Physically Based Shading in Theory and Practice

SIGGRAPH 2016 Course

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Presenters

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Dan Lobl
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Additional Contributors

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Adrián Jarabo
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Sébastien Lachambre
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Angelo Pesce
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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 s2016course@selfshadow.com.

Presenters

Roger Cordes is the Digital Production Supervisor for Lucasfilm's Advanced Development Group. He oversees asset production, lighting, and overall look-development efforts for the group. Roger has been with the Lucasfilm organization since 2010, and has focused primarily on real-time rendering, shading, and material expression.

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.

Sébastien Hillaire is a rendering engineer within the Frostbite engine team at Electronic Arts. You can find him pushing visual quality and performance in many areas, such as physically based volumetric simulation and rendering, visual effects or post processing, to name a few. He obtained his PhD in Computer Science from the French National Institute of Applied Science in 2010, during which he focused on using gaze tracking to visually enhance the virtual reality user experience. Before joining Frostbite, he worked at Dynamixyz and Criterion Games.

Naty Hoffman is a Principal Engineer & Architect in the Lucasfilm Advanced Development Group. Previously he was the Vice President of Technology at 2K, and before that he worked at Activision (doing graphics R&D for various titles, including the *Call of Duty* series), SCE 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 Unreal Engine 4, focusing on physically based shading, anti-aliasing and geometry. Prior to joining Epic in 2012, he was employed at Human Head Studios and created the renderer for *Prey 2*.

Jorge Jiménez is a Graphics R&D Technical Director at Activision Blizzard. He received his PhD in Real-Time Graphics from Universidad de Zaragoza (Spain) in 2012. He has made contributions to conferences, books, and journals, including SIGGRAPH and GDC, the GPU Pro series, Game Developer magazine and ACM Transactions on Graphics. He co-organized the course *Filtering Approaches for Real-Time Anti-Aliasing* at SIGGRAPH 2011, declaring open war against the jaggies. At GDC 2013, he co-presented the talk *Next Generation Character Rendering*, and collaborated on the *Digital Ira* project, which used this character rendering technology. Since then, he has worked on the *Call of Duty* franchise, including *Advanced Warfare* and *Black Ops III*. His interests include photorealism, special effects and attention to the details.

Sébastien Lagarde is a software engineering graduate who has worked in the game industry since 2003 as an engine programmer with expertise in rendering. He has worked on many consoles for a lot of different titles, from small casual games to AAA (*Remember Me*, *Mirror Edge 2*, *Star Wars Battlefront* etc.). He also developed the kernel of the Trioviz SDK, a stereoscopic system used in many AAA games (*Batman: Arkham City* and *Arkham Asylum*, *Assassin's Creed II*, *Gears of War 3*, etc.). Sébastien has worked for Neko Entertainment, Darkworks, Trioviz, Dontnod and EA Frostbite. He is now at Unity Technologies as Director of Rendering Research.

Dan Lobl is a VFX Digital Asset Supervisor at Industrial Light & Magic. He oversaw the lighting and rendering for *Star Wars: The Force Awakens*, and facilitated the development of artist tools and workflows. Since starting with the company in 1997, Dan has contributed to over 25 feature films, with particular contributions in the areas of Look Development, Set Capture, Asset Management, Crowd Pipelines and Materials Development.

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.

Additional Contributors

Florian Hecht joined Pixar in 2011 and currently works in the Research Rendering group. He developed a GPU volume renderer for final frames and worked on Pixar's switch to path tracing with *Finding Dory*, with a focus on the lighting technology. Before coming to Pixar, he spent some time at the UC Berkeley Computer Graphics group, after graduating with an MSc in Computer Science from the Karlsruhe Institute of Technology as well as the Georgia Institute of Technology.

Adrián Jarabo is a post-doctoral researcher at Universidad de Zaragoza, where he received his PhD in Computer Graphics in 2015, under the supervision of Prof. Diego Gutierrez. During his predoctoral studies, he enjoyed research placements at Trinity College Dublin and Microsoft Research Asia. His research focuses on topics such as light transport simulation, plenoptic manipulation, and virtual human depiction.

Cyril Jover has been working in the videogame industry for more than 10 years as a Technical Artist. He has experienced very different domains such as VFX and terrain generation (at Eugen Systems), tools and physics (at Darkworks), character geometry and material acquisition (at Eisko), plus destruction and city generation (at Dontnod). He joined Unity Technologies in 2015 as a Technical Artist.

Sébastien Lachambre has been working in the videogame industry for twenty years, as an Artist, Lead Artist and Technical Artist. He has worked on many productions for PC and consoles, at Silmarils, Infogrames, Delphine Software, PAM Development, Cyanide and Ubisoft. He joined Unity Technologies in 2015 as a Technical Artist and has been working on HDRI, photogrammetry, material

acquisition, etc.

Angelo Pesce started coding computer graphics in his teens within the demoscene. After a few forgettable productions and obtaining a master's degree in Computer Science, he left his PhD to start working in the videogame industry. Since then, he has been helping rendering teams on many projects, for companies such as Milestone, Electronic Arts, Capcom, and Relic Entertainment. He currently serves as a Technical Director within the Activision Central Technology group.

Xian-Chun Wu serves as an R&D Graphics Programmer within the Activision Central Technology Group, where he works on the *Call of Duty* franchise. He received his BSc degree from the Department of Mathematics of the Northeastern University of China. Before Activision Blizzard, he worked for Tencent as a Senior Engine Programmer. He likes to solve videogame rendering, animation and physics problems with mathematics.

Presentation Schedule

14:00–14:20 **Recent Advances in Physically Based Shading** *(Hoffman)*

14:20–15:00 **Unified Shading and Asset Development at Lucasfilm and ILM** *(Cordes and Lobl)*

15:00–15:30 **Physically Based Sky, Atmosphere and Cloud Rendering in Frostbite** *(Hillaire)*

15:30–15:45 **Break**

15:45–16:05 **An Artist-Friendly Workflow for Panoramic HDRI** *(Lagarde)*

16:05–16:25 **Physically Based Hair Shading in Unreal** *(Karis)*

16:25–16:45 **Practical Real-Time Strategies for Accurate Indirect Occlusion** *(Jiménez)*

16:45–17:15 **Towards Bidirectional Path Tracing at Pixar** *(Hery and Villemin)*

Abstracts

Recent Advances in Physically Based Shading

Naty Hoffman

This year's course introduction will follow a different approach than previous years, presenting an overview of recent advances in the theory and practice of physically based shading. Last year's introduction, *Physics and Math of Shading*, is available from last year's course page and is recommended background for anyone attending the course for the first time.

Physically Based Hair Shading in Unreal

Brian Karis

The common method for shading hair in games is still based on ad hoc models. I will discuss the hair shading model we developed for Unreal Engine 4, which is being used on *Paragon*. To accomplish this, we gathered copious reference photography, built ground truth implementations and set about approximating a state-of-the-art model currently used in film. I will cover how the complex calculations were approximated both for punctual light sources and image-based lighting.

Practical Real-Time Strategies for Accurate Indirect Occlusion

Jorge Jiménez, Angelo Pesce and Xian-Chun Wu

This talk will cover accurate screen-space approaches to diffuse and specular occlusion of indirect lighting, engineered to match Monte Carlo ground truth references.

For diffuse occlusion, we propose cosine-weighted horizon-based ambient occlusion, for which we will show its ground truth analytical derivation. Furthermore, regular ambient occlusion shows higher contrast than the occlusion observed in ground truth references, due to secondary bounces. To improve on this, we locally approximate multiple bounces of colored occlusion by fitting to ray-traced references. Finally, our specular occlusion is performed by calculating the intersection of the visibility cone by the actual specular lobe, which is accurately achieved by means of a look-up table.

The performance of these techniques allows for practical integration into game engines. In particular, the ambient occlusion component takes 0.5ms (PS4, 1080p) and has been used successfully in production.

Physically Based Sky, Atmosphere and Cloud Rendering in Frostbite

Sébastien Hillaire

Games are becoming more and more demanding in terms of visual quality and dynamism. Some (e.g. open-world games) may require lots of dynamic elements, such as "time of day" lighting and real-time evolving weather. The dynamic and often global nature of these elements make them difficult to simulate and render in real time. Sky, atmosphere and clouds are the three main components we need to simulate in order to achieve dynamic time of day and weather conditions. They are difficult to render due to their very detailed and specific volumetric nature. These elements also interact together, such as clouds affecting atmospheric lighting and vice versa. We present the practical physically based solutions we have implemented in Frostbite to simulate and combine all of these elements, and to render the complex interactions in-between. We will also expose how this fits into Frostbite's physically based shading framework as well as how artists author such elements, along with performance characteristics.

An Artist-Friendly Workflow for Panoramic HDRI

Sébastien Lagarde, Sébastien Lachambre and Cyril Jover

Image-based lighting with high dynamic range images (HDRI) is a well-known concept in the visual effects and videogame industries, since Paul Debevec's SIGGRAPH'98 paper popularized the technique. Panoramic HDRI as a lighting source allows one to easily reproduce lighting from the real world and to better integrate a CG object inside an environment—a technique that's widely used today. Nowadays there's a lot of software available to aid in generating panoramic HDRIs, along with plenty of resources describing the process. However, in spite of this, we have found that artists are still unaware of how to create a correct HDRI for use as a light source. Moreover, various software packages can easily introduce non-linearity during the reconstruction process.

A correct HDRI:

- captures the full range of lighting in the scene, without clipping (no glare; correct sun intensity)
- has all lens artifacts removed (chromatic aberration, lens flare)
- is linear
- doesn't include any artistic effects

In addition to the above requirements, we found that artists often mix panoramic HDRIs with virtual lights, by "eye balling" the intensity. In the context of physically based rendering, we want to use physical light units with reference from the real world, and thus we need to use HDRIs with absolute range instead of a relative range for such an automatic mix. This talk will describe an artist-friendly workflow for producing correct HDRIs with the best practices we found when shooting our own HDRIs for Unity. For this workflow, we have avoided using complex devices or building a custom setup, so that as many artists as possible will be able to reproduce our steps. The talk will also introduce an easy method for photometric calibration to reconstruct absolute HDRI, and to replace a strong light source (such as the sun) within the HDRI by a virtual light of equivalent intensity.

Towards Bidirectional Path Tracing at Pixar

Christophe Hery, Ryusuke Villemin and Florian Hecht

On *Finding Dory* and *Piper*, we were faced with rendering a lot of water, or creatures and sets seen through water and glass. So we worked with production artists to give controls for generating and resolving these difficult light transports. We also learned to cheat these effects where appropriate. In this course, we will elaborate on some of the constraints that bidirectional path tracing as well as progressive refinement imposed on us, and our solutions for them.

Unified Shading and Asset Development at Lucasfilm and ILM

Roger Cordes and Dan Lobl

We will discuss the development of a new physically based shading model at Lucasfilm and ILM, and a set of digital asset production standards designed to enable content sharing across many varied media platforms. This unified asset specification and unified shading approach is a cornerstone of our transmedia strategy for *Star Wars* franchise content development. We will cover some historical detail of how these production methodologies matured over the past few years, including relevant developments from *Star Wars 1313* at LucasArts, through digital post-production on *Star Wars: The Force Awakens*, and beyond.