current-generation console and PC game development, where it has proven its merit as a practical methodology for producing materials with a higher degree of realism. With the jump in graphics processing capabilities promised by next-generation consoles, we are presented with an exciting opportunity to expand to more complex and robust reflectance models. However, transitioning to Cook-Torrance and other physically based shading models can bring its own set of unique challenges that require practical solutions in order to simultaneously ensure quality, performance and production scalability. This talk will cover some of the issues that we've encountered while developing a physically based shading model at Ready at Dawn Studios, and will also provide an overview of the solutions that were developed for these problems.

First, we will discuss the development of our film-inspired material compositing and inheritance pipeline. Compositing enables material artists to carefully choose parameters for "pure" base materials—such as gold or concrete—that typically have few spatially varying properties. These base material parameters are then automatically converted into texture maps, and composited with other materials using blend maps (specifying material boundaries). The result is that rich materials with high degrees of spatial variance can be produced without artists needing to hand-paint albedo or roughness maps. Additionally, our artists wanted to create a workflow for easily feeding our material pipeline different textiles they acquired from costume designers and trade events. We developed a custom hardware acquisition device to scan in materials to acquire their albedo, normal, depth, and roughness maps. This allows us to create complex and highly detailed materials at a fraction of the cost it would take to author by hand.

Finally, we were inspired by last year's SIGGRAPH talks on physically based shading and aliasing. We then asked the question: "How can we control specular aliasing without modifying the work we've done to our BRDFs?", since many solutions for aliasing are currently tied to a particular BRDF. We will present the results of our research into existing techniques for reducing aliasing of the specular term caused by undersampling in the pixel shader, as well as how we adapted them to maintain the integrity of our custom BRDFs.

Everything You Always Wanted to Know About `mia_material`

Håkan "Zap" Andersson

Development of the mental ray shader `mia_material` started in 2006, with the express goal of helping users render with a more "physical" shading model. It has since gone on to be widely used in architectural visualization and blockbuster movies, become the root of all the standard "Autodesk materials" used throughout the product line, and is probably one of the most ubiquitous shaders on the planet, having had its feature set cloned by many a renderer developer.

This talk will start by discussing the background of the shader, why it was made the way it was, and where the inspiration came from for some of its behavior. We will decipher the rationale behind the model of layering and energy conservation. We will then continue with some insights into the internals, and where it—quite intentionally—deviates from some standard practices within physical rendering, and why. We will touch both upon technical questions (e.g. "What kind of glossiness is used?" and "What do certain values mean?") as well as philosophical (e.g. "Why does most glossiness models look unrealistic?" and "What perceptual quirks makes a user turn the wrong knob?"). We will also reveal some deep, dark secrets.

Finally, we will end on some thoughts for the future: where to go from here, what would have been done differently today, and where the challenges in physical rendering lie going forward.

OSL The Great and Powerful

Adam Martinez

Completion of the visual effects work on Disney's *Oz The Great and Powerful* (2013) represents a milestone in the development of OSL at Sony Pictures Imageworks. In addition to being the largest show in sheer shot count, it also contains the widest variety of character, creature, environment and effects work that been undertaken in the OSL shading pipeline to date.

This talk will focus on Imageworks' use of OSL on the show. For instance, we leveraged the flexibility and rapid shader development turnaround of the OSL workflow to create a more effective skin shading solution. While previous skin shading techniques were largely the responsibility of individual productions, we built a generalized facility-level solution based on Eugene d'Eon's work on Gaussian subsurface scattering diffusion profiles.

We also quickly and successfully integrated and deployed new hair shading techniques in the middle of production, without disruption. This allowed us to bring all of the subtleties of our image-based illumination pipeline to bear on hair, as effectively as on other surfaces.

All of these techniques were employed for Finley—the endearing flying monkey—who I will be using as a demonstration case for each topic. Additionally, volumetric effects played a significant role in this production, so I will discuss some of the specifics of working with volumes in OSL.

Both the talk and the accompanying course notes will provide practical examples of writing OSL shaders, building upon content from the SIGGRAPH 2012 course.

Physically Based Shading at Pixar

Christophe Hery and Ryusuke Villemin

Over the past few years, the shading system at Pixar has been rewritten to give artists a powerful but simple solution for lighting. The new system—developed originally for the show *Monsters University*—aims to provide good images right out of the box, whilst using ray-tracing throughout to minimize the number of caches or precomputations. It consists of three main parts:

- Lights: real, physically correct, sampled area lights

- BRDFs: physically correct, energy conserving BRDF models, describing how light interacts with object surfaces

- Integrators: functions that combine lights and BRDFs to produce the final color

The first half of the talk will describe these three parts, and how they interact, passing information between them. In the second half, we will take the examples of the sphere area light, Beckmann BRDF and the direct integrator, and discuss how those are effectively implemented at Pixar in `prman` using co-shaders.