Physically Based Shading in Theory and Practice

SIGGRAPH 2017 Course

Course Organizers

Stephen Hill
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Presenters

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DreamWorks Animation
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Additional Contributors

Adam Micciulla
Independent

Ryusuke Villemin
Pixar

Course Description

Physically based shading has transformed the way we approach production rendering and simplified the lives of artists in the process. By employing shading models that adhere to physical principles, one can readily create high quality, realistic materials that maintain their appearance under a variety of lighting environments. In contrast, traditional ad hoc models required extensive tweaking to achieve comparable results—due to less intuitive behavior or unnecessary complexity—and were liable to break under different illumination.

Consequently, physically based models have become widely adopted in film and game production, particularly as they are often no more difficult to implement or evaluate. That being said, physically based shading is not a solved problem, and thus the aim of this course is to share the latest theory as well as lessons from 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 here.

Contact

Please address questions or comments to `s2017course@selfshadow.com`.

Organizers

STEPHEN HILL is a Senior Rendering Engineer within Lucasfilm's Advanced Development group, where he is engaged in physically based rendering R&D for real-time productions such as the recent *Carne y Arena* VR installation experience. He was previously a 3D Technical Lead at Ubisoft Montreal, where he contributed to a number of *Splinter Cell* titles as well as *Assassin's Creed Unity*.

STEPHEN MCAULEY is a 3D Technical Lead on the *Far Cry* brand at Ubisoft, where he has worked on *Far Cry 3*, *4* and *Primal*. His primary focus has been spearheading the switch to physically based shading and calibrating lighting and materials. He has also worked at Bizarre Creations, where he shipped games such as *Blood Stone*, *Blur* and *Project Gotham Racing*, and developed a system for deferred lighting on the SPUs.

Presenters

ALEJANDRO CONTY is a senior rendering engineer at Sony Pictures Imageworks since 2009 and has developed several components of the physically based rendering pipeline such as BSDFs, lighting and integration algorithms, including Bidirectional Path Tracing and other hybrid techniques. Previous to that he was the creator and main developer of YafRay, an open-source render engine released around 2003. He lives in Gijon, Spain.

MICHAŁ DROBOT is a Principal Rendering Engineer at Infinity Ward, Activision. Most recently, he worked on the rendering engine architecture of *Call of Duty: Infinite Warfare*. Before that he helped in designing and optimizing the 3D renderer in *Far Cry 4* at Ubisoft Montreal. Prior to that, he worked at Guerrilla Games, designing and optimizing the rendering pipeline for the PlayStation 4 launch title *Killzone: Shadow Fall*. Michał specializes in rendering algorithms, renderer design, hardware architectures and low-level optimizations.

ERIC HEITZ is a graphics researcher at Unity Technologies. He works on physically based rendering, with a strong focus on shading and level-of-detail techniques. Eric got his PhD from Grenoble University at INRIA in France.

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 more recently for *Finding Dory* and *Piper*, 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.

Christopher Kulla is a principal software engineer at Sony Picture Imageworks where he has worked on the in-house branch of the Arnold renderer since 2007. He focuses on ray-tracing kernels, sampling techniques and volume rendering. In 2017 he was recognized with a Scientific and Engineering Award from the Academy of Motion Picture Arts and Sciences for his work on the Arnold renderer.

Jon Lanz is a Senior Software Engineer on the Shading team at DreamWorks Animation. He has twenty years experience in feature animation and video games, with focus on look development, lighting, rendering and shading. His recent projects include developing a streamlined set of layerable, physically based production shaders.

Junyi Ling is a characters co-supervisor at Pixar Animation Studios. Most recently he was responsible for some of the shading and look development efforts on *Cars 3* and *The Good Dinosaur*. He has also worked as a shading and grooming Technical Director on *Ratatouille*, *Up*, *Toy Story 3*, *Cars 2* and other Pixar films. His current production and research interests are focused on general look development, material modeling and illumination.

Nathan Walster is head of the Shading department and a CG Supervisor at Framestore. He focuses on the approaches the studio takes toward rendering, lighting and look development. Nathan has been with Framestore since 2006, having worked on films such as *Gravity* and *Guardians of the Galaxy*.

Feng Xie started working for DreamWorks as a rendering engineer in 2001. She has credits on over 20 films at the studio, from *Shrek 2* to the most recent release, *The Boss Baby*. Feng had been a principal engineer and the shading architect for DreamWorks Animation since 2009, where she lead the development and adoption of physically based shaders within the studio. In spring of 2017, Feng returned to Stanford to complete her PhD research on rendering with Prof. Pat Hanrahan.

Additional Contributors

Adam Micciulla is an independent software engineer living in Portland, Oregon. Previously, he was a Senior Software Engineer at Infinity Ward, Activision, where he worked on the material system and post effects pipeline for *Call of Duty: Infinite Warfare*. Prior to that, Adam worked on engine development and optimization for a number of titles at Neversoft Entertainment, including *Call of Duty: Ghosts*, *Guitar Hero* and *Tony Hawk*.

Ryusuke Villemin began his career at BUF Compagnie in 2001, where he co-developed BUF's in-house ray-tracing 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 a couple of Japanese studios (OLM Digital and Polygon Pictures), he joined Pixar in 2011 as a TD. He currently works in the Research Rendering department, on light transport and physically based rendering.

Presentation Schedule

14:00–14:30	**Real-Time Line and Disk Light Shading** *(Heitz and Hill)*
14:30–15:00	**Physically Based Shading at DreamWorks Animation** *(Xie and Lanz)*
15:00–15:30	**Volumetric Skin and Fabric Shading at Framestore** *(Walster)*
15:30–15:45	**Break**
15:45–16:05	**Practical Multilayered Materials in Call of Duty: Infinite Warfare** *(Drobot)*
16:05–16:35	**Pixar's Foundation for Materials:** `PxrSurface` **and** `PxrMarschnerHair` *(Hery and Ling)*
16:35–17:15	**Revisiting Physically Based Shading at Imageworks** *(Kulla and Conty)*

Abstracts

Real-Time Line and Disk Light Shading

Eric Heitz and Stephen Hill

At SIGGRAPH 2016, we presented a new real-time area lighting technique for polygonal sources. In this talk, we will show how the underlying framework, based on *Linearly Transformed Cosines* (LTCs), can be extended to support line and disk lights. We will discuss the theory behind these approaches as well as practical implementation tips and tricks concerning numerical precision and performance.

Physically Based Shading at DreamWorks Animation

Feng Xie and Jon Lanz

PDI/DreamWorks was one of the first animation studios to adopt global illumination in production rendering. Concurrently, we have also been developing and applying physically based shading principles to improve the consistency and realism of our material models, while balancing the need for intuitive artistic control required for feature animations.

In this talk, we will start by presenting the evolution of physically based shading in our films. Then we will present some fundamental principles with respect to importance sampling and energy conservation in our BSDF framework with a pragmatic and efficient approach to transimssion fresnel modeling. Finally, we will present our new set of physically plausible production shaders for our new path tracer, which includes our new hard surface shader, our approach to material layering and some new developments in fabric and glitter shading.

Volumetric Skin and Fabric Shading at Framestore

Nathan Walster

Recent advances in shading have led to the use of free-path sampling to better solve complex light transport within volumetric materials. In this talk, we describe how we have implemented these ideas and techniques within a production environment, their application on recent shows—such as *Guardians of the Galaxy Vol. 2* and *Alien: Covenant*—and the effect this has had on artists' workflow within our studio.

Practical Multilayered Materials in Call of Duty: Infinite Warfare

Michał Drobot

This talk presents a practical approach to multilayer, physically based surface rendering, specifically optimized for Forward+ rendering pipelines. The presented pipeline allows for the creation of complex surface by decomposing them into different mediums, each represented by a simple BRDF/BSSRDF and set of simple, physical macro properties, such as thickness, scattering and absorption. The described model is explained via practical examples of common multilayer materials such as car paint, lacquered wood, ice, and semi-translucent plastics. Finally, the talk describes intrinsic implementation details for achieving a low performance budget for 60 Hz titles as well as supporting multiple rendering modes: opaque, alpha blend, and refractive blend.

Pixar's Foundation for Materials: `PxrSurface` and `PxrMarschnerHair`

Christophe Hery and Junyi Ling

Pixar's Foundation Materials, `PxrSurface` and `PxrMarschnerHair`, began shipping with RenderMan 21.

`PxrSurface` is the standard surface shader developed in the studio for *Finding Dory* and used more recently for *Cars 3* and *Coco*. This shader contains nine lobes that cover the entire gamut of surface materials for these two films: diffuse, three specular, iridescence, fuzz, subsurface, single scatter and a glass lobe. Each of these BxDF lobes is energy conserving, but conservation is not enforced between lobes on the surface level. We use parameter layering methods to feed a `PxrSurface` with pre-layered material descriptions. This simultaneously allows us the flexibility of a multilayered shading pipeline together with efficient and consistent rendering behavior.

We also implemented our individual BxDFs with the latest state-of-the-art techniques. For example, our three specular lobes can be switched between Beckmann and GGX modes. Many compound materials have multiple layers of specular; these lobes interact with each other modulated by the Fresnel effect of the clearcoat layer. We also leverage LEADR mapping to recreate sub-displacement micro features such as metal flakes and clearcoat scratches.

Another example is that `PxrSurface` ships with Jensen, d'Eon and Burley diffusion profiles. Additionally, we implemented a novel subsurface model using path-traced volumetric scattering, which represents a significant advancement. It captures zero and single scattering events of subsurface scattering implicit to the path-tracing algorithm. The user can adjust the phase-function of the scattering events and change the extinction profiles, and it also comes with standardized color inversion features for intuitive albedo input. To the best of our knowledge, this is the first commercially available rendering system to model these features and the rendering cost is comparable to classic diffusion subsurface scattering models.

`PxrMarschnerHair` implements Marschner's seminal hair illumination model with importance sampling. We also account for the residual energy left after the R, TT, TRT and glint lobes, through a fifth diffuse lobe. We show that this hair surface shader can reproduce dark and blonde hair effectively in a path-traced production context. Volumetric scattering from fiber to fiber changes the perceived hue and saturation of a groom, so we also provide a color inversion scheme to invert input albedos, such that the artistic inputs are straightforward and intuitive.

Revisiting Physically Based Shading at Imageworks

Christopher Kulla and Alejandro Conty

Two years ago, the rendering and shading groups at Sony Imageworks embarked on a project to review the structure of our physically based shaders in an effort to simplify their implementation, improve quality and pave the way to take advantage of future improvements in light transport algorithms.

We started from classic microfacet BRDF building blocks and investigated energy conservation and artist friendly parametrizations. We continued by unifying volume rendering and subsurface scattering algorithms and put in place a system for medium tracking to improve the setup of nested media. Finally, from all these building blocks, we rebuilt our artist-facing shaders with a simplified interface and a more flexible layering approach through parameter blending.

Our talk will discuss the details of our various building blocks, what worked and what didn't, as well as some future research directions we are still interested in exploring.