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[CV](#) [Publications](#)

News: I started here at the University of California, San Diego [CSE@UCSD](#) on Jul 1, 2014, moving from UC Berkeley. My goal is to build a world-leading graphics and vision group at UCSD. (See launch of new [UC San Diego Center for Visual Computing](#) with [newspaper article at UT San Diego](#), UCSD TV Computing Primetime on [Visual Computing](#), appointment to [endowed chair](#), selection as [ACM Fellow](#) and earlier [UCSD News Release](#) on my appointment). We are actively looking to hire at all levels: junior and senior faculty, postdocs and graduate students. Please contact me if you are interested.

Older News: [Online Lectures](#) for a self-contained 6 week computer graphics course released. Check out the archived lectures, assignments and subscribe to our [YouTube Channel](#).
 UC San Diego and edX [launch partnership](#) with [CSE 167x](#) as the first UC San DiegoX course, now self paced. Please sign up. Also see article in [ThisWeek@UCSanDiego](#).

New: Launch of first online [Virtual Reality \(VR\) App Development Professional Certificate](#), featuring [CSE 167x](#) (now updated to modern OpenGL). Also see [CSE article](#).

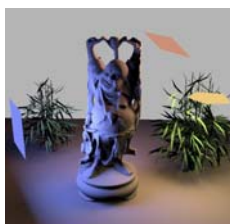
New: [Website for Light Field Projects](#). Includes papers and datasets.

Teaching					
CSE 167	Computer Graphics	Winter 2019	Winter 2017		
CSE 274	Topics in Computer Graphics	Fall 2018 (Samp./Recon. Visual Appearance)	Winter 2018	Fall 2015 (High Quality Real-Time Rendering)	Winter 2015 (CSE 291)
CSE 163	Advanced Computer Graphics	Spring 2018	Spring 2017	Winter 2016 (CSE 190)	Spring 2015 (CSE 190)

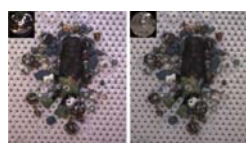
Selected Awards				
2017 ACM Fellow	CSE Article	SIGGRAPH Article	ACM Announcement	Certificate
2017 edX Prize for Exceptional Online Teaching and Learning (finalist)	edX Blog	UCSD art.	Prize Certificate	
2017 IEEE Fellow	CSE Article	Letter	Certificate	
2016 edX Prize for Exceptional Online Teaching and Learning (inaugural finalist)	edX Blog	UCSD art.	Prize Certificate	
2016 Ronald L. Graham (Endowed) Chair of Computer Science	CSE Article	Announcement Card		
2011 Okawa Foundation Research Grant	Award Certificate	Website		
2008 PECASE (Presidential Early Career Awards for Scientists and Engineers)	Award Certificate	Award Photo	Group Photo with President Bush	White House Press Release
2007 SIGGRAPH Significant New Researcher Award for Computer Graphics	Video	Citation	Press Release	

Selected New Research: 2016-18

Selected New Papers in 2018: [SIGGRAPH](#), [SIGASIA](#), [ECCV](#) (See [pub. list](#) for 2019, others)



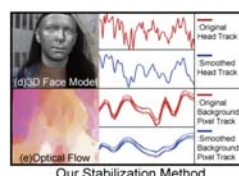
[Analytic SH Area Lights](#)
[\(SIGGRAPH 18\)](#)



[Deep IBR Sparse Samples](#)
[\(SIGGRAPH 18\)](#)



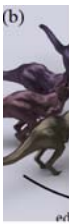
[Rendering Specular Wave Optics](#)
[\(SIGGRAPH 18\)](#)



[Selfie Video Stabilization](#)
[\(ECCV 18\)](#)



[Learning Shape+SVBRDF Single Image \(SIGASIA 18\)](#)



[Conne](#)
[An](#)
[\(SI](#)

Selected New

Papers in
2017:
SIGGRAPH,
CVPR,
ICCV
(See [pub.
list](#) for
others)



[Multiscale Fur
Reflectance
\(SIGGRAPH 17\)](#)

[Light Field Video
\(SIGGRAPH 17\)](#)

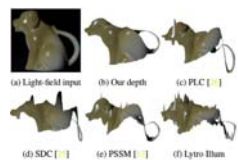
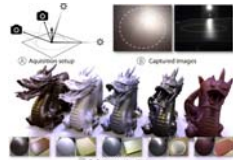
[Deep Learning
HDR \(SIGGRAPH 17\)](#)

[Light Field Motion
Blur \(CVPR 17\)](#)

[RGBD Light Field
Single Image \(ICCV 17\)](#)

[Line:
Polariz](#)

Selected
New
Papers in
2016: SIG,
SIGASIA,
CVPR,
ECCV
(See [pub.
list](#) for
others)



[Specular
MicroStructure
\(SIGGRAPH 16\)](#)

[View Synthesis Light
Fields \(SIGASIA 16\)](#)

[Two-Shot BRDF
Near-Field \(SIGASIA
16\)](#)

[Downsampling
Scattering \(SIGASIA 16\)](#)

[SVBRDF-Invariant
LF Depth \(CVPR 16\)](#)

[Line:
Pola](#)

Research Summary

My research group develops the *theoretical foundations, mathematical representations and computational models* for the *visual appearance* of objects, digitally recreating or *rendering* the complexity of natural appearance. Our research program cuts across computer graphics, computer vision and signal processing with applications in sparse reconstruction and frequency analysis, Monte Carlo importance sampling, interactive photorealistic rendering, acquisition and representation of data-driven appearance, volumetric scattering, animation, image and video editing, light-field cameras, physics-based vision and lighting-insensitive recognition. This work has led to more than 150 publications, including more than 60 SIGGRAPH or TOG papers, and has been recognized in 2005 by a [Sloan Fellowship](#) and an [NSF CAREER](#) award, and in 2007 with an [ONR Young Investigator Award](#) and the [ACM SIGGRAPH Significant New Researcher Award](#). More recently, I received a [Presidential Early Career Award](#) in a White House ceremony in Dec 2008, and an [Okawa Foundation Award](#) in 2011. In Spring 2016, I was appointed the inaugural holder of the [Ronald L. Graham](#) Chair of Computer Science. Most recently, I was named a finalist for the inaugural [edX prize](#) for exceptional contributions in online teaching and learning (and again in 2017, as the only computer science and only two-time finalist). In 2017, I was also elevated to [IEEE fellow](#) for contributions to foundations of computer graphics and computer vision, and to [ACM fellow](#) for contributions to computer graphics rendering and physics-based computer vision. A full [CV](#) is available.

While my focus has been primarily on academic publication, many of my papers have been refined and later widely implemented in products and commercial applications. For example, my work on spherical harmonic lighting and [irradiance environment maps](#) is now widely included in games (such as the Halo series), and is increasingly adopted in movie production (being a critical component of the rendering pipeline in Avatar in 2010, and now an integral part of RenderMan 16, since mid-2011). These ideas are also being used by Adobe for relighting, and are now included in many standard textbooks. My research on [importance sampling](#) has inspired a sampling and image-based lighting pipeline that is becoming standard for production rendering (also included in RenderMan 16) and is used for example on the Pixar movie, Monsters University (my papers discussing production use methods are presented at [EGSR 2012](#) and the inaugural [JCGT](#) paper). Models for [volumetric scattering](#) have been used in demos by NVIDIA, and elsewhere in industry. I also participated in developing the first [electronic field guide](#); a subsequent [iPhone app](#) developed by Prof. Belhumeur and colleagues is now widely used by the public for visual species identification. Most recently, work on sampling and reconstruction for rendering ([frequency analysis](#), [adaptive wavelet rendering](#)) has inspired widespread use of Monte Carlo denoising in industry, and been recognized as seminal in a [EG STAR report](#). Subsequent work on real-time physically-based rendering and denoising ([axis-aligned filtering for soft shadows](#)) has inspired modern software and hardware real-time AI denoisers, which are now integrated into Optix5 and NVIDIA's RTX chips (2017, 18). As a result, physically-based (raytraced) rendering with denoising is now a reality in both offline and real-time rendering pipelines. Our new [Fur Reflectance Model](#) has been used for all animal fur in the 2017 movie War for the Planet of the Apes, nominated for a visual effects Oscar, while new [glint models](#) have been used in Autodesk Fusion 360 and games.

A somewhat out of date summary of [research projects](#) is available (the listing of papers below is up to date). I am still interested in many of the same areas, as well as a broader range of topics. My current funding and research interests fall in four main directions: (1) Signal Processing and Sparse Reconstruction of Visual Appearance, with implications across Rendering, Imaging and Animation (see [position paper](#)); (2) A Digital Visual Appearance Pipeline for complex visually rich materials; (3) Physics-Based Computer Vision with realistic reflectance, illumination and light transport, and more generally problems at the vision-graphics interface, including image and video editing and manipulation; (4) Light Field Cameras and RGBD data for depth and reflectance recovery, and higher-level vision/graphics applications. Please see our [Light Field Website](#). I am also interested in collaborations in and outside the field that leverage expertise in these areas.

Funding: We gratefully acknowledge funding from the [National Science Foundation](#), and the [Office of Naval Research](#). Additional support comes through gifts and equipment from industry, and to the [center for visual computing](#): [Sony](#), [Adobe](#), [Pixar](#), [SamSung](#), [Nokia](#), [Google](#), [Qualcomm](#), [Draper](#), [AutoDesk](#), [Cubic](#), [BASF](#), as well as awards from private foundations: [Sloan](#) and [Okawa](#).

Overview Talks and Videos

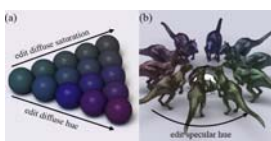
Here is a selection of recent invited talks that give an overview of research.

- [Light Fields: From Shape Recovery to Sparse Reconstruction](#) (Keynote at Workshop on Light Fields for Computer Vision, Jul 2017).
- [Visual Computing: Grand Opportunities](#) (Featured Speaker Presentation on UC San Diego [Center for Visual Computing](#), Jacobs Research Expo, Apr 2015)
- [Sampling and Reconstruction of High-Dimensional Visual Appearance](#) (Keynote ISVC Dec 2015, Distinguished Lecture, UCSD, Feb 2014, Keynote CAD/Graphics Nov 2013, USC ICT Oct 2013)
- [Sparse and Multiresolution Representations of Visual Appearance](#) (SPIE Wavelets and Sparsity XIV Keynote, Aug 2011)
- [Sampling and Reconstruction of High-Dimensional Visual Appearance](#) (MIT, Oct 2010, ASTAR, NUS, UMD Feb/Mar 2011)
- [Computational Models of Visual Appearance for Computer Vision](#) (ONR, Oct 2010)
- [Representations of Visual Appearance for Computer Graphics and Vision](#) (Faculty candidate talk: UCB, UCSD, UCLA, Feb-Apr 2008; UNC, UPenn Sep 2007)
- [Representations of Visual Appearance for Computer Graphics](#) (UCB, UW, MSR, Cornell, May/Jun 2006)
- [High Quality Real-Time Rendering](#) (Princeton, Nov 2006)
- [Data-Driven Appearance Representations](#) (MERL, CMU, May/Jun 2006)
- [Spherical Convolution in Computer Graphics and Vision](#) (SIAM Imaging Science Conference, May 2006)
- [Signal-Theoretic Representations of Visual Appearance](#) (Carnegie Mellon Univ., MIT, Stevens Inst. Tech. Apr, May 2005 ; Univ. Maryland, Rutgers Univ., Siemens, Oct 2004)
- [Real-Time Rendering and Interaction with Complex Illumination and Materials](#) (Intel, Aug 2004)
- [A Signal-Processing Framework for Forward and Inverse Rendering](#) (Faculty candidate talk, Feb-Apr 2002)

Here is a selection of recent SIGGRAPH and other videos:

- [Shape and Spatially-Varying Reflectance from a Single Image](#) MOV (110M), SIGGRAPH Asia 2018
- [Selfie Video Stabilization](#) MP4 (101M), ECCV 2018
- [Rendering Specular Microgeometry with Wave Optics](#) MOV (267M), SIGGRAPH 2018
- [Deep Image-Based Relighting from Optimal Sparse Samples](#) MP4 (506M), SIGGRAPH 2018
- [Analytic Spherical Harmonic Coefficients for Polygonal Area Lights](#) MOV (313M), SIGGRAPH 2018
- [Learning to Synthesize a 4D RGBD Light Field from a Single Image](#) MPEG (99M), ICCV 2017
- [An Efficient and Practical Near and Far-Field Fur Reflectance Model](#) QT (226M), SIGGRAPH 2017
- [Light Field Video Capture Using a Learning-Based Hybrid Imaging System](#) MPEG (130M), SIGGRAPH 2017
- [Patch-Based Optimization for Image-Based Texture Mapping](#) MPEG (370M), SIGGRAPH 2017
- [Learning-Based View Synthesis for Light Field Cameras](#) MPEG (307M), SIGGRAPH ASIA 2016
- [Position-Normal Distributions for Efficient Rendering of Specular Microstructure](#) MPEG (110M), SIGGRAPH 2016
- [Fast 4D Sheared Filtering for Interactive Rendering of Distribution Effects](#) MPEG (196M), TOG 2015
- [Factored Axis-Aligned Filtering for Rendering Multiple Distribution Effects](#) MPEG (96M), SIGGRAPH 2014
- [Rendering Glints on High-Resolution Normal-Mapped Specular Surfaces](#) MPEG (114M), SIGGRAPH 2014
- [Discrete Stochastic Microfacet Models](#) MPEG (185M), SIGGRAPH 2014
- [High-Order Similarity Relations in Radiative Transfer](#) MPEG (14M), SIGGRAPH 2014
- [Axis-Aligned Filtering for Interactive Physically-Based Diffuse Indirect Lighting](#) MPEG (76M), SIGGRAPH 2013
- [Interactive Albedo Editing in Path-Traced Volumetric Materials](#) MPEG (18M), TOG 2013
- [Automatic Cinemagraph Portraits](#) MPEG (58M), EGSR 2013
- [Modular Flux Transfer](#) MPEG (125M), SIGGRAPH 2013
- [Selectively De-Animating Video](#) MPEG (100M), SIGGRAPH 2012 Shorter [Teaser Video](#)
- [Data-Driven Elastic Models for Cloth: Modeling and Measurement](#) MPEG (55M, no audio), SIGGRAPH 2011
- [Multi-Resolution Isotropic Strain Limiting](#) MPEG (86M, no audio), SIGGRAPH Asia 2010
- [Example-Based Wrinkle Synthesis for Clothing Animation](#) MPEG (no audio), SIGGRAPH 2010
- [Affine Double and Triple Product Wavelet Integrals for Rendering](#) (AVI 16M), TOG 2009 (presented at SIGGRAPH 2009)
- [Moving Gradients: A Path-Based Method for Plausible Image Interpolation](#) (QT 55M), SIGGRAPH 2009
- [Interactive BRDF Editing with Global Illumination](#) (AVI 7M), TOG 2008 (presented at SIGGRAPH 2008)
- [Light Field Transfer: Global Illumination Between Real and Synthetic Scenes](#) (MOV 55M), SIGGRAPH 2008
- [Frequency Domain Normal Map Filtering](#) (AVI 103M), SIGGRAPH 2007 [Very Cool Trailer](#) (MOV 54M), Fast Forward
- [Inverse Shade Trees for Non-Parametric Material Representation and Editing](#) (AVI 21M), SIGGRAPH 2006
- [Time-Varying Surface Appearance: Acquisition, Modeling and Rendering](#) (QT 64M), SIGGRAPH 2006
- [Real-Time BRDF Editing in Complex Lighting](#) (AVI 62M), SIGGRAPH 2006
- [Reflectance Sharing: Image-Based Rendering from a Sparse Set of Images](#) (QT 83M), PAMI 2006
- [A Practical Analytic Single Scattering Model for Real Time Rendering](#) (MPEG4 74M), SIGGRAPH 2005
- [Triple Product Wavelet Integrals for All-Frequency Relighting](#) (AVI 17M), SIGGRAPH 2004
- [All-Frequency Shadows Using Non-Linear Wavelet Lighting Approximation](#) (AVI 42M), SIGGRAPH 2003
- [Structured Importance Sampling of Environment Maps](#) (AVI 19M), SIGGRAPH 2003
- [An Efficient Representation for Irradiance Environment Maps](#) (Streaming Real-Player), SIGGRAPH 2001

Publications



Connecting Measured BRDFs to Analytic BRDFs by Data-Driven Diffuse-Specular Separation *SIGGRAPH Asia 2018*

We propose a novel framework for connecting measured and analytic BRDFs, by separating a measured BRDF into diffuse and specular components. This enables measured BRDF editing, a compact measured BRDF model, and insights in relating measured and analytic BRDFs. We also design a robust analytic fitting algorithm for two-lobe materials.

Paper: [PDF](#) Supplementary: [PDF](#)



Learning to Reconstruct Shape and Spatially-Varying Reflectance from a Single Image *SIGGRAPH Asia 2018*

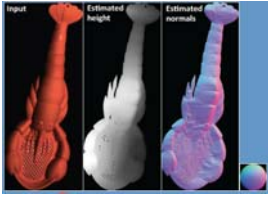
We demonstrate that we can recover non-Lambertian, spatially-varying BRDFs and complex

geometry belonging to any arbitrary shape class, from a single RGB image captured under a combination of unknown environment illumination and flash lighting. We achieve this by training a deep neural network to regress shape and reflectance from the image. We incorporate an in-network rendering layer that includes global illumination.

Paper: [PDF](#) Video: [MOV](#) Supplementary: [PDF](#)

Height-from-Polarisation with Unknown Lighting or Albedo *PAMI Aug 2018*

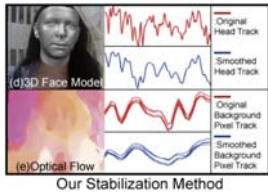
We present a method for estimating surface height directly from a single polarisation image simply by solving a large, sparse system of linear equations. Our method is applicable to dielectric objects exhibiting diffuse and specular reflectance, though lighting and albedo must be known. We relax this requirement by showing that either spatially varying albedo or illumination can be estimated from the polarisation image alone using nonlinear methods. We believe that our method is the first passive, monocular shape-from-x technique that enables well-posed height estimation with only a single, uncalibrated illumination condition.



Paper: [PDF](#)

Selfie Video Stabilization *ECCV 2018*

We propose a novel algorithm for stabilizing selfie videos. Our goal is to automatically generate stabilized video that has optimal smooth motion in the sense of both foreground and background. The key insight is that non-rigid foreground motion in selfie videos can be analyzed using a 3D face model, and background motion can be analyzed using optical flow.



Paper: [PDF](#) Video: [MP4](#)

Rendering Specular Microgeometry with Wave Optics *SIGGRAPH 2018*

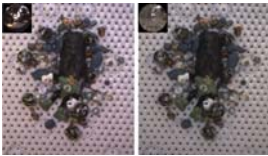
We design the first rendering algorithm based on a wave optics model, but also able to compute spatially-varying specular highlights with high-resolution detail. We compute a wave optics reflection integral over the coherence area; our solution is based on approximating the phase-delay grating representation of a micron-resolution surface heightfield using Gabor kernels. Our results show both single-wavelength and spectral solution to reflection from common everyday objects, such as brushed, scratched and bumpy metals.



Paper: [PDF](#) Video: [MP4](#) Supplementary: [Supplementary](#)

Deep Image-Based Relighting from Optimal Sparse Samples *SIGGRAPH 2018*

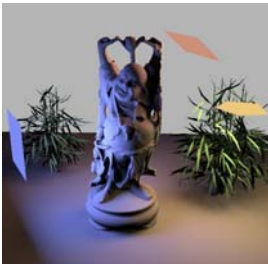
We present an image-based relighting method that can synthesize scene appearance under novel, distant illumination from the visible hemisphere, from only five images captured under pre-defined directional lights. We show that by combining a custom-designed sampling network with the relighting network, we can jointly learn both the optimal input light directions and the relighting function.



Paper: [PDF](#) Video: [MOV](#) Project: [Code, Data](#)

Analytic Spherical Harmonic Coefficients for Polygonal Area Lights *SIGGRAPH 2018*

We present an efficient closed-form solution for projection of uniform polygonal area lights to spherical harmonic coefficients of arbitrary order, enabling easy adoption of accurate area lighting in PRT systems, with no modifications required to the core PRT framework. Our method only requires computing zonal harmonic (ZH) coefficients, for which we introduce a novel recurrence relation.



Paper: [PDF](#) Video: [MOV](#) Project: [Code, Data](#)

Deep Adaptive Sampling for Low Sample Count Rendering *EGSR 2018*

Recently, deep learning approaches have proven successful at removing noise from Monte Carlo (MC) rendered images at extremely low sampling rates, e.g., 1-4 samples per pixel (spp). While these methods provide dramatic speedups, they operate on uniformly sampled MC rendered images. We address this issue by proposing a deep learning approach for joint adaptive sampling and reconstruction of MC rendered images with extremely low sample counts.



Paper: [PDF](#)

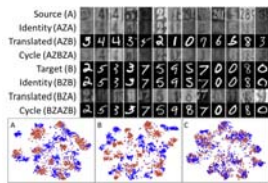
Deep Hybrid Real and Synthetic Training for Intrinsic Decomposition *EGSR 2018*

Intrinsic image decomposition is the process of separating the reflectance and shading layers of an image. In this paper, we propose to systematically address this problem using a deep convolutional neural network (CNN). In addition to directly supervising the network using synthetic images, we train the network by enforcing it to produce the same reflectance for a pair of images of the same real-world scene with different illuminations. Furthermore, we improve the results by incorporating a bilateral solver layer into our system during both training and test stages.



Paper: [PDF](#)

Image to Image Translation for Domain Adaptation *CVPR 2018*



We propose a general framework for unsupervised domain adaptation, which allows deep neural networks trained on a source domain to be tested on a different target domain without requiring any training annotations in the target domain. We apply our method for domain adaptation between MNIST, USPS, and SVHN datasets, and Amazon, Webcam and DSLR Office datasets in classification tasks, and also between GTA5 and Cityscapes datasets for a segmentation task. We demonstrate state of the art performance on each of these datasets.

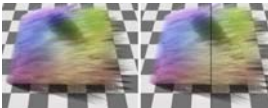
Paper: [PDF](#)



[Learning to See through Turbulent Water](#) *WACV 2018*

This paper proposes training a deep convolution neural network to undistort dynamic refractive effects using only a single image. Unlike prior works on water undistortion, our method is trained end-to-end, only requires a single image and does not use a ground truth template at test time.

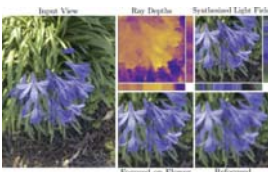
Paper: [PDF](#) Project: [Code/Data](#)



[A BSSRDF Model for Efficient Rendering of Fur with Global Illumination](#) *SIGGRAPH Asia 2017*

We present the first global illumination model, based on dipole diffusion for subsurface scattering, to approximate light bouncing between individual fur fibers. We model complex light and fur interactions as subsurface scattering, and use a simple neural network to convert from fur fibers' properties to scattering parameters.

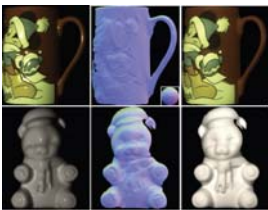
Paper: [PDF](#) Video: [QI](#)



[Learning to Synthesize a 4D RGBD Light Field from a Single Image](#) *ICCV 2017*

We present a machine learning algorithm that takes as input a 2D RGB image and synthesizes a 4D RGBD light field (color and depth of the scene in each ray direction). For training, we introduce the largest public light field dataset, consisting of over 3300 plenoptic camera light fields of scenes containing flowers and plants.

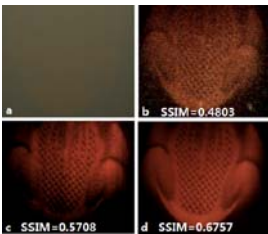
Paper: [PDF](#) Video: [MPEG](#) Supplementary: [PDF](#)



[Linear Differential Constraints for Photo-polarimetric Height Estimation](#) *ICCV 2017*

In this paper we present a differential approach to photo-polarimetric shape estimation. We propose several alternative differential constraints based on polarisation and photometric shading information and show how to express them in a unified partial differential system. Our method uses the image ratios technique to combine shading and polarisation information in order to directly reconstruct surface height, without first computing surface normal vectors.

Paper: [PDF](#)



[Depth and Image Restoration from Light Field in a Scattering Medium](#) *ICCV 2017*

Traditional imaging methods and computer vision algorithms are often ineffective when images are acquired in scattering media, such as underwater, fog, and biological tissue. Here, we explore the use of light field imaging and algorithms for image restoration and depth estimation that address the image degradation from the medium. We propose shearing and refocusing multiple views of the light field to recover a single image of higher quality than what is possible from a single view. We demonstrate the benefits of our method through extensive experimental results in a water tank.

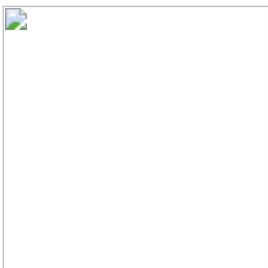
Paper: [PDF](#)



[An Efficient and Practical Near and Far Field Fur Reflectance Model](#) *SIGGRAPH 2017*

We derive a compact BCSDf model for fur reflectance with only 5 lobes. Our model unifies hair and fur rendering, making it easy to implement within standard hair rendering software. By exploiting piecewise analytic integration, our method further enables a multi-scale rendering scheme that transitions between near and far-field rendering smoothly and efficiently for the first time.

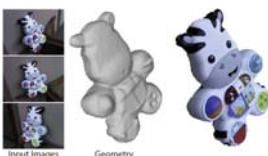
Paper: [PDF](#) Video: [QI](#) Papers Trailer: [Video](#)



[Light Field Video Capture Using a Learning-Based Hybrid Imaging System](#) *SIGGRAPH 2017*

We develop a hybrid imaging system, adding a standard video camera to a light field camera to capture the temporal information. Given a 3 fps light field sequence and a standard 30 fps 2D video, our system can then generate a full light field video at 30 fps. We adopt a learning-based approach, which can be decomposed into two steps: spatio-temporal flow estimation and appearance estimation, enabling consumer light field videography.

Paper: [PDF](#) Video: [MPEG](#) Code/Data: [Project](#)



[Patch-Based Optimization for Image-Based Texture Mapping](#) *SIGGRAPH 2017*

Image-based texture mapping is a common way of producing texture maps for geometric models of real-world objects. We propose a novel global patch-based optimization system to synthesize the aligned images. Specifically, we use patch-based synthesis to reconstruct a set of photometrically-consistent aligned images by drawing information from the source images. Our optimization system is simple, flexible, and more suitable for correcting large misalignments than other techniques such as local warping.

Paper: [PDF](#) Video: [MPEG](#) Supplementary: [PDF](#)

[Deep High Dynamic Range Imaging of Dynamic Scenes](#) *SIGGRAPH 2017*



Producing a high dynamic range (HDR) image from a set of images with different exposures is a challenging process for dynamic scenes. We use a convolutional neural network (CNN) as our learning model and present and compare three different system architectures to model the HDR merge process. Furthermore, we create a large dataset of input LDR images and their corresponding ground truth HDR images to train our system.

Paper: [PDF](#) Project Page: [Code/Data](#)

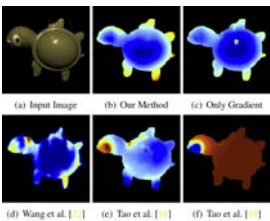
[Light Field Blind Motion Deblurring](#) *CVPR 2017*



By analyzing the motion-blurred light field in the primal and Fourier domains, we develop intuition into the effects of camera motion on the light field, show the advantages of capturing a 4D light field instead of a conventional 2D image for motion deblurring, and derive simple methods of motion deblurring in certain cases. We then present an algorithm to blindly deblur light fields of general scenes without any estimation of scene geometry.

Paper: [PDF](#)

[Robust Energy Minimization for BRDF-Invariant Shape from Light Fields](#) *CVPR 2017*



We present a variational energy minimization framework for robust recovery of shape in multiview stereo with complex, unknown BRDFs. While our formulation is general, we demonstrate its efficacy on shape recovery using a single light field image, where the microlens array may be considered as a realization of a purely translational multiview stereo setup. Our formulation automatically balances contributions from texture gradients, traditional Lambertian photoconsistency, an appropriate BRDF-invariant PDE and a smoothness prior.

Paper: [PDF](#) [Supplementary](#)

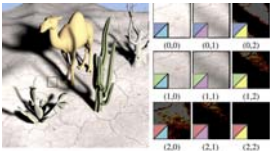
[Gradient-Domain Vertex Connection and Merging](#) *EGSR 2017*



We present gradient-domain vertex connection and merging (G-VCN), a new gradient-domain technique motivated by primal domain VCN. Our method enables robust gradient sampling in the presence of complex transport, such as specular-diffuse-specular paths, while retaining the denoising power and fast convergence of gradient-domain bidirectional path tracing.

Paper: [PDF](#)

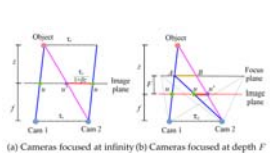
[Multiple Axis-Aligned Filters for Rendering of Combined Distribution Effects](#) *EGSR 2017*



We present a novel filter for efficient rendering of combined effects, involving soft shadows and depth of field, with global (diffuse indirect) illumination. We approximate the wedge spectrum with multiple axis-aligned filters, marrying the speed of axis-aligned filtering with an even more accurate (compact and tighter) representation than sheared filtering.

Paper: [PDF](#) Video: [AVI](#)

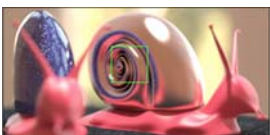
[SVBRDF-Invariant Shape and Reflectance Estimation from a Light-Field Camera](#) *PAMI 2017*



Light-field cameras have recently emerged as a powerful tool for one-shot passive 3D shape capture. However, obtaining the shape of glossy objects like metals or plastics remains challenging, since standard Lambertian cues like photo-consistency cannot be easily applied. In this paper, we derive a spatially-varying (SV)BRDF-invariant theory for recovering 3D shape and reflectance from light-field cameras.

Paper: [PDF](#)

[Antialiasing Complex Global Illumination Effects in Path-space](#) *TOG 2017*



We present the first method to efficiently predict antialiasing footprints to pre-filter color-, normal-, and displacement-mapped appearance in the context of multi-bounce global illumination. We derive Fourier spectra for radiance and importance functions that allow us to compute spatial-angular filtering footprints at path vertices.

Paper: [PDF](#)

[Learning-Based View Synthesis for Light Field Cameras](#) *SIGGRAPH Asia 2016*

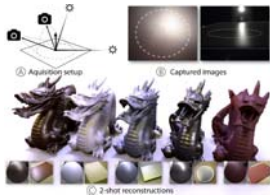


we propose a novel learning-based approach to synthesize new views from a sparse set of input views for light field cameras. We use two sequential convolutional neural networks to model these two components and train both networks simultaneously by minimizing the error between the synthesized and ground truth images.

Paper: [PDF](#) Video: [MPEG](#) Dataset: [Project Page](#)

[Minimal BRDF Sampling for Two-Shot Near-Field Reflectance Acquisition](#) *SIGGRAPH Asia 2016*

We develop a method to acquire the BRDF of a homogeneous flat sample from only two images, taken by a near-field perspective camera, and lit by a directional light source. We develop a



mathematical framework to estimate error from a given set of measurements, including the use of multiple measurements in an image simultaneously, as needed for acquisition from near-field setups.

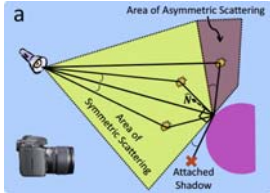
Paper: [PDF](#) Supplementary: [PDF](#) Comparison Video: [QI](#)



Downsampling Scattering Parameters for Rendering Anisotropic Media *SIGGRAPH Asia 2016*

Volumetric micro-appearance models have provided remarkably high-quality renderings, but are highly data intensive and usually require tens of gigabytes in storage. We introduce a joint optimization of single-scattering albedos and phase functions to accurately downsample heterogeneous and anisotropic media.

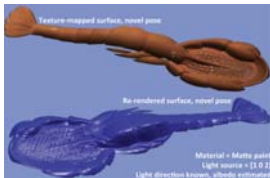
Paper: [PDF](#) Video: [MPEG](#)



Photometric Stereo in a Scattering Medium *PAMI 2016*

Photometric stereo is widely used for 3D reconstruction. However, its use in scattering media such as water, biological tissue and fog has been limited until now, because of forward scattered light from both the source and object, as well as light scattered back from the medium (backscatter). Here we make three contributions to address the key modes of light propagation, under the common single scattering assumption for dilute media.

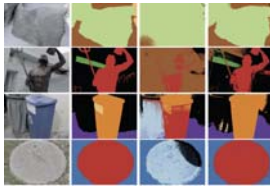
Paper: [PDF](#)



Linear Depth Estimation from an Uncalibrated, Monocular Polarisation Image *ECCV 2016*

We present a method for estimating surface height directly from a single polarisation image simply by solving a large, sparse system of linear equations. To do so, we show how to express polarisation constraints as equations that are linear in the unknown depth. Our method is applicable to objects with uniform albedo exhibiting diffuse and specular reflectance. We believe that our method is the first monocular, passive shape-from-x technique that enables well-posed depth estimation with only a single, uncalibrated illumination condition.

Paper: [PDF](#)



A 4D Light-Field Dataset and CNN Architectures for Material Recognition *ECCV 2016*

We introduce a new light-field dataset of materials, and take advantage of the recent success of deep learning to perform material recognition on the 4D light-field. Our dataset contains 12 material categories, each with 100 images taken with a Lytro Illum. Since recognition networks have not been trained on 4D images before, we propose and compare several novel CNN architectures to train on light-field images. In our experiments, the best performing CNN architecture achieves a 7% boost compared with 2D image classification.

Paper: [PDF](#) [HTML Comparison](#) [dataset \(2D thumbnail\)](#) [Full Dataset \(16GB\)](#)



Sparse Sampling for Image-Based SVBRDF Acquisition *Material Appearance Modeling Workshop, 2016*

We acquire the data-driven spatially-varying (SV)BRDF of a flat sample from only a small number of images (typically 20). We generalize the homogenous BRDF acquisition work of Nielsen et al., who derived an optimal minimal set of lighting/view directions. We demonstrate our method on SVBRDF measurements of new flat materials, showing that full data-driven SVBRDF acquisition is now possible from a sparse set of only about 20 light-view pairs.

Paper: [PDF](#)



Position-Normal Distributions for Efficient Rendering of Specular Microstructure *SIGGRAPH 2016*

Specular BRDF rendering traditionally approximates surface microstructure using a smooth normal distribution, but this ignores glinty effects, easily observable in the real world. We treat a specular surface as a four-dimensional position-normal distribution, and fit this distribution using millions of 4D Gaussians, which we call elements. This leads to closed-form solutions to the required BRDF evaluation and sampling queries, enabling the first practical solution to rendering specular microstructure.

Paper: [PDF](#) Video: [MP4](#) Press: [UCSD](#) [PhysOrg](#) [Digital Trends](#) [Eureka Alert](#) [Tech Crunch](#)



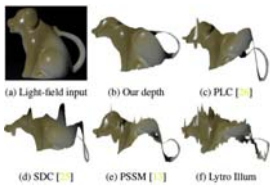
Shape Estimation from Shading, Defocus, and Correspondence Using Light-Field Angular Coherence *PAMI 2016*

We show that combining all three sources of information: defocus, correspondence, and shading, outperforms state-of-the-art light-field depth estimation algorithms in multiple scenarios.

Paper: [PDF](#)

SVBRDF-Invariant Shape and Reflectance Estimation from Light-Field Cameras *CVPR 2016*

Light-field cameras have recently emerged as a powerful tool for one-shot passive 3D shape capture. However, obtaining the shape of glossy objects like metals, plastics or ceramics remains



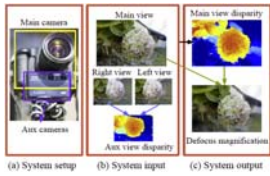
challenging, since standard Lambertian cues like photo-consistency cannot be easily applied. In this paper, we derive a spatially-varying (SV)BRDF-invariant theory for recovering 3D shape and reflectance from light-field cameras.

Paper: [PDF](#)

Depth from Semi-Calibrated Stereo and Defocus *CVPR 2016*

In this work, we propose a multi-camera system where we combine a main high-quality camera with two low-res auxiliary cameras. Our goal is, given the low-res depth map from the auxiliary cameras, generate a depth map from the viewpoint of the main camera. Ours is a semi-calibrated system, where the auxiliary stereo cameras are calibrated, but the main camera has an interchangeable lens, and is not calibrated beforehand.

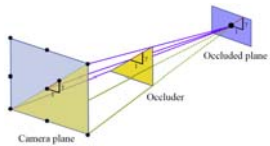
Paper: [PDF](#)



Depth Estimation with Occlusion Modeling Using Light-field Cameras *PAMI 2016*

In this paper, an occlusion-aware depth estimation algorithm is developed; the method also enables identification of occlusion edges, which may be useful in other applications. It can be shown that although photo-consistency is not preserved for pixels at occlusions, it still holds in approximately half the viewpoints. Moreover, the line separating the two view regions (occluded object vs. occluder) has the same orientation as that of the occlusion edge in the spatial domain. By ensuring photo-consistency in only the occluded view region, depth estimation can be improved.

Paper: [PDF](#)



Fast 4D Sheared Filtering for Interactive Rendering of Distribution Effects *ACM Trans. Graphics Dec 2015*

We present a new approach for fast sheared filtering on the GPU. Our algorithm factors the 4D sheared filter into four 1D filters. We derive complexity bounds for our method, showing that the per-pixel complexity is reduced from $O(n^2 l^2)$ to $O(nl)$, where n is the linear filter width (filter size is $O(n^2)$) and l is the (usually very small) number of samples for each dimension of the light or lens per pixel (spp is 12). We thus reduce sheared filtering overhead dramatically.

Paper: [PDF](#) Video: [MPEG](#)



Physically-Accurate Fur Reflectance: Modeling, Measurement and Rendering *SIGGRAPH Asia 2015*

In this paper, we develop a physically-accurate reflectance model for fur fibers. Based on anatomical literature and measurements, we develop a double cylinder model for the reflectance of a single fur fiber, where an outer cylinder represents the biological observation of a cortex covered by multiple cuticle layers, and an inner cylinder represents the scattering interior structure known as the medulla.

Paper: [PDF](#) [MS thesis](#) of Chiwei Tseng [Data](#)



Anisotropic Gaussian Mutations for Metropolis Light Transport through Hessian-Hamiltonian Dynamics *SIGGRAPH Asia 2015*

We present a Markov Chain Monte Carlo (MCMC) rendering algorithm that extends Metropolis Light Transport by automatically and explicitly adapting to the local shape of the integrand, thereby increasing the acceptance rate. Our algorithm characterizes the local behavior of throughput in path space using its gradient as well as its Hessian. In particular, the Hessian is able to capture the strong anisotropy of the integrand.

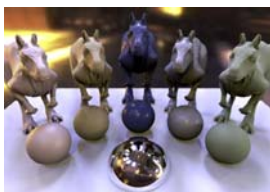
Paper: [PDF](#)



On Optimal, Minimal BRDF Sampling for Reflectance Acquisition *SIGGRAPH Asia 2015*

In this paper, we address the problem of reconstructing a measured BRDF from a limited number of samples. We present a novel mapping of the BRDF space, allowing for extraction of descriptive principal components from measured databases, such as the MERL BRDF database. We optimize for the best sampling directions, and explicitly provide the optimal set of incident and outgoing directions in the Rusinkiewicz parameterization for $n = 1; 2; 5; 10; 20$ samples. Based on the principal components, we describe a method for accurately reconstructing BRDF data from these limited sets of samples.

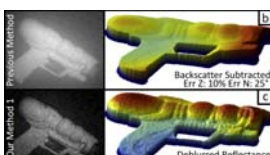
Paper: [PDF](#)

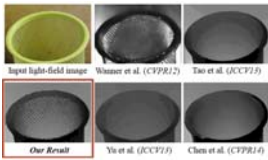


Photometric Stereo in a Scattering Medium *ICCV 2015*

Photometric stereo is widely used for 3D reconstruction. However, its use in scattering media such as water, biological tissue and fog has been limited until now, because of forward scattered light from both the source and object, as well as light scattered back from the medium (backscatter). Here we make three contributions to address the key modes of light propagation, under the common single scattering assumption for dilute media.

Paper: [PDF](#)

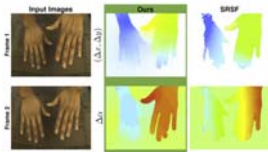




Occlusion-aware Depth Estimation Using Light-field Cameras *ICCV 2015*

In this paper, we develop a depth estimation algorithm for light field cameras that treats occlusion explicitly; the method also enables identification of occlusion edges, which may be useful in other applications. We show that, although pixels at occlusions do not preserve photo-consistency in general, they are still consistent in approximately half the viewpoints.

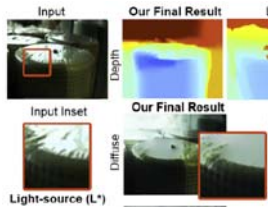
Paper: [PDF](#)



Oriented Light-Field Windows for Scene Flow *ICCV 2015*

For Lambertian surfaces focused to the correct depth, the 2D distribution of angular rays from a pixel remains consistent. We build on this idea to develop an oriented 4D light-field window that accounts for shearing(depth), translation (matching), and windowing. Our main application is to scene flow, a generalization of optical flow to the 3D vector field describing the motion of each point in the scene.

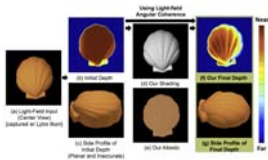
Paper: [PDF](#)



Depth Estimation and Specular Removal for Glossy Surfaces Using Point and Line Consistency with Light-Field Cameras *PAMI 2015 (to appear)*

Light-field cameras have now become available in both consumer and industrial applications, and recent papers have demonstrated practical algorithms for depth recovery from a passive single-shot capture. However, current light-field depth estimation methods are designed for Lambertian objects and fail or degrade for glossy or specular surfaces. In this paper, we present a novel theory of the relationship between light-field data and reflectance from the dichromatic model.

Paper: [PDF](#)



Depth from Shading, Defocus, and Correspondence Using Light-Field Angular Coherence *CVPR 2015*

Using shading information is essential to improve shape estimation from light field cameras. We develop an improved technique for local shape estimation from defocus and correspondence cues, and show how shading can be used to further refine the depth. We show that the angular pixels have angular coherence, which exhibits three properties: photoconsistency, depth consistency, and shading consistency.

Paper: [PDF](#)



Probabilistic Connections for Bidirectional Path Tracing *Computer Graphics Forum (EGSR) 2015*

Bidirectional path tracing (BDPT) with Multiple Importance Sampling is one of the most versatile unbiased rendering algorithms today. BDPT repeatedly generates sub-paths from the eye and the lights, which are connected for each pixel and then discarded. Unfortunately, many such bidirectional connections turn out to have low contribution to the solution. Our key observation is that we can importance sample connections to an eye sub-path by considering multiple light sub-paths at once and creating connections probabilistically.

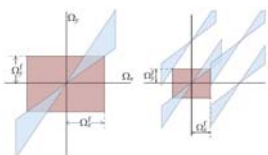
Paper: [PDF](#)



Filtering Environment Illumination for Interactive Physically-Based Rendering in Mixed Reality *EGSR 2015*

We propose accurate filtering of a noisy Monte-Carlo image using Fourier analysis. Our novel analysis extends previous works by showing that the shape of illumination spectra is not always a line or wedge, as in previous approximations, but rather an ellipsoid. Our primary contribution is an axis-aligned filtering scheme that preserves the frequency content of the illumination. We also propose a novel application of our technique to mixed reality scenes, in which virtual objects are inserted into a real video stream so as to become indistinguishable from the real objects.

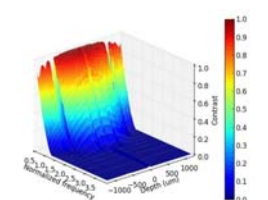
Paper: [PDF](#) Video: [MP4](#) Supplementary: [PDF](#)



Recent Advances in Adaptive Sampling and Reconstruction for Monte Carlo Rendering *EUROGRAPHICS 2015*

In this paper we survey recent advances in adaptive sampling and reconstruction. We distinguish between *a priori* methods that analyze the light transport equations and derive sampling rates and reconstruction filters from this analysis, and *a posteriori* methods that apply statistical techniques to sets of samples.

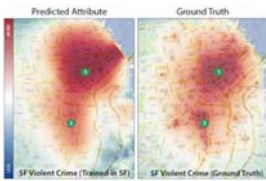
Paper: [PDF](#)



A Light Transport Framework for Lenslet Light Field Cameras *ACM Transactions on Graphics (Apr 2015)*

It is often stated that there is a fundamental tradeoff between spatial and angular resolution of lenslet light field cameras, but there has been limited understanding of this tradeoff theoretically or numerically. In this paper, we develop a light transport framework for understanding the fundamental limits of light field camera resolution.

Paper: [PDF](#) Supplementary Images: [PDF](#)



City Forensics: Using Visual Elements to Predict Non-Visual City Attributes *IEEE TVCG [SciVis 2014]. Honorable Mention for Best Paper Award*

We present a method for automatically identifying and validating predictive relationships between the visual appearance of a city and its non-visual attributes (e.g. crime statistics, housing prices, population density etc.). We also test human performance for predicting theft based on street-level images and show that our predictor outperforms this baseline with 33% higher accuracy on average.

Paper: [PDF](#)



High-Order Similarity Relations in Radiative Transfer *SIGGRAPH 2014.*

Radiative transfer equations (RTEs) with different scattering parameters can lead to identical solution radiance fields. Similarity theory studies this effect by introducing a hierarchy of equivalence relations called similarity relations. Unfortunately, given a set of scattering parameters, it remains unclear how to find altered ones satisfying these relations, significantly limiting the theory's practical value. This paper presents a complete exposition of similarity theory, which provides fundamental insights into the structure of the RTE's parameter space. To utilize the theory in its general high-order form, we introduce a new approach to solve for the altered parameters including the absorption and scattering coefficients as well as a fully tabulated phase function.

Paper: [PDF](#) [Video \(MPEG\)](#)



Rendering Glints on High-Resolution Normal-Mapped Specular Surfaces *SIGGRAPH 2014.*

Complex specular surfaces under sharp point lighting show a fascinating glinty appearance, but rendering it is an unsolved problem. Using Monte Carlo pixel sampling for this purpose is impractical: the energy is concentrated in tiny highlights that take up a minuscule fraction of the pixel. We instead compute an accurate solution using a completely different deterministic approach.

Paper: [PDF](#) [Video \(MPEG\)](#)



Factored Axis-Aligned Filtering for Rendering Multiple Distribution Effects *SIGGRAPH 2014.*

We propose an approach to adaptively sample and filter for simultaneously rendering primary (defocus blur) and secondary (soft shadows and indirect illumination) distribution effects, based on a multi-dimensional frequency analysis of the direct and indirect illumination light fields, and factoring texture and irradiance.

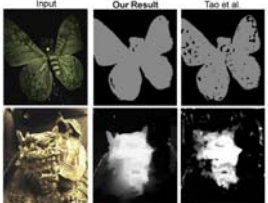
Paper: [PDF](#) [Video \(MPEG\)](#)



Discrete Stochastic Microfacet Models *SIGGRAPH 2014.*

This paper investigates rendering glittery surfaces, ones which exhibit shifting random patterns of glints as the surface or view moves. It applies both to dramatically glittery surfaces that contain mirror-like flakes and also to rough surfaces that exhibit more subtle small scale glitter, without which most glossy surfaces appear too smooth in close-up. In this paper we present a stochastic model for the effects of random subpixel structures that generates glitter and spatial noise that behave correctly under different illumination conditions and viewing distances, while also being temporally coherent so that they look right in motion.

Paper: [PDF](#) [Video \(MPEG\)](#)



Depth Estimation for Glossy Surfaces with Light-Field Cameras *ECCV 14 Workshop Light Fields Computer Vision.*

Light-field cameras have now become available in both consumer and industrial applications, and recent papers have demonstrated practical algorithms for depth recovery from a passive single-shot capture. In this paper, we develop an iterative approach to use the benefits of light-field data to estimate and remove the specular component, improving the depth estimation. The approach enables light-field data depth estimation to support both specular and diffuse scenes.

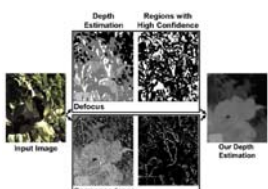
Paper: [PDF](#)



User-Assisted Video Stabilization *EGSR 2014.*

We present a user-assisted video stabilization algorithm that is able to stabilize challenging videos. First, we cluster tracks and visualize them on the warped video. The user ensures that appropriate tracks are selected by clicking on track clusters to include or exclude them. Second, the user can directly specify how regions in the output video should look by drawing quadrilaterals to select and deform parts of the frame.

Paper: [PDF](#) [Video \(MPEG\)](#)



Depth from Combining Defocus and Correspondence Using Light-Field Cameras *ICCV 2013.*

Light-field cameras have recently become available to the consumer market. An array of micro-lenses captures enough information that one can refocus images after acquisition, as well as shift one's viewpoint within the sub-apertures of the main lens, effectively obtaining multiple views. Thus, depth cues from both defocus and correspondence are available simultaneously in a single capture, and we show how to exploit both by analyzing the EPI.

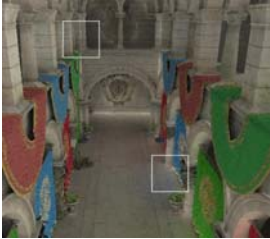
Paper: [PDF](#) [Video \(MPEG\)](#)



External mask based depth and light field camera *ICCV 13 Workshop Consumer Depth Cameras for Vision*.

We present a method to convert a digital single-lens reflex (DSLR) camera into a high-resolution consumer depth and light-field camera by affixing an external aperture mask to the main lens. Compared to the existing consumer depth and light field cameras, our camera is easy to construct with minimal additional costs, and our design is camera and lens agnostic. The main advantage of our design is the ease of switching between an SLR camera and a native resolution depth/light field camera. We also do not need to modify the internals of the camera or the lens.

Paper: [PDF](#) [Video \(MPEG\)](#).



Axis-Aligned Filtering for Interactive Physically-Based Diffuse Indirect Lighting *SIGGRAPH 2013*.

We introduce an algorithm for interactive rendering of physically-based global illumination, based on a novel frequency analysis of indirect lighting. Our method combines adaptive sampling by Monte Carlo ray or path tracing, using a standard GPU-accelerated raytracer, with real-time reconstruction of the resulting noisy images.

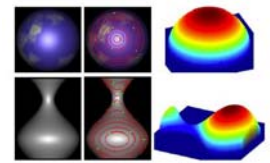
Paper: [PDF](#) [Video \(MPEG\)](#).



Modular Flux Transfer: Efficient Rendering of High-Resolution Volumes with Repeated Structures *SIGGRAPH 2013*.

Common volumetric materials (fabrics, finished wood, synthesized solid textures) are structured, with repeated patterns approximated by tiling a small number of exemplar blocks. In this paper, we introduce a precomputation-based rendering approach for such volumetric media with repeated structures based on a modular transfer formulation. We model each exemplar block as a voxel grid and precompute voxel-to-voxel, patch-to-patch, and patch-to-voxel flux transfer matrices.

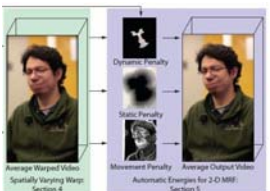
Paper: [PDF](#) [Video \(MPEG\)](#).



What Object Motion Reveals About Shape with Unknown BRDF and Lighting *CVPR 2013*.

We present a theory that addresses the problem of determining shape from the (small or differential) motion of an object with unknown isotropic reflectance, under arbitrary unknown distant illumination, for both orthographic and perspective projection. Our theory imposes fundamental limits on the hardness of surface reconstruction, independent of the method involved. Under orthographic projection, we prove that three differential motions suffice to yield an invariant that relates shape to image derivatives, regardless of BRDF and illumination. Under perspective projection, we show that four differential motions suffice to yield depth and a linear constraint on the surface gradient.

Paper: [PDF](#).



Automatic Cinemagraph Portraits *EGSR 2013*.

Cinemagraphs are a popular new type of visual media that lie in-between photos and video; some parts of the frame are animated and loop seamlessly, while other parts of the frame remain completely still. Cinemagraphs are especially effective for portraits because they capture the nuances of our dynamic facial expressions. We present a completely automatic algorithm for generating portrait cinemagraphs from a short video captured with a hand-held camera.

Paper: [PDF](#) [Video \(MPEG\)](#).



Interactive Albedo Editing in Path-Traced Volumetric Materials *TOG 2013 (April Cover Image)*.

In this paper, we develop an editing algorithm that enables a material designer to set the local (single-scattering) albedo coefficients interactively, and see an immediate update of the emergent appearance in the image. We also extend the technique to editing the overall mean free path of the material. This is a difficult problem, since the function from materials to pixel values is neither linear nor low-order polynomial.

Paper: [PDF](#) [Video \(MPEG\)](#).



Gloss Perception in Painterly and Cartoon Rendering *TOG 2013*.

We describe the first study of material perception in stylized images (specifically painting and cartoon) and use non-photorealistic rendering algorithms to evaluate how such stylization alters the perception of gloss. This mapping allows users of NPR algorithms to predict, and correct for, the perception of gloss in their images.

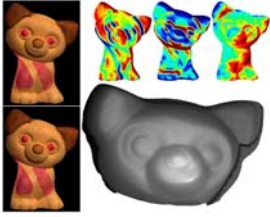
Paper: [PDF](#).



Sharpening Out of Focus Images using High-Frequency Transfer *EuroGraphics 2013*.

We propose a new method to sharpen out-of-focus images, that uses a similar but different assisting sharp image provided by the user (such as multiple images of the same subject in different positions captured using a burst of photographs). We demonstrate sharpened results on out-of-focus images in macro, sports, portrait and wildlife photography.

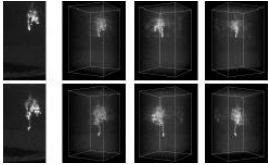
Paper: [PDF](#) [Video \(MPEG\)](#) [Supplementary HTML](#)



[On Differential Photometric Reconstruction for Unknown, Isotropic BRDFs](#) *PAMI 2013.*

This paper presents a comprehensive theory of photometric surface reconstruction from image derivatives, in the presence of a general, unknown isotropic BRDF. We derive precise topological classes up to which the surface may be determined and specify exact priors for a full geometric reconstruction, for both shape from shading and photometric stereo.

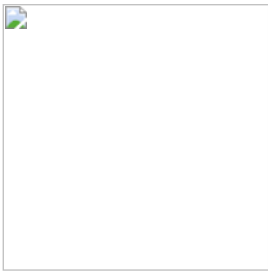
Paper: [PDF](#)



[Compressive Structured Light for Recovering Inhomogeneous Participating Media](#) *PAMI 2013.*

We propose a new method named compressive structured light for recovering inhomogeneous participating media. Whereas conventional structured light methods emit coded light patterns onto the surface of an opaque object to establish correspondence for triangulation, compressive structured light projects patterns into a volume of participating medium to produce images which are integral measurements of the volume density along the line of sight.

Paper: [PDF](#)



[Axis-Aligned Filtering for Interactive Sampled Soft Shadows](#) *Siggraph Asia 2012.*

We develop a simple and efficient method for soft shadows from planar area light sources, based on explicit occlusion calculation by raytracing, followed by adaptive image-space filtering. Since the method is based on Monte Carlo sampling, it is accurate. Since the filtering is in image-space, it adds minimal overhead and can be performed at real-time frame rates. We obtain interactive speeds, using the Optix GPU raytracing framework. Our technical approach derives from recent work on frequency analysis and sheared pixel-light filtering for offline soft shadows. While sample counts can be reduced dramatically, the sheared filtering step is slow, adding minutes of overhead. We develop the theoretical analysis to instead consider axis-aligned filtering, deriving the sampling rates and filter sizes.

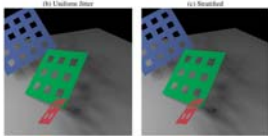
Paper: [PDF](#) [Video \(MPEG\)](#) [Source Code](#)



[Frequency-Space Decomposition and Acquisition of Light Transport under Spatially Varying Illumination](#) *ECCV 2012.*

We show that, under spatially varying illumination, the light transport of diffuse scenes can be decomposed into direct, near-range (subsurface scattering and local inter-reflections) and far range transports (diffuse inter-reflections). We show that these three component transports are redundant either in the spatial or the frequency domain and can be separated using appropriate illumination patterns, achieving a theoretical lower bound.

Paper: [PDF](#)



[A Theory of Monte Carlo Visibility Sampling](#) *ACM TOG Aug 2012.*

We develop a comprehensive theoretical analysis of different sampling patterns for Monte Carlo visibility. In particular, we show the benefits of uniform jitter sampling over stratified in some cases, and demonstrate that it produces the lowest variance for linear lights. Surprisingly, the best pattern depends on the shape of the light source for area lights, with uniform jitter preferred for circular lights and stratified for square lights.

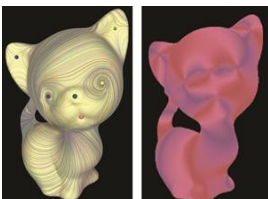
Paper: [PDF](#) Video: [MPEG4](#) Talk: [PPT](#)



[Selectively De-Animating Video](#) *SIGGRAPH 2012.*

We present a semi-automated technique for selectively de-animating video to remove the large-scale motions of one or more objects so that other motions are easier to see. Our technique enables a number of applications such as clearer motion visualization, simpler creation of artistic cinemagraphs (photos that include looping motions in some regions), and new ways to edit appearance and complicated motion paths in video by manipulating a de-animated representation.

Paper: [PDF](#) Video: [MPEG4](#) Teaser Video: [MPEG4](#)



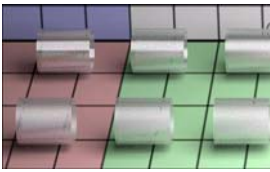
[Analytic Tangent Irradiance Environment Maps for Anisotropic Surfaces](#) *EGSR 2012.*

We extend spherical harmonic irradiance maps to anisotropic surfaces, replacing Lambertian reflectance with the diffuse term of the popular Kajiya-Kay model. We show that the terms decay even more rapidly than for Lambertian reflectance. Existing code for irradiance environment maps can be trivially adapted for real-time rendering with tangent irradiance maps. We also demonstrate an application to offline rendering of the diffuse component of fibers, using our formula as a control variate for Monte Carlo sampling.

Paper: [PDF](#)

[Importance Sampling of Reflection from Hair Fibers](#) *JCGT 2012 (Inaugural Article).*

Hair and fur are increasingly important visual features in production rendering, and physically-



based light scattering models are now commonly used. In this paper, we enable efficient Monte Carlo rendering of specular reflections from hair fibers. We describe a simple and practical importance sampling strategy for the reflection term in the Marschner hair model. Our method has been widely used in production for more than a year, and complete pseudocode is provided.

Paper: [PDF](#)

[Real-Time Rendering of Rough Refraction](#) *IEEE TVCG Feb 2012.*



We present an algorithm to render objects made of transparent materials with rough surfaces in real-time, under distant illumination. Rough surfaces cause wide scattering as light enters and exits objects, which significantly complicates the rendering of such materials. We approximate the Bidirectional Transmittance Distribution Function (BTDF), using spherical Gaussians. We also propose two extensions, to support spatially-varying roughness and local lighting on thin objects.

Paper: [PDF](#) [Youtube Video](#) (from I3D 2011)

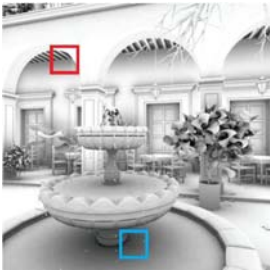
[From the Rendering Equation to Stratified Light Transport Inversion](#) *International Journal of Computer Vision, 2012*



In this work, we explore a theoretical analysis of inverse light transport, relating it to its forward counterpart, expressed in the form of the rendering equation. We show the existence of an inverse Neumann series, that zeroes out the corresponding physical bounces of light, which we refer to as stratified light transport inversion. Our practical application is to radiometric compensation, where we seek to project patterns onto real-world surfaces, undoing the effects of global illumination.

Paper: [PDF](#)

[Practical Filtering for Efficient Ray-Traced Directional Occlusion](#) *SIGGRAPH Asia 2011*



Ambient occlusion and directional (spherical harmonic) occlusion have become a staple of production rendering, but are expensive to compute. We give a frequency analysis of shadow light fields using distant illumination with a general BRDF and normal mapping, allowing us to share ray information even among complex receivers. We also present a new rotationally-invariant filter that easily handles samples spread over a large angular domain. Our method can deliver 4x speed up for scenes that are computationally bound by ray tracing costs.

Paper: [PDF](#) Supplementary Animations [AVI](#)

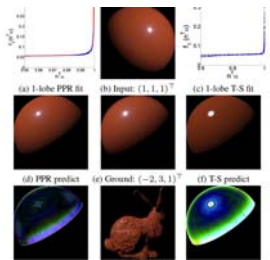
[Sparse Reconstruction of Visual Appearance for Computer Graphics and Vision](#) *SPIE Keynote, Wavelets and Sparsity XIV 2011*



A broad range of problems in computer graphics rendering, appearance acquisition for graphics and vision, and imaging, involve sampling, reconstruction, and integration of high-dimensional (4D-8D) signals. We argue that dramatically sparser sampling and reconstruction of these signals is possible, before the full dataset is acquired or simulated. Our key idea is to exploit the structure of the data that often lies in lower-frequency, sparse, or low-dimensional spaces.

Paper: [PDF](#)

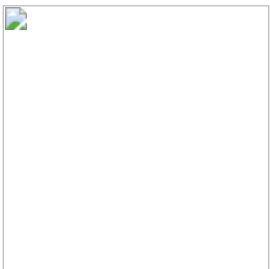
[What an Image Reveals About Material Reflectance](#) *ICCV 2011*



We derive precise conditions under which material reflectance properties may be estimated from a single image of a homogeneous curved surface (canonically a sphere), lit by a directional source. Based on the observation that light is reflected along certain (a priori unknown) preferred directions such as the half-angle, we propose a semiparametric BRDF abstraction that lies between purely parametric and purely data-driven models. While it is well-known that fitting multi-lobe BRDFs may be ill-posed under certain conditions, prior to this work, precise results for the well-posedness of BRDF estimation had remained elusive.

Paper: [PDF](#)

[On the Duality of Forward and Inverse Light Transport](#) *PAMI 2011, ECCV 2010*



Inverse light transport seeks to undo global illumination effects, such as interreflections, that pervade images of most scenes. This paper presents the theoretical and computational foundations for inverse light transport as a dual of forward rendering. We demonstrate two practical applications, namely, separation of individual bounces of the light transport and fast projector radiometric compensation to display images free of global illumination artifacts in real-world environments.

Paper: [PAMI](#) [ECCV](#) [Tech Report](#) [Video](#)

[Data-Driven Elastic Models for Cloth: Modeling and Measurement](#) *SIGGRAPH 2011*

Cloth often has complicated nonlinear, anisotropic elastic behavior due to its woven pattern and fiber properties. However, most current cloth simulation techniques simply use linear and isotropic elastic models with manually selected stiffness parameters. Such simple simulations do not allow differentiating the behavior of distinct cloth materials such as silk or denim, and they cannot model most materials with fidelity to their real-world counterparts. In this paper, we present a data-driven technique to more realistically animate cloth. These measurements can be used in most cloth simulation systems to create natural and realistic clothing wrinkles and shapes, for a range of



different materials.

Paper: [PDF](#) [Video](#)

[Illumination Decomposition for Material Recoloring with Consistent Interreflections](#) *SIGGRAPH 2011*



Changing the color of an object is a basic image editing operation, but a high quality result must also preserve natural shading. A common approach is to first compute reflectance and illumination intrinsic images. Reflectances can then be edited independently, and recomposed with the illumination. However, manipulating only the reflectance color does not account for diffuse interreflections, and can result in inconsistent shading in the edited image. We propose an approach for further decomposing illumination into direct lighting, and indirect diffuse illumination from each material.

Paper: [PDF](#)

[Frequency Analysis and Sheared Filtering for Shadow Light Fields of Complex Occluders](#) *TOG 2011*



Monte Carlo ray tracing of soft shadows produced by area lighting and intricate geometries, such as the shadows through plant leaves or arrays of blockers, is a critical challenge. This article develops an efficient diffuse soft shadow technique for mid to far occluders that relies on a new 4D cache and sheared reconstruction filter. Our analysis subsumes convolution soft shadows for parallel planes as a special case.

Paper: [PDF](#) [Supplemental Animations](#)

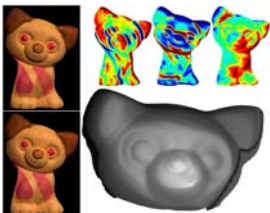
[Optimizing Environment Maps for Material Depiction](#) *EGSR 2011*



We present an automated system for optimizing and synthesizing environment maps that enhance the appearance of materials in a scene. We first identify a set of lighting design principles for material depiction. Each principle specifies the distinctive visual features of a material and describes how environment maps can emphasize those features. We express these principles as linear or quadratic image quality metrics, and present a general optimization framework to solve for the environment map that maximizes these metrics. We accelerate metric evaluation using an approach dual to precomputed radiance transfer (PRT).

Paper: [PDF](#) [Video of Quality Metric](#)

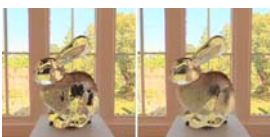
[A Theory of Differential Photometric Stereo for Unknown Isotropic BRDFs](#) *CVPR 2011*



We present a comprehensive theory of photometric surface reconstruction from image derivatives. For unknown isotropic BRDFs, we show that two measurements of spatial and temporal image derivatives, under unknown light sources on a circle, suffice to determine the surface. This result is the culmination of a series of fundamental observations. Our theoretical results are illustrated with several examples on synthetic and real data.

Paper: [PDF](#) [Tech Report](#)

[Real-Time Rough Refraction](#) *ISD 2011 Best Paper Award*



We present an algorithm to render objects of transparent materials with rough surfaces in real-time, under distant illumination. Rough surfaces cause wide scattering as light enters and exits objects, which significantly complicates the rendering of such materials. We approximate the Bidirectional Transmittance Distribution Function (BTDF), using spherical Gaussians, suitable for real-time estimation of environment lighting using pre-convolution.

Paper: [PDF](#) [Youtube Video](#)

[Multi-Resolution Isotropic Strain Limiting](#) *SIGGRAPH Asia 2010*

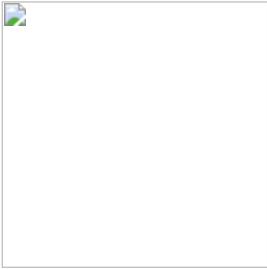


In this paper we describe a fast strain-limiting method that allows stiff, incompressible materials to be simulated efficiently. Unlike prior approaches, which act on springs or individual strain components, this method acts on the strain tensors in a coordinate-invariant fashion allowing isotropic behavior. For triangulated surfaces in three-dimensional space, we also describe a complementary edge-angle-limiting method to limit out-of-plane bending. To accelerate convergence, we also propose a novel multi-resolution algorithm that enforces fitted limits at each level of a non-conforming hierarchy.

Paper: [PDF](#) [Video](#)

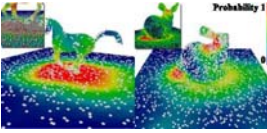
[Example-Based Wrinkle Synthesis for Clothing Animation](#) *SIGGRAPH 2010*

This paper describes a method for animating the appearance of clothing, such as pants or a shirt, that fits closely to a figure's body. Based on the observation that the wrinkles in close-fitting



clothing behave in a predominantly kinematic fashion, we have developed an example-based wrinkle synthesis technique. Our method drives wrinkle generation from the pose of the figure's kinematic skeleton. This approach allows high quality clothing wrinkles to be combined with a coarse cloth simulation that computes the global and dynamic aspects of the clothing motion. Further, the combined system runs at interactive rates, making it suitable for applications where high-resolution offline simulations would not be a viable option.

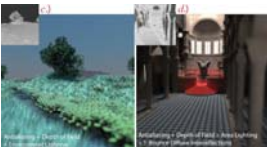
Paper: [PDF](#) [Video](#) [Papers Trailer](#)



[Sparsely Precomputing the Light Transport Matrix for Real-Time Rendering](#) *EGSR 2010*.

Precomputation-based methods have enabled real-time rendering with natural illumination, all-frequency shadows, and global illumination. However, a major bottleneck is the precomputation time, that can take hours to days. While the final real-time data structures are typically heavily compressed with clustered principal component analysis and/or wavelets, a full light transport matrix still needs to be precomputed for a synthetic scene, often by exhaustive sampling and raytracing. In this paper, we show that the precomputation can be made much more efficient by adaptive and sparse sampling of light transport. We demonstrate sparse sampling and precomputation 5x faster than previous methods.

Paper: [PDF \(if no EG DL subscription see TR\)](#) [Tech Report](#) [Video](#)



[Adaptive Wavelet Rendering](#) *SIGGRAPH Asia 2009*.

Effects such as depth of field, area lighting, antialiasing and global illumination require evaluating a complex high-dimensional integral at each pixel of an image. We develop a new adaptive rendering algorithm that greatly reduces the number of samples needed for Monte Carlo integration. Our method renders directly into an image-space wavelet basis. Moreover, the method introduces minimal overhead, and can be efficiently included in an optimized ray-tracing system.

Paper: [PDF \(44M\)](#)



[Removing Image Artifacts Due to Dirty Camera Lenses and Thin Occluders](#) *SIGGRAPH Asia 2009*.

There are often physical layers between the scene and the imaging system. For example, the lenses of consumer digital cameras often accumulate various types of contaminants over time (e.g., fingerprints, dust, dirt). Also, photographs are often taken through a layer of thin occluders (e.g., fences, meshes, window shutters, curtains, tree branches) which partially obstruct the scene. We show that both effects can be described by a single image formation model, and removed from digital photographs.

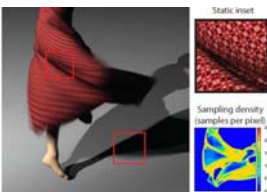
Paper: [PDF](#)



[Precomputation-Based Rendering](#) *Foundations and Trends in Computer Graphics and Vision 3(4), 281-369*.

Precomputation-based relighting and radiance transfer has a long history with a spurt of renewed interest, including adoption in commercial video games, due to recent mathematical developments and hardware advances. In this survey, we describe the mathematical foundations, history, current research and future directions for precomputation-based rendering.

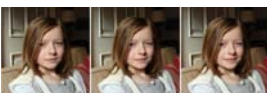
Paper: [PDF](#)



[Frequency Analysis and Sheared Reconstruction for Rendering Motion Blur](#) *SIGGRAPH 09*.

Motion blur is crucial for high-quality rendering, but is also very expensive. Our first contribution is a frequency analysis of motionblurred scenes, including moving objects, specular reflections, and shadows. We show that motion induces a shear in the frequency domain, and that the spectrum of moving scenes is usually contained in a wedge. This allows us to compute adaptive space-time sampling rates, to accelerate rendering. Our second contribution is a novel sheared reconstruction filter that is aligned to the first-order direction of motion and enables even lower sampling rates.

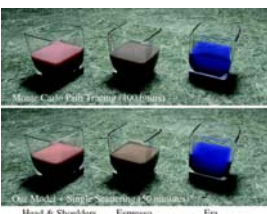
Paper: [PDF](#)



[Moving Gradients: A Path-Based Method for Plausible Image Interpolation](#) *SIGGRAPH 09*.

We describe a method for plausible interpolation of images, with a wide range of applications like temporal up-sampling for smooth playback of lower frame rate video, smooth view interpolation, and animation of still images. We develop a novel path-based framework, greater flexibility via transition points, new ways to handle visibility, and Poisson reconstruction to produce smooth interpolations.

Paper: [PDF](#) [Video \(QT 55M\)](#)



[An Empirical BSSRDF Model](#) *SIGGRAPH 09*.

Current scattering models are tuned to the two extremes of thin media and single scattering, or highly scattering materials modeled using the diffusion approximation. The vast intermediate range of materials has no efficient approximation. In this work, we simulate the full space of BSSRDFs, analogous to work on measured BRDF databases. We show new types of scattering behavior, fitting an analytic model and tabulating its parameters. This allows new efficient rendering and reflectance models for a variety of BSSRDFs.

Paper: [PDF](#)

Affine Double and Triple Product Wavelet Integrals for Rendering *ACM Transactions on Graphics 28(2), Article 14, pages 1-17, Apr 2009.*



Many problems in computer graphics involve integrations of products of functions. Double- and triple-product integrals are commonly used in applications such as all-frequency relighting or importance sampling, but are limited to distant illumination. In contrast, near-field lighting from planar area lights involves an affine transform of the source radiance at different points in space. Our main contribution is a novel affine double- and triple-product integral theory.

Paper: [PDF](#) [Video \(AVI 16M\)](#)

Compressive Light Transport Sensing *ACM Transactions on Graphics 28(1), Article 3, pages 1-18, Jan 2009.*



In this article we propose a new framework for capturing light transport data of a real scene, based on the recently developed theory of compressive sensing for sparse signals. We develop a novel hierarchical decoding algorithm that improves reconstruction quality by exploiting interpixel coherency relations. Additionally, we design new nonadaptive illumination patterns that minimize measurement noise.

Paper: [PDF](#)

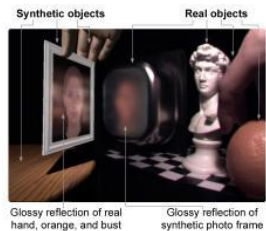
Multiscale Texture Synthesis *SIGGRAPH 08, Article 51, pages 1-8.*



The appearance of many textures changes dramatically with scale; imagine zooming into the planet from outer space to see large scale continent and ocean features, then smaller cities, forests, and finally people and trees. By using an exemplar graph with a few small single-scale exemplars and modifying a standard parallel synthesis method, we develop the first multiscale texture synthesis algorithm.

Paper: [PDF](#) [Video \(175M\)](#)

Light Field Transfer: Global Illumination between Real and Synthetic Objects *SIGGRAPH 08, Article 57, pages 1-6.*



By using a light field interface between real and synthetic scenes, we can composite real and virtual objects. Moreover, we can directly simulate multiple bounces of global illumination between them. Our method is suited even for dynamic scenes, and does not require geometric properties or complex image-based appearance capture of the real objects.

Paper: [PDF](#) [Video \(55M\)](#)

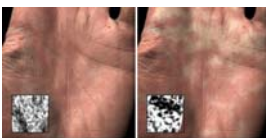
A Precomputed Polynomial Representation for Interactive BRDF Editing with Global Illumination *ACM Transactions on Graphics 27(2), Article 13, pages 1--13. Presented at SIGGRAPH 2008.*



We develop a mathematical framework and practical algorithms to edit BRDFs with global illumination in a complex scene. A key challenge is that light transport for multiple bounces is non-linear in the scene BRDFs. We address this by developing a new bilinear representation of the reflection operator, deriving a polynomial multi-bounce tensor precomputed framework, and reducing the complexity of further bounces.

Paper: [PDF](#) [Video \(7M\)](#)

A Layered, Heterogeneous Reflectance Model for Acquiring and Rendering Human Skin *SIGGRAPH Asia 2008.*



We introduce a layered, heterogeneous spectral reflectance model for human skin. The model captures the inter-scattering of light among layers, each of which may have an independent set of spatially-varying absorption and scattering parameters. To obtain parameters for our model, we use a novel acquisition method that begins with multi-spectral photographs. We create complex skin visual effects such as veins, tattoos, rashes, and freckles.

Paper: [PDF \(8M\)](#)

Compressive Structured Light for Recovering Inhomogeneous Participating Media *ECCV 2008.*



Recovering dynamic inhomogeneous participating media is a significant challenge in vision and graphics. We introduce a new framework of compressive structured light, where patterns are emitted to obtain a line integral of the volume density at each camera pixel. The framework of compressive sensing is then used to recover the density from a sparse set of patterns.

Paper: [PDF](#) [Video \(25M\)](#)

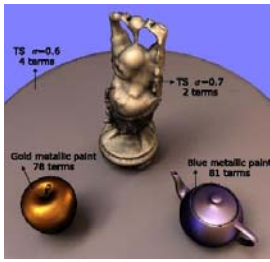
Searching the World's Herbaria: Visual Identification of Plant Species *ECCV 2008.*



This paper describes our electronic field guide project: a collaboration of researchers in computer vision, mobile computing and botany (the Smithsonian Institution). We have developed a hand-held prototype and recognition algorithms that enable users to take the picture of a leaf and identify the species in the field. The field guide works for Plummer's Island, the woody plants in the DC area, and the trees of NYC's Central Park. *Subsequent to this paper, Prof. Belhumeur and collaborators*

developed and released [LeafSnap](#) which is a free iPhone App for visual plant species identification.

Paper: [PDF](#) [Earlier Taxon 2006 paper \(PDF\)](#) [Project Website](#) [LeafSnap](#)



[An Analysis of the BRDF In-Out Factorization for View-Dependent Relighting](#) *EuroGraphics Symposium on Rendering 2008.*

Interactive rendering with dynamic lighting and changing view is a long standing problem and many recent PRT methods seek to address this by a factorization of the BRDF into incident and outgoing angles. In this paper, we analyze this factorization theoretically using spherical harmonics, and derive the number of terms needed based on the BRDF. One result is that a very large number of terms (10s to 100s) are needed for specular materials.

Paper: [PDF](#) [Video \(18M\)](#)

[Large Ray Packets for Real-Time Whitted Ray Tracing](#) *IEEE Symposium on Interactive Ray Tracing 2008.*

Real-Time Ray Tracing going beyond primary rays and hard shadows, to reflections and refractions, is a long-standing challenge. In this work, we evaluate and develop new algorithms for traversal and frustum culling with large ray packets to get speedups of 3x-6x, enabling real-time Whitted ray tracing on commodity hardware.

Paper: [PDF](#)

[A First Order Analysis of Lighting, Shading, and Shadows](#) *ACM Transactions on Graphics, article 2, pages 1-21, Jan 2007.*

We derive a complete first order or gradient theory of lighting, reflection and shadows, taking both spatial and angular variation of the light field into account. The gradient is by definition a sum of terms, allowing us to consider the relative weight of spatial and angular lighting variation, geometric curvature and bump mapping. Moreover, we derive analytic formulas for the gradients in soft shadow or penumbra regions, demonstrating applications to gradient-based interpolation and sampling.

Paper: [PDF](#)

[A Theory of Locally Low Dimensional Light Transport](#) *SIGGRAPH 07, article 62, pages 1-9.*

We develop a theory of locally low dimensional light transport, to analytically derive the dimensionality of light transport for a local patch. We analyze the eigenvalues for canonical configurations using Szego's eigenvalue theorem. We show mathematically that for symmetric patches of area A , the number of basis functions for glossy reflections increases linearly with A , while for simple cast shadows, it often increases as \sqrt{A} . There are practical applications to CPCA and other PRT algorithms.

Paper: [PDF](#) [Video \(30M\)](#)

[Frequency Domain Normal Map Filtering](#) *SIGGRAPH 07, article 28, pages 1-11.*

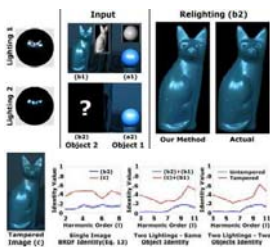
Filtering is critical for representing image-based detail, such as textures or normal maps, across a variety of scales. While mipmapping textures is commonplace, accurate normal map filtering remains a challenging problem because of nonlinearities in shading--we cannot simply average nearby surface normals. In this paper, we show analytically that normal map filtering can be formalized as a spherical convolution of the normal distribution function (NDF) and the BRDF, for a large class of common BRDFs such as Lambertian, microfacet and factored measurements. Our practical algorithms leverage a significant body of previous work that has studied lighting-BRDF convolution. We show how spherical harmonics can be used to filter the NDF for Lambertian and low-frequency specular BRDFs, while spherical von Mises-Fisher distributions can be used for high-frequency materials.

Paper: [PDF](#) [Video \(103M\)](#) [Very Cool Trailer](#) (MOV 54M)

[A Theory of Frequency Domain Invariants: Spherical Harmonic Identities for BRDF/Lighting Transfer and Image Consistency](#) *ECCV 06, vol IV, pp 41-55, PAMI 30(2), pages 197-213, Feb 2008.*

We develop new mathematical results based on the spherical harmonic convolution framework for reflection. We derive novel identities, which are the angular frequency domain analogs to common spatial domain invariants such as reflectance ratios. These lead to more general transfer algorithms for inverse rendering, and a novel framework for checking the consistency of images, to detect tampering.

Paper: [PDF \(PAMI 08\)](#) [PDF \(ECCV 06\)](#)

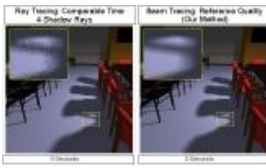


[Dirty Glass: Rendering Contamination on Transparent Surfaces](#) *EuroGraphics Symposium on Rendering, 2007.*

Real-world transparent objects are seldom clean: Their surfaces have a variety of contaminants such as dust, dirt, and lipids. These contaminations produce a number of complex volumetric scattering effects that must be taken into account when creating realistic renderings. We construct an analytical model for optically thin contaminants, measure the spatially varying thicknesses for a

number of glass panes of dust, dirt and lipids, and demonstrate renderings with a variety of volumetric scattering effects.

Paper: [PDF](#) [Video](#)



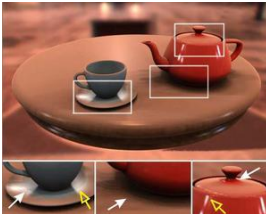
A Real-Time Beam Tracer with Application to Exact Soft Shadows *EuroGraphics Symposium on Rendering, 2007.*

Beam tracing is one solution to efficiently calculate accurate soft shadows from area light sources. In this paper, we adapt many of the methods for accelerated ray tracing to develop a real-time beam tracer, that is as fast as the best ray tracers for primary rays, and up to 30 times faster for difficult secondary rays, as needed in soft shadows. Moreover, we obtain reference quality exact shadows, without stochastic noise.

Paper: [PDF](#) [Video](#)

Time-Varying BRDFs *IEEE Transactions on Visualization and Computer Graphics 13, 3 pages 595-609, 2007.*

The properties of virtually all real-world materials change with time, causing their BRDFs to be time-varying. In this work, we address the acquisition, analysis, modeling and rendering of a wide range of time-varying BRDFs, including the drying of various types of paints (watercolor, spray, and oil), the drying of wet rough surfaces (cement, plaster, and fabrics), the accumulation of dusts (household and joint compound) on surfaces, and the melting of materials (chocolate). Analytic BRDF functions are fit to these measurements and the model parameters variations with time are analyzed. Each category exhibits interesting and sometimes non-intuitive parameter trends. These parameter trends are then used to develop analytic time-varying BRDF (TVBRDF) models.



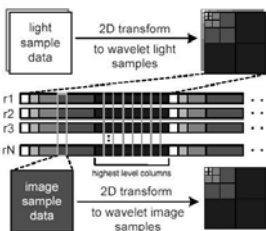
Paper: [PDF](#) [Video \(49MB\)](#)

Viewpoint-Coded Structured Light *CVPR 2007.*

We introduce a theoretical framework and practical algorithms for replacing time-coded structured light patterns with viewpoint codes, in the form of additional camera locations. Current structured light methods typically use $\log(N)$ light patterns, encoded over time, to unambiguously reconstruct N unique depths. We demonstrate that each additional camera location may replace one frame in a temporal binary code.



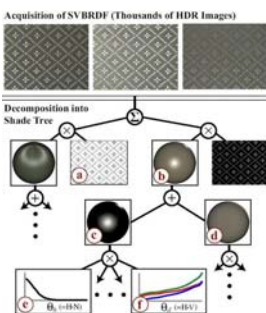
Paper: [PDF](#)



4D Compression and Relighting with High-Resolution Light Transport Matrices *ACM Symposium on Interactive 3D graphics, 2007, pages 81--88.*

We use a 4D wavelet transform for relighting with all-frequency illumination. A key observation is that a standard 4D wavelet transform can actually inflate portions of the light transport matrix. Therefore, we present an adaptive 4D wavelet transform that terminates at a level that avoids inflation and maximizes sparsity in the matrix data. Finally, we present an algorithm for fast relighting from adaptively compressed transport matrices.

Paper: [PDF](#) [Video](#)



Inverse Shade Trees for Non-Parametric Material Representation and Editing *SIGGRAPH 06, pages 735-745.*

We develop an *inverse shade tree* framework of hierarchical matrix factorizations to provide intuitive, editable representations of high-dimensional measured reflectance datasets of spatially-varying appearance. We introduce a new alternating constrained least squares framework for these decompositions, that preserves the key features of linearity, positivity, sparsity and domain-specific constraints. The SVBRDF is decomposed onto 1D curves and 2D maps, that are easily edited.

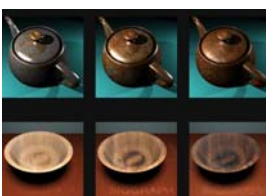
Paper: [PDF](#) [Video \(24M\)](#)



Real-Time BRDF Editing in Complex Lighting *SIGGRAPH 06, pages 945-954.*

In this project, we develop the theory and algorithms to for the first time allow users to edit measured and analytic BRDFs in real time to design materials in their final placement in a scene with complex natural illumination and cast shadows. The system can take as input a variety of analytic and data-driven reflectance models, including the curve-based BRDFs obtained from the inverse shade tree factorization.

Paper: [PDF \(20M\)](#) [Video \(59M\)](#)



Time-Varying Surface Appearance: Acquisition, Modeling and Rendering *SIGGRAPH 06, pages 762-771.*

We conduct the first comprehensive study of time-varying surface appearance, including acquisition of the first database of time-varying processes like burning, drying and decay. We then develop a nonlinear space-time appearance factorization (STAF) that allows easy editing or manipulation such as control, transfer and texture synthesis. We demonstrate a variety of novel time-varying rendering applications using the STAF model.

Paper: [PDF](#) [Video QT \(64M\)](#) [Video AVI \(46M\)](#)



A Compact Factored Representation of Heterogeneous Subsurface Scattering *SIGGRAPH 06, pages 746-753.*

Heterogeneous subsurface scattering in translucent materials is one of the most beautiful but complex effects. We acquire spatial BSSRDF datasets using a projector, and develop a novel nonlinear factorization that separates a homogeneous kernel, and heterogeneous discontinuities. This enables rendering of complex spatially-varying translucent materials.

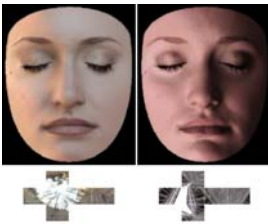
Paper: [PDF \(11M\)](#)

Acquiring Scattering Properties of Participating Media by Dilution *SIGGRAPH 06, pages 1003-1012.*



We present a simple device and technique for robustly estimating the properties of a broad class of participating media that can be either (a) diluted in water such as juices or beverages, (b) dissolved in water such as powders and sugar/salt crystals, or (c) suspended in water, such as impurities. By diluting in water, we can measure robustly in the single scattering regime.

Paper: [PDF](#)



Reflectance Sharing: Image-Based Rendering from a Sparse Set of Images *PAMI Aug 06, pages 1287-1302, EGSR 05, pages 253-264*

We develop the theoretical framework and practical results for image-based rendering of spatially-varying reflectance from a very small number of images. In doing so, we trade off some spatial variation of the reflectance for an increased number of angular samples. The upcoming PAMI paper also includes a novel Fourier analysis of spatial and angular coherence.

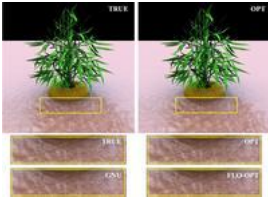
Paper: [PDF](#) [Video \(83M\)](#) [EGSR 05 \(PDF\)](#)



Exploiting Temporal Coherence for Incremental All-Frequency Relighting *EGSR 06, .*

Current PRT methods exploit spatial coherence of the lighting (such as with wavelets) and of light transport (such as with CPCA). We consider a significant, yet unexplored form of coherence, temporal coherence of the lighting from frame to frame. We achieve speedups of 3x-4x over conventional PRT with minimal implementation effort, and can trivially be added to almost any existing PRT algorithm.

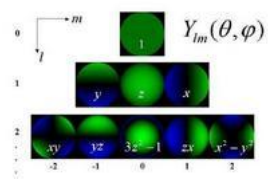
Paper: [PDF](#)



Efficient Shadows from Sampled Environment Maps *JGT 06 11(1):13-36*

There are a number of recent methods to importance sample environment maps. However, these techniques do not exploit the coherence in visibility between nearby rays. We investigate a number of alternatives and develop a simple technique that can speed up the rendering of scenes lit by natural illumination by an order of magnitude with essentially no loss in accuracy.

Paper: [PDF](#)



Modeling Illumination Variation with Spherical Harmonics *Book chapter in Face Processing: Advanced Modeling Methods (pages 385-424, 2006)*

The appearance of objects including human faces can vary dramatically with the lighting. We present results that use spherical harmonic illumination basis functions to understand this variation for face modeling and recognition, as well as a number of other applications in graphics and vision.

Paper: [PDF](#)

A Practical Analytic Single Scattering Model for Real Time Rendering *Siggraph 05, pages 1040-1049.*



We present a physically-based model that allows for real-time rendering of a variety of scattering effects like glows around light sources, the effects of scattering on surface shading, and the appearance with complex lighting and BRDFs. The model is based on an analytic integration of the single scattering equations, and can be implemented with simple fragment programs on modern graphics hardware.

Paper: [PDF](#) [Video \(74M\)](#)



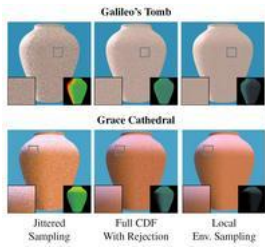
Efficiently Combining Positions and Normals for Precise 3D Geometry *Siggraph 05, pages 536-543.*

We show how depth and normal information, such as from a depth scanner and from photometric stereo, can be efficiently combined to remove the distortions and noise in both, producing very high quality meshes for computer graphics.

Paper: [PDF](#)

Adaptive Numerical Cumulative Distribution Functions for Efficient Importance Sampling *EGSR 05, pages 11-20*

Importance sampling high-dimensional functions like lighting and BRDFs is increasingly important,



but a direct tabular representation has storage cost exponential in the number of dimensions. By placing samples non-uniformly, we show that we can develop compact CDFs that enable new applications like sampling from oriented environment maps and multiple importance sampling.

Paper: [PDF](#)

$$B_{lmnpq} = \sqrt{\frac{8\pi^2}{2l+1}} L_{lm} \hat{p}_{ln,pq}$$

A Signal-Processing Framework for Reflection *ACM Transactions on Graphics (volume 23(4), Oct 2004, pages 1004-1042)*

We present a signal-processing framework for analyzing the reflected light field from a homogeneous convex curved surface under distant illumination. This generalizes many of our previous results, showing a unified framework for 2D, 3D lambertian, 3D isotropic and 3D anisotropic cases.

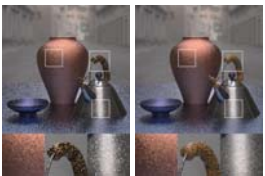
Paper: [PDF](#)



Triple Product Wavelet Integrals for All-Frequency Relighting *Siggraph 04, pages 475-485*

We propose a new mathematical and computational analysis of pre-computed light transport. We use factored forms, separately pre-computing the effects of visibility and material properties. Rendering then requires computing *triple product integrals* at each vertex, involving the lighting, visibility and BRDF. Our main contribution is a general analysis of these triple products likely to have broad applicability in computer graphics and numerical analysis.

Paper: [PDF \(5M\)](#) [Video \(17M\)](#)



Efficient BRDF Importance Sampling Using a Factored Representation *Siggraph 04, pages 494-503*

We introduce a Monte Carlo Importance sampling technique for general analytic and measured BRDFs based on a new BRDF factorization.

[PDF \(8M\)](#)



A Fourier Theory for Cast Shadows *ECCV 04, pages 146-162 ; PAMI Feb 05, pages 288-295*

We show that cast shadows can be mathematically analyzed for many simple configurations, resulting in a standard convolution formula that can be derived analytically in 2D and analyzed numerically in 3D. The results help explain many effects of lighting variability in 3D textures and suggest new bases for that purpose.

Paper: [ECCV 04](#) [PAMI 05](#)



Practical Rendering of Multiple Scattering Effects in Participating Media *EGSR 04*

Volumetric light transport effects are significant for many materials like skin, smoke, clouds, snow or water. In particular, one must consider the multiple scattering of light within the volume. We develop a general framework for incorporating analytic point spread functions based on beam spreading, while considering multiple scattering in inhomogeneous media.

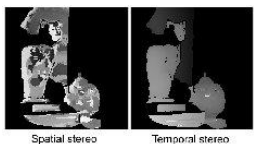
[PDF \(2M\)](#)



Using Specularities for Recognition *ICCV 03, pages 1512-1519*

We present the first method for using specularities as a positive feature for lighting-insensitive recognition. The method is applied to very difficult objects like shiny crockery and wine glasses.

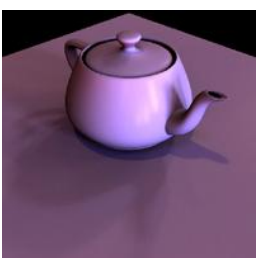
Paper: [PDF](#)



Spacetime Stereo: A Unifying Framework for Depth from Triangulation *CVPR 03, II-359--II-366 ; PAMI Feb 05, pages 296-302*

We propose a common framework, spacetime stereo, which unifies many previous depth from triangulation methods like stereo, laser scanning, and coded structured light. As a practical example, we discuss a new temporal stereo technique for improved shape estimation in static scenes under variable illumination.

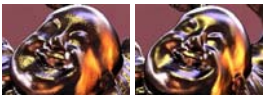
Paper: [CVPR 03](#) [PAMI 05](#)



All-Frequency Shadows Using Non-Linear Wavelet Lighting Approximation *Siggraph 03, pages 376-381*

We present a method, based on pre-computed light transport, for real-time rendering of objects under all-frequency, time-varying illumination represented as a high-resolution environment map. For accurate rendering, using non-linear wavelets is an order of magnitude faster than using linear spherical harmonics, the current best technique.

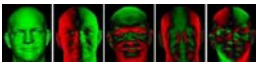
[PDF \(1M\)](#) [Video \(42MB\)](#)



[Structured Importance Sampling of Environment Maps](#) *Siggraph 03, pages 605-612*

We introduce structured importance sampling, a new technique for efficiently rendering scenes illuminated by distant natural illumination given in an environment map.

[PDF](#) [Video](#)



[Analytic PCA Construction for Theoretical Analysis of Lighting Variability, Including Attached Shadows, in a Single Image of a Convex Lambertian Object](#) *PAMI Oct 2002, pp 1322-1333.*

We explain for the first time some classic empirical results on lighting variability, and take a first step toward analyzing many classic vision problems under complex lighting.

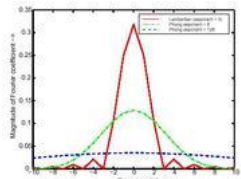
Full Paper: [PDF \(.8M\)](#)



[Frequency Space Environment Map Rendering](#) *Siggraph 02, pages 517-526*

We present a new method for real-time rendering of objects with complex isotropic BRDFs under distant natural illumination, as specified by an environment map. Our approach is based on spherical frequency space analysis.

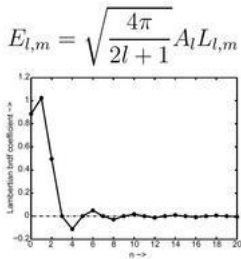
Full Paper: [gzipped PS \(4.2M\)](#) [PDF \(3.3M\)](#)



[Analysis of Planar Light Fields From Homogeneous Convex Curved Surfaces Under Distant Illumination](#) *Proceedings of Human Vision and Electronic Imaging VI (part of Photonics West, 2001), pages 185--198*

This relatively simple to read paper is the first on the reflection is convolution idea underlying my PhD thesis, and considers the 2D case using only Fourier transforms.

Full Paper: [gzipped PS \(.6M\)](#) [PDF \(.2M\)](#) Talk: [PDF \(.8M\)](#)

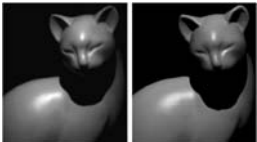


[On the relationship between Radiance and Irradiance: Determining the illumination from images of a convex Lambertian object](#) *Journal of the Optical Society of America (JOSA A) Oct 2001, pages 2448-2459*

This paper considers the 3D Lambertian case using spherical harmonics and derives an analytic formula for the irradiance in terms of the radiance, including the 9 parameter Lambertian BRDF approximation. One practical application is interactive rendering with [An Efficient Representation for Irradiance Environment Maps](#).

Full Paper: [PDF \(.4M\)](#)

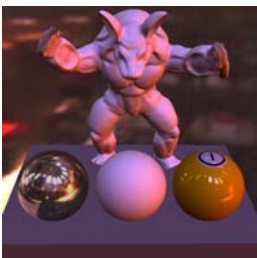
Correction: In equation 19, there is a small misprint. The last term should be $((n/2)!)^2$, not $(n!/2)^2$



[A Signal-Processing Framework for Inverse Rendering](#) *Siggraph 01, pages 117-128*

This paper is the most mathematical so far and derives the theory for the general 3D case with arbitrary isotropic BRDFs. It also applies the results to the practical problem of inverse rendering under complex illumination.

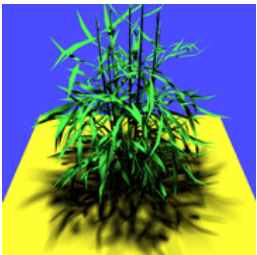
Full Paper: [gzipped PS \(3.7M\)](#) [PDF \(1M\)](#) Talk: [PPT \(1.3M\)](#)
[SIGGRAPH 2002 Course Notes: Acquiring Material Models Using Inverse Rendering](#)



[An Efficient Representation for Irradiance Environment Maps](#) *Siggraph 01, pages 497-500*

We consider the rendering of diffuse objects under distant illumination, as specified by an environment map. Using an analytic expression for the irradiance in terms of spherical harmonic coefficients of the lighting, we show that one needs to compute and use only 9 coefficients, corresponding to the lowest-frequency modes of the illumination, in order to achieve average errors of only 1%.

Full Paper: [gzipped PS \(3.4M\)](#) [PDF \(1M\)](#) Talk: [PPT \(1.8M\)](#) [Video](#)



[Efficient Image-Based Methods for Rendering Soft Shadows](#) *Siggraph 00, pages 375-384*

We present two efficient image-based approaches for computation and display of high-quality soft shadows from area light sources. Our methods are related to shadow maps and provide the associated benefits.

Full Paper: [gzipped PS \(4M\)](#) [PDF \(1.7M\)](#) Talk: [PPT \(1.8M\)](#)

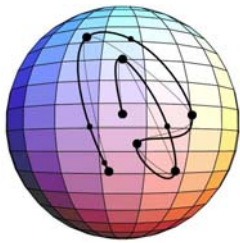


[Creating Generative Models from Range Images](#) *Siggraph 99, pages 195-204*

We have explored the creation of high-level parametric models from low-level range data. Our model-based approach is relatively insensitive to noise and missing data and is fairly robust.

Full Paper: [PS \(2.5M\)](#) [PDF \(1.5M\)](#)

[Fast Construction of Accurate Quaternion Splines](#) *Siggraph 97, pages 287-292.*



[Dynamic Splines with Constraints for Animation:](#) *Caltech CS-TR-97-03.*

We have explored the use of improved numerical approaches for optimization to automatically create animation from keyframes. The numerical tools developed include adaptive refinement based on the Euler-Lagrange error functional. We have applied this approach to quaternion splines, greatly speeding up a numerical method to construct the optimal rotational curve.

Full Paper: [Sig 97 PDF](#) [Tech Report](#)

Teaching (at Berkeley)

CS 283 Advanced Computer Graphics [Spring 2013](#) [Fall 2010](#) [Fall 2009](#)

CS 184 Computer Graphics [Fall 2012](#) [Spring 2012](#) [Spring 2010](#)

Teaching (at Columbia)

COMS 4160	Computer Graphics	Fall 2008	Spring 2008	Fall 2006	Fall 2005	Fall 2004
COMS 4162	Advanced Computer Graphics	Spring 2006	Spring 2005			
COMS 6160	Topics in Computer Graphics	Visual Appearance (Spring 2007)	Real-Time Rendering (Fall 2004)	Appearance Models (6998 Fall 2002)		

Students, Alumni and Collaborators

[Lytro Pictures](#) of student and alumni dinner at SIGGRAPH 2014 in Vancouver (courtesy Ren Ng). And standard 2D [photograph](#).

Current PhD Students: [Pratul Srinivasan](#), Zexiang Xu, Lifan Wu, Sai Bi, Jiyang Yu, Alexandr Kuznetsov, Tiancheng Sun, Mohammad Shafiei, Kai-En Lin

Alumni: [Nima Khademi Kalantari](#) (Postdoc 2016-2018, now at TAMU), [Ling-Qi Yan](#) (PhD 2018, now at UCSB), Zak Murez (PhD 2018, now at Magic Leap), Jingwen Wang (MS 2018), Shradha Agarwal (MS 2018), Jean Choi (MS 2018), Ting-Chun Wang (PhD 2017, now at NVIDIA), [Weilun Sun](#) (MS 2017), Muhammad Riaz (MS Aug 2016, now at Apple), [Michael Tao](#) (PhD Aug 2015, now at Apple), [Soham Uday Mehta](#) (PhD May 2015, now at Light), [Chi-Wei Tseng](#) (MS thesis Jun 2015, now at Dreamworks), Jong-Chyi Su (MS Jun 2015, now PhD student at UMass), Krishna Mullia (MS Jun 2015, now at Dreamworks), [Jiamin Bai](#) (PhD Sep 2014, now at Light), [Eno Toeppe](#) (Postdoc 2013-2014, now at Magic Leap), [Dikpal Reddy](#) (Postdoc 2011-2013, now at NVIDIA), [Brandon Wang](#) (MS,BS 2011-2013, now at Pixar), [Milos Hasan](#) (Postdoc 2010-2012, now at AutoDesk), [Kevin Egan](#) (PhD Aug 2011, now at DE Shaw), [Charles Han](#) (PhD May 2011, now at Google), [Manmohan Chandraker](#) (Postdoc 2009-2011, now at UCSD!), [Huamin Wang](#) (Postdoc 2009-2011, now at Ohio State), [Adrien Bousseau](#) (Postdoc 2009-2010, now at INRIA), [Craig Donner](#) (Postdoc 2007-2009, now at Google), [Jinwei Gu](#) (PhD May 2010, now at Sarnoff), [Fu-Chung Huang](#) (MS May 2010, now at NVIDIA after PhD), [Dhruv Mahajan](#) (PhD Aug 2009, now at Microsoft Research), [Ryan Overbeck](#) (PhD Aug 2009, now at Google), [Bo Sun](#) (PhD Aug 2008, now at Intu Financial), [Aner Ben-Artzi](#) (PhD May 2007, now at Sony), [Jason Lawrence \(Princeton\)](#) (PhD June 2006, now faculty at UVA), [Simon Premoze](#) (postdoc 2003-2005, now at ILM), [Sebastian Enrique](#) (MS May 2005, now at Electronic Arts), [Kalyan Sunkavalli](#) (MS May 2006, now at Adobe after PhD at Harvard), Nandan Dixit (MS Dec 2006, now at Google), [Diego Nehab \(Princeton\)](#) (PhD Jun 2007, now at MSR -> IMPA), [Yu-Ting Tseng](#) (MS Dec 2008, now at Google).

Background

I joined the [Computer Science and Engineering Department](#) at UC San Diego, starting July 2014. I was on the faculty of the [Electrical Engineering and Computer Science Department](#) at UC Berkeley from January 2009 to June 2014. Since the fall of 2002 (until Dec 2008), I was on the faculty of the [Columbia Computer Science Department](#). Earlier (1998-2002), I completed my Ph.D in the [Stanford Computer Science Department](#), working in the [Computer Graphics Laboratory](#). Earlier (1994-1998), I was an undergraduate at the [California Institute of Technology](#), getting a BS, MS in Computer Science and an MS in Physics. A full [CV](#) is also available.

Personal

[A BRIEF AUTOBIOGRAPHY](#) [DITCH DAY 98](#)

[Ravi Ramamoorthi](#) Last modified on Sep 18, 2018