








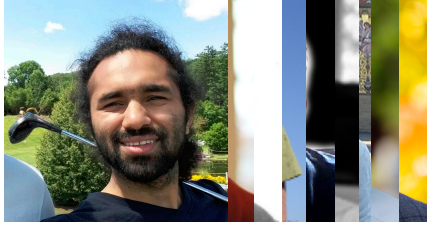


Eurographics2019 

Analysis of Sample Correlations for Monte Carlo Rendering

Gurprit Singh 	Cengiz Oztireli 	Abdalla G. Ahmed 	David Coeurjolly 
Kartic Subr 	Oliver Deussen 	Victor Ostromoukhov 	Wojciech Jarosz 

Good morning everyone, thank you for being here. This is a joint survey work done with many people from the rendering and sampling community [CLICK]



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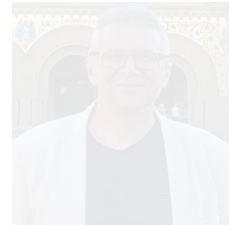
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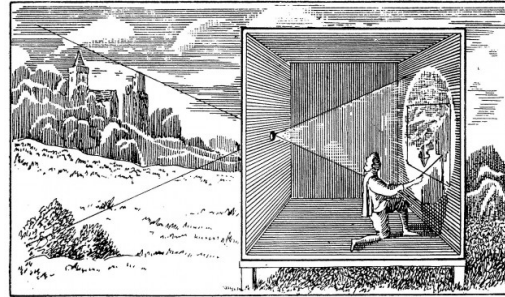
Wojciech Jarosz

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Rendering = Geometry + Radiometry

Geometry / Projection

for pin-hole model is known since 400BC

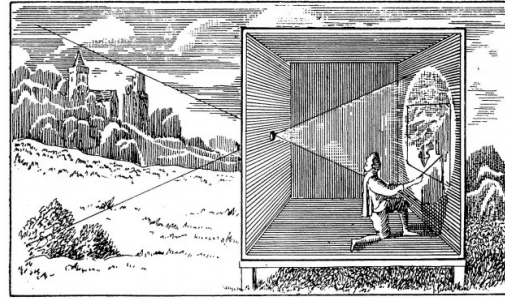


The idea of projecting real world on a 2D surface has a long history, where a pin-hole model allows projection of real world onto a screen (or a wall).

Rendering = Geometry + Radiometry

Geometry / Projection

for pin-hole model is known since 400BC



Radiometrically accurate simulation

is importance of realism



However, adding radiometric entities to a geometry is equally important to simulate realism

Rendering = Geometry + Radiometry

Geometry / Projection

for pin-hole model is known since 400BC



Radiometrically accurate simulation

is importance of realism



Many rendering algorithms are developed using this pin-hole camera.

Radiometric fidelity improves photorealism

Papas et al. [2013]



To show the relevance of photometric accuracy, here is one example where one of the object is real and the other one is fabricated.

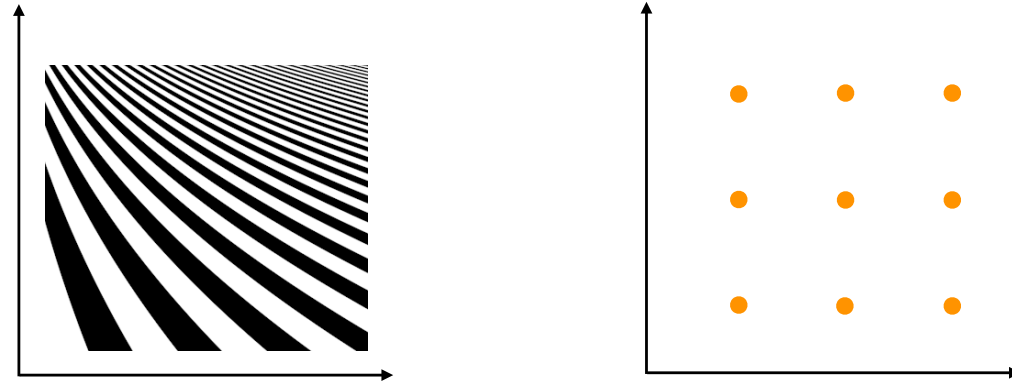
Radiometric fidelity improves photorealism

Krivanek et al. [2014]



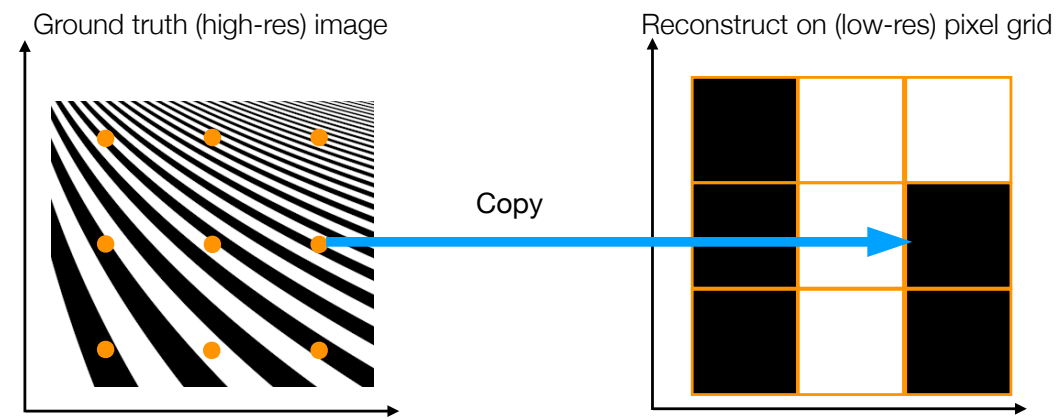
The fidelity of the virtual scene becomes unquestionable.

Reconstruction: Estimate image samples



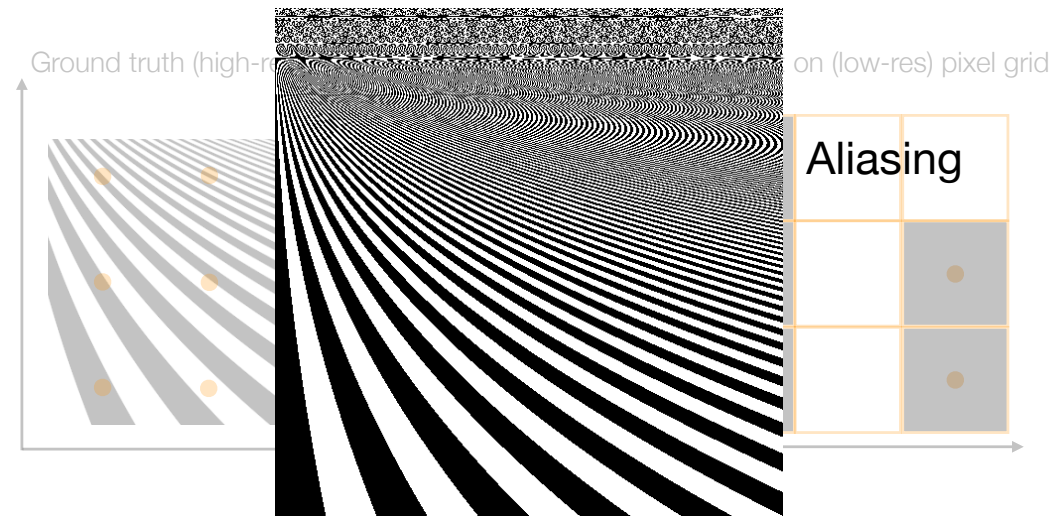
We start from the very basic. Let's start by looking at reconstruction. On one side, we are looking at a simple function with black and white stripes and on the right side we are looking at the samples (or pixel centers) of a image where we want to reproduce this function.

Naive method: sample image at grid locations



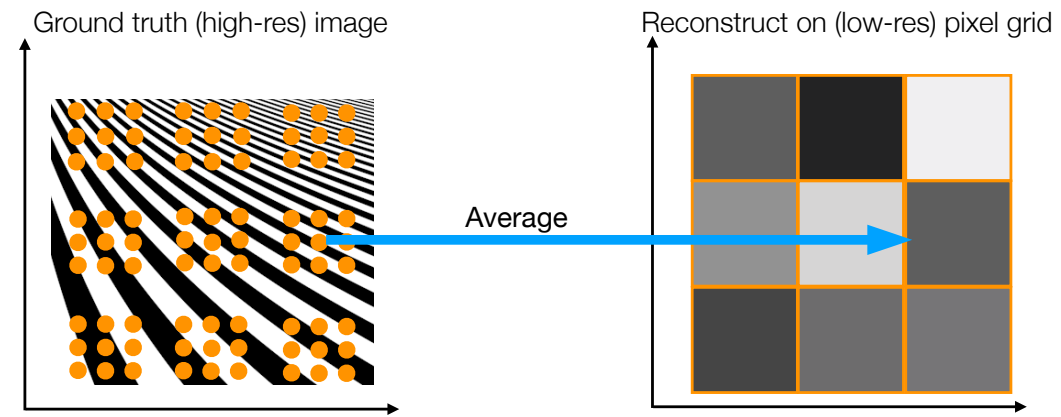
Naive approach goes by simply "copying" the values of the underlying function values to the pixels. This is bad as it gives...

Naive method: sample image at grid locations



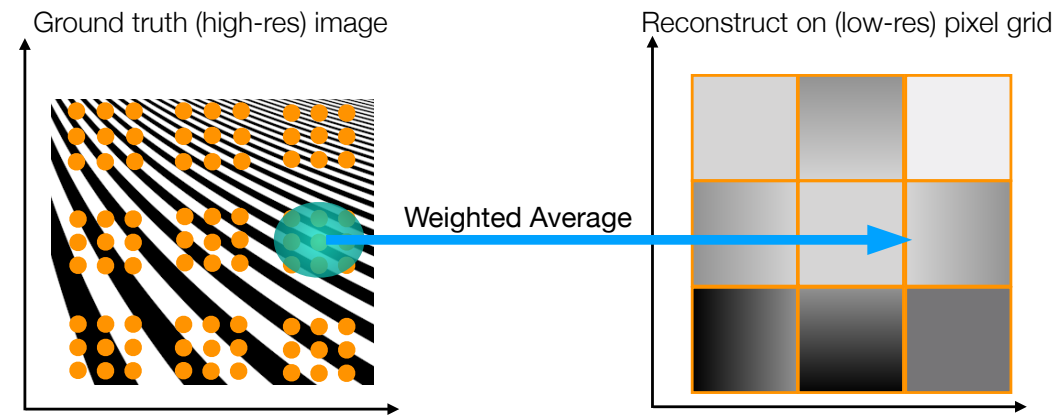
...structured noise,, also known as aliasing.

Naive method: sample image at grid locations



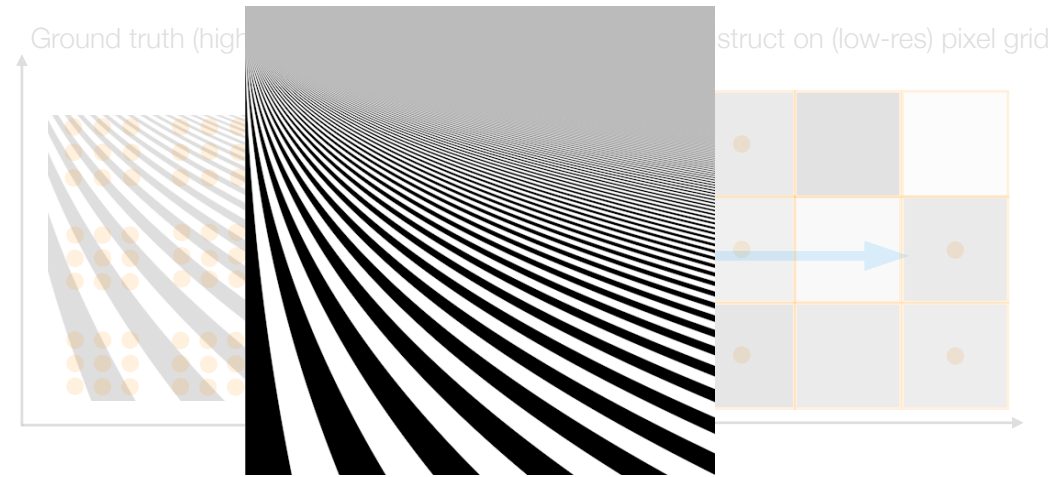
An easy way to get rid of this aliasing artifacts is to perform supersampling which involves generating multiple grid samples per pixel, evaluating the function values for each sample and average their values.

Antialiasing using general reconstruction filters



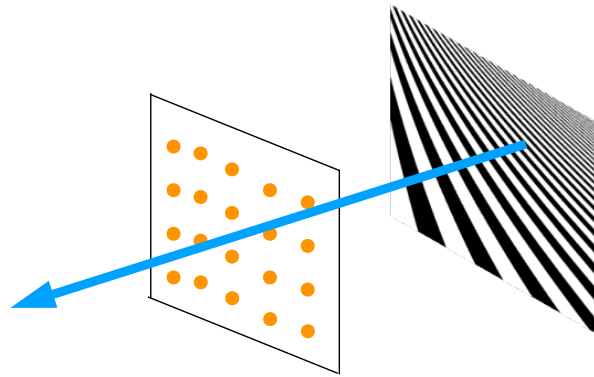
This average could be done using a reconstruction kernel which assigns some weights to each sample.

Naive method: sample image at grid locations



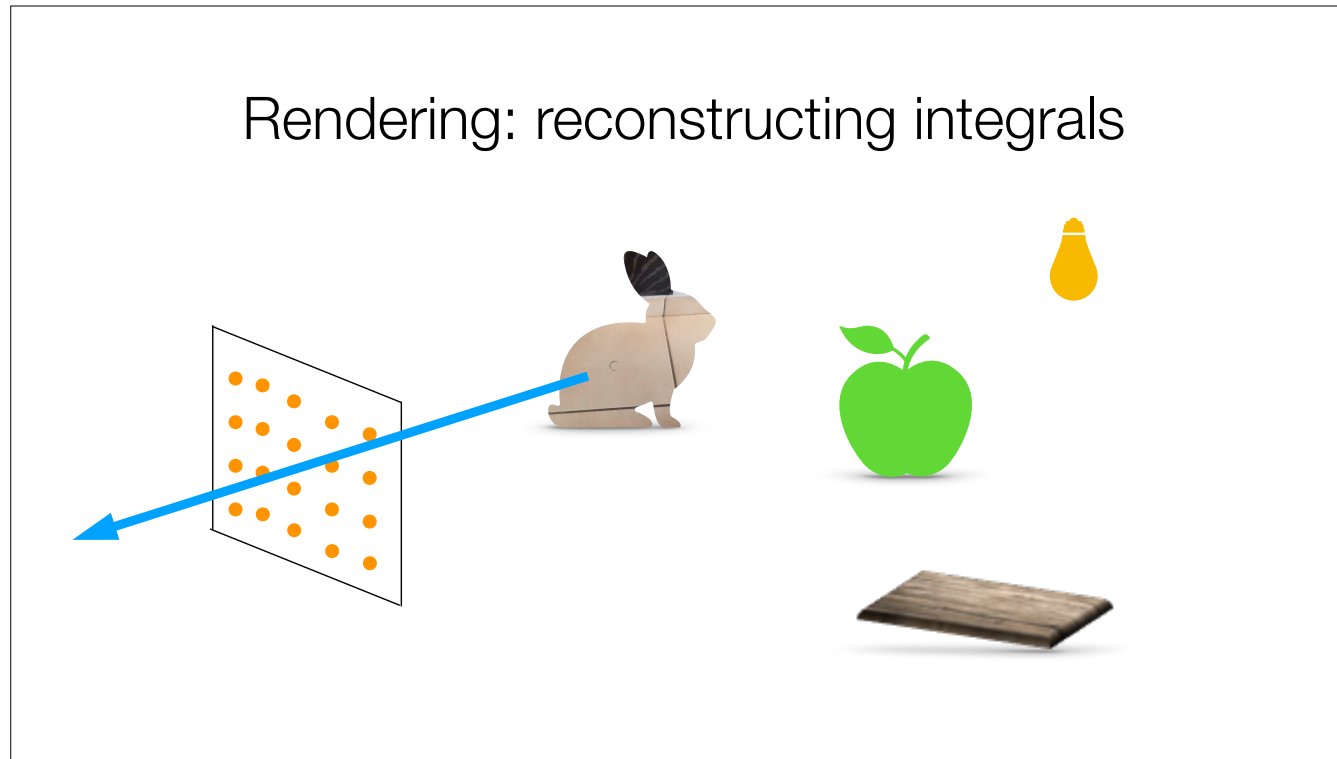
The result looks better to the human eye with more smooth transition from low frequency texture to the high frequency texture.

Rendering: reconstructing integrals



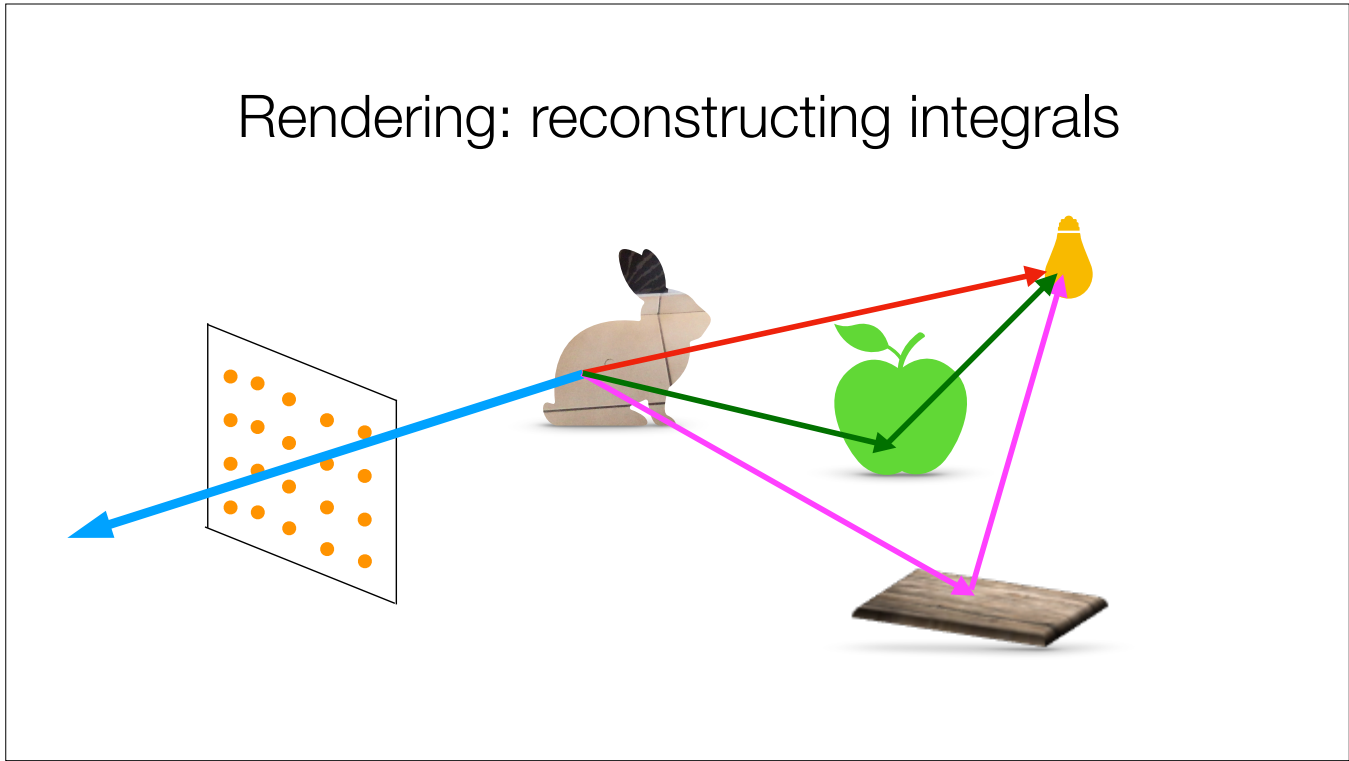
In rendering context, we can look at this as a ray shot from a sample within a pixel or image plane (or vice versa) and hitting this texture function. The function value is then stored in a pixel for a given sample. However,...

Rendering: reconstructing integrals



...in rendering we have more complex setup with 3D objects and multiple light sources. In this simple illustration, we assume a single light source.

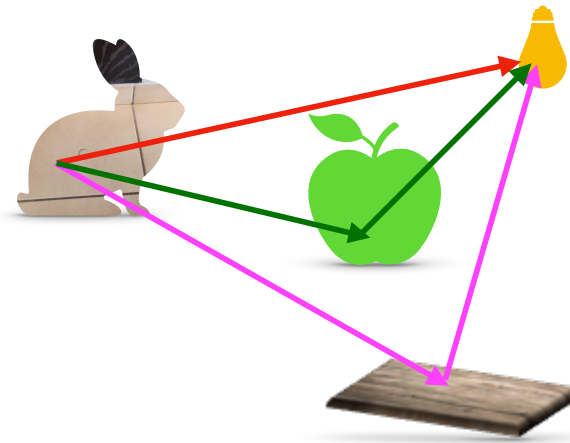
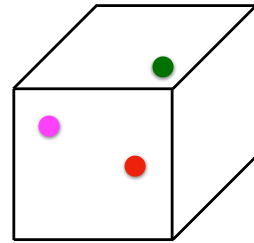
Rendering: reconstructing integrals



Here, the radiance or color value projected back to the image plane has been already reflected from multiple objects [CLICK], generating multiple paths.

Rendering: reconstructing integrals

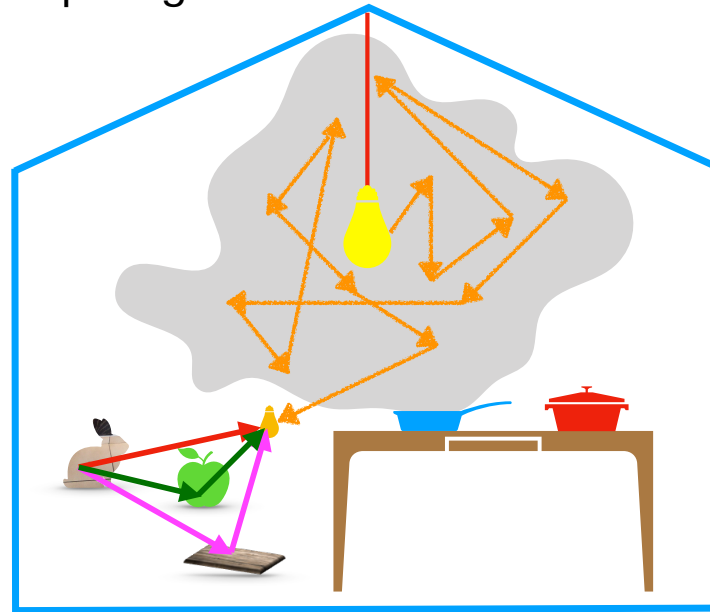
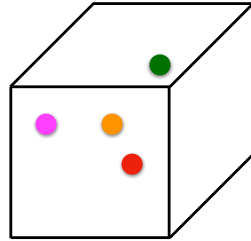
Each path has an associated radiance value



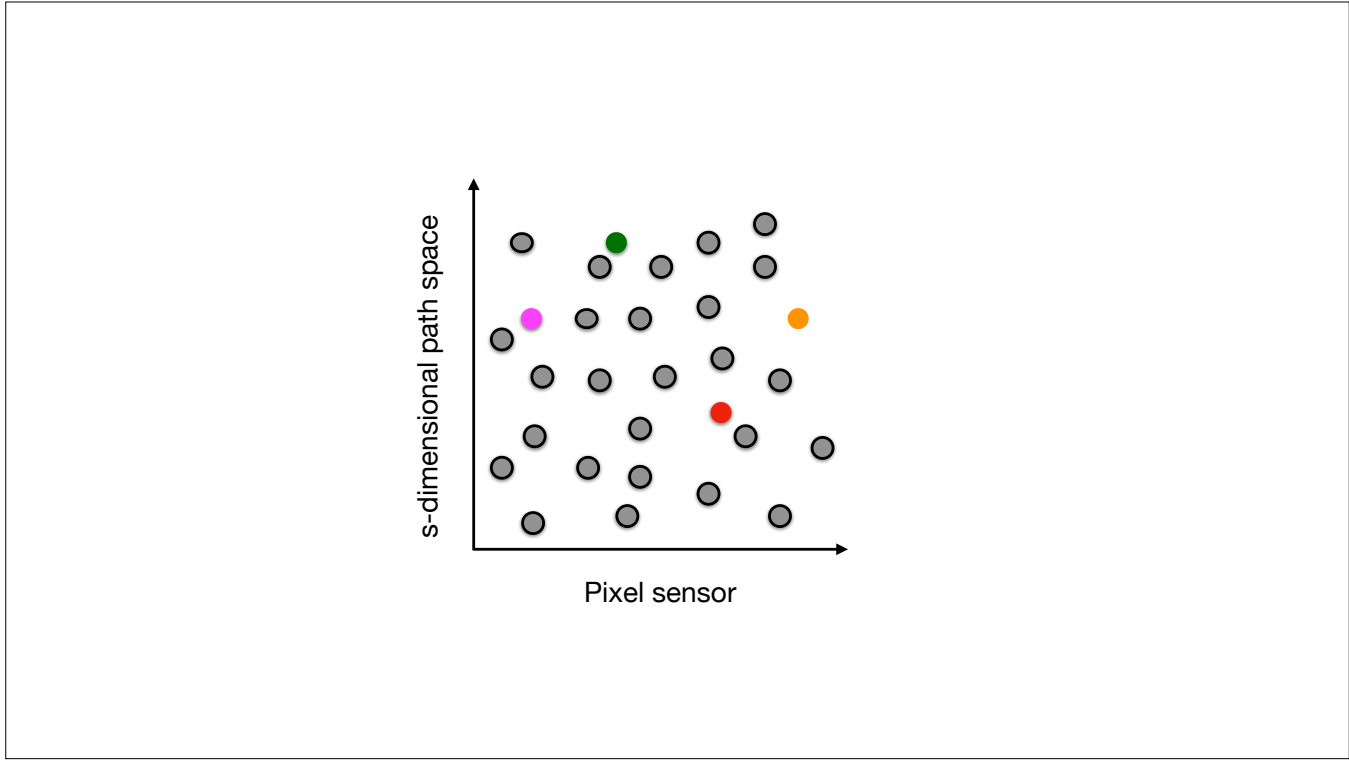
Each path has an associated radiance value.

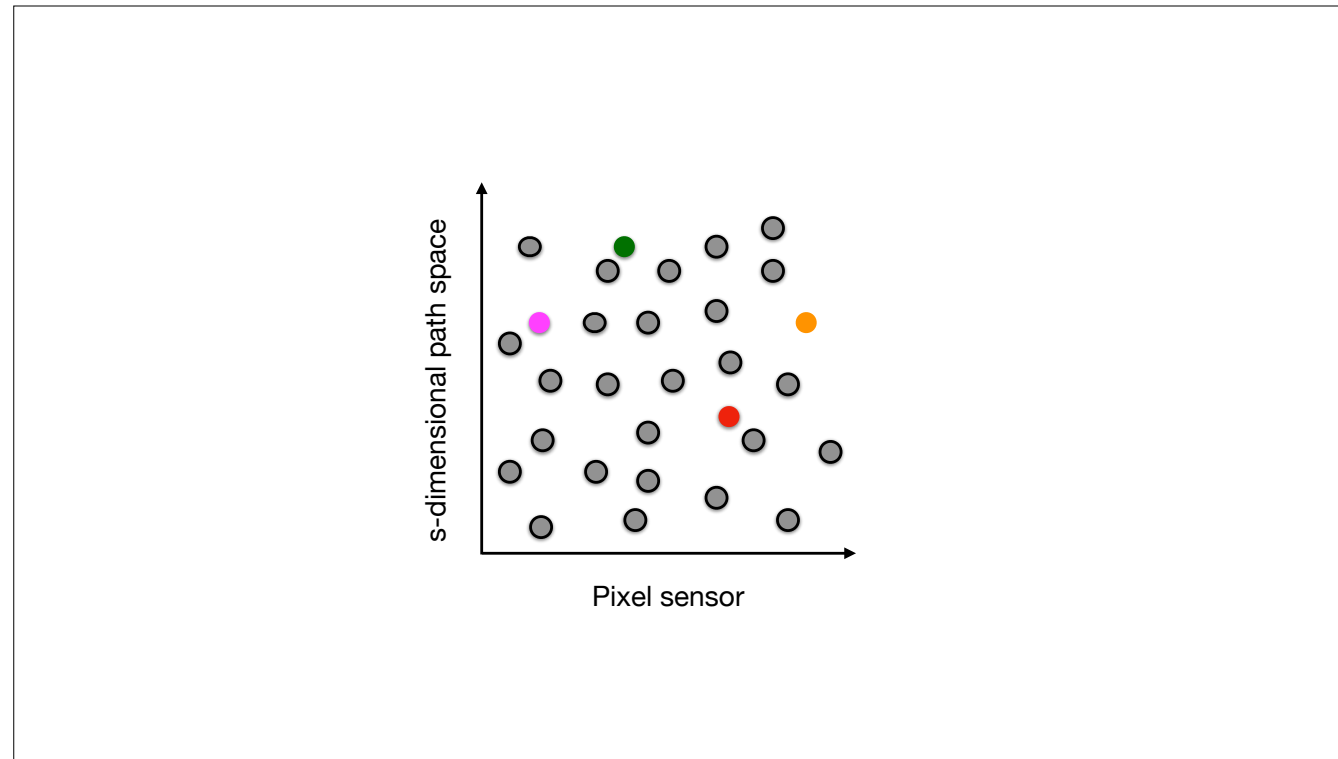
Global Illumination: Participating media

Each path has an associated radiance value

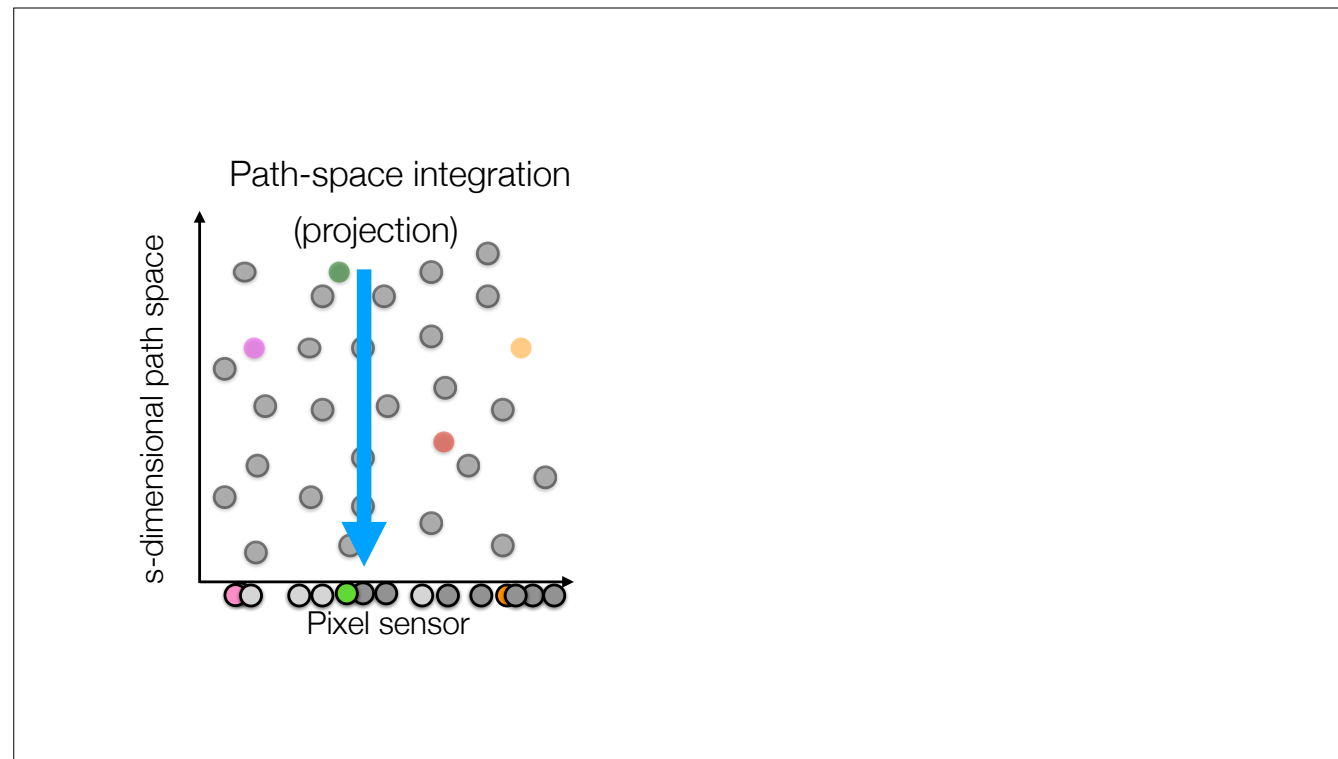


In a more complex setting, with participating media like smoke, the paths can be quite long.



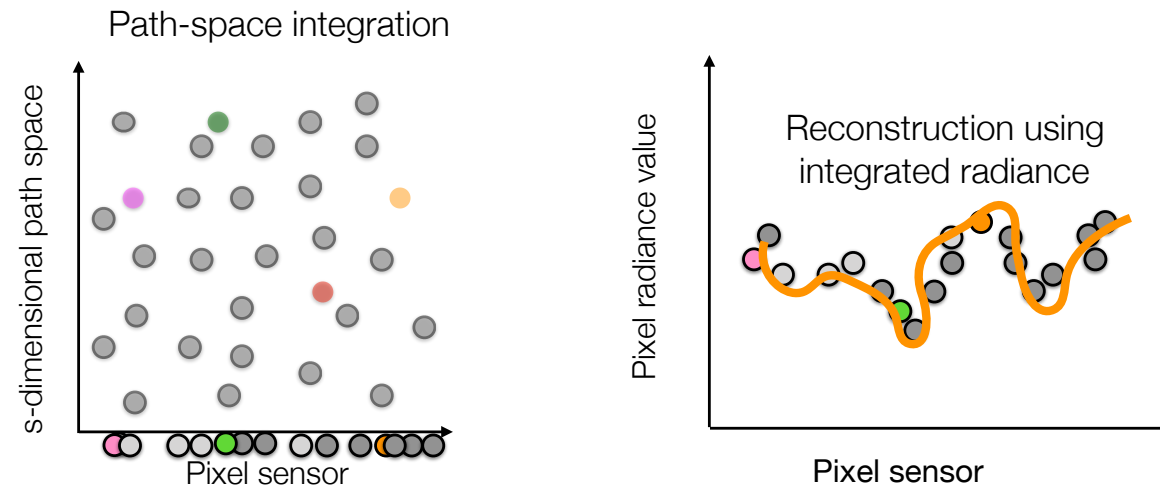


We can look at contribution of all these paths on this flatland illustration where the vertical axis represents the radiance value of s-dimensional paths and the horizontal direction represents the pixels of our image or a sensor.



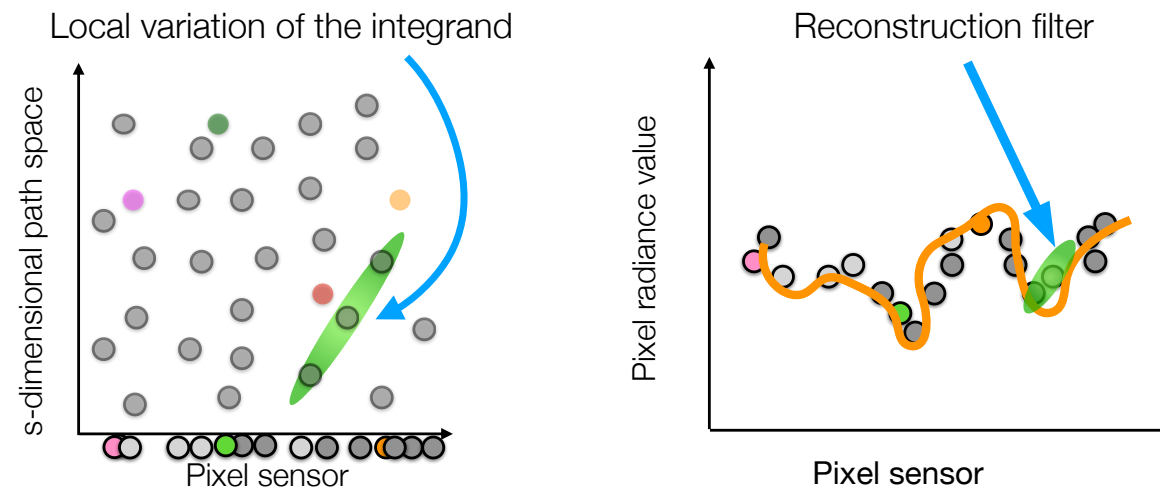
To get a value at a pixel, we project these path values [CLICK] to the corresponding pixels.

Rendering = integration + reconstruction



These pixel sensor values are then reconstructed to get a more smooth appearance on the image plane of the scene.

Frequency analysis of light fields in rendering



There is a quite a lot of work has been done over more than a decade in the Frequency domain where Fourier tools are used to better understand the local variation [CLICK] of the integrands in the path space or ray space to design or orient filters for better reconstruction.

A Frequency Analysis of Light Transport

Frédo Durand¹ MIT-CSAIL Nicolas Holzschuch² ARTIS' GRAVIR/IMAG-INRIA Cyril Soler² INRIA Eric Chan¹ MIT-CSAIL François X. Sillion² ARTIS' GRAVIR/IMAG-INRIA

Abstract
We present a signal-processing framework for light transport. We study the frequency content of radiance and how it is altered by

To appear in the ACM SIGGRAPH conference proceedings

Frequency Analysis and Sheared Reconstruction for Rendering Motion Blur

Kevin Egan^{*} Columbia University Yu-Ting Tseng¹ Columbia University Nicolas Holzschuch² INRIA — LJK Frédo Durand¹ MIT CSAIL Ravi Ramamoorthi³ UC Berkeley

(a) Our Method
4 samples/pixel

(b) Stratified Sampling
4 samples/pixel

(c) Multidimensional Adaptive Sampling
4 samples/pixel

(d) Our Method
4 samples/pixel

(e) Ground Truth
256 samples/pixel

5D Covariance Tracing for Efficient Defocus and Motion Blur

LAURENT BELCOUR¹, CYRIL SOLER², KARTIC SUBR³, NICOLAS HOLZSCHUCH², and FREDO DURAND¹

Practical Filtering for Efficient Ray-Traced Directional Occlusion

Kevin Egan^{*} Columbia University Frédo Durand¹ MIT CSAIL Ravi Ramamoorthi³ University of California, Berkeley

a) Our Method
32 rays / shading pt, 1 hr 48 min

b) Monte Carlo
40 rays, 1 hr 42 min
Equal Time

c) Our Method
32 rays, 1 hr 48 min

d) Monte Carlo
256 rays, 7 hrs 4 min
Equal Quality

e) Relighting output from (a)
30 seconds each

4D Frequency Analysis of Computational Cameras for Depth of Field Extension

Anat Levin^{1,2} Samuel W. Hasinoff¹ Paul Green¹ Frédo Durand¹ William T. Freeman¹
¹MIT CSAIL ²Weizmann Institute

Standard lens image

Our lattice-focal lens: input

Lattice-focal lens: all-focused output

Figure 1: Left: Image from a standard lens showing limited depth of field, with only the rightmost subject in focus. Center: Input from our lattice-focal lens. The defocus kernel of this lens is designed to preserve high frequencies over a wide depth range. Right: An all-focused image reconstructed from the lattice-focal lens input. Since the defocus kernel preserves high frequencies, we achieve a novel restoration over the

Temporal Light Field Reconstruction for Rendering Distribution Effects

Jaakko Lehtinen¹ NVIDIA Research Tuno Aila¹ NVIDIA Research Jiawen Chen¹ MIT CSAIL Samuli Laine¹ NVIDIA Research Frédo Durand¹ MIT CSAIL

PBRT, 16 spp, 403 s

PBRT, 256 spp, 6426 s

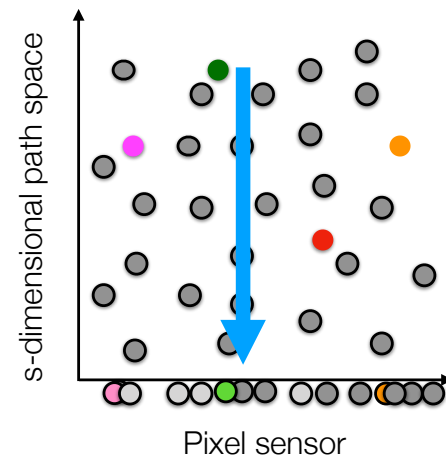
Our result, 16 spp, 403 + 10 s (+2.5%)

Figure 1: A scene with complex occlusion rendered with depth of field. Left: Images rendered by PBRT [Pharr and Humphreys 2010] using 16 and 256 low-discrepancy samples per pixel (spp) and traditional axis-aligned filtering. Right: Image reconstructed by our algorithm in 10 seconds from the same 16 samples per pixel. We obtain defocus quality similar to the 256 spp result in approximately 1/16th of the time.

Abstract
Traditionally, effects that require evaluating multidimensional integrals for each pixel, such as motion blur, depth of field, and dramatic reductions in sampling rate, rely on fairly simple reconstruction that suffers from a number of limitations. First, because they use linear reconstruction kernels and a simple model of

You can go over some of these papers to get an idea about these methods.

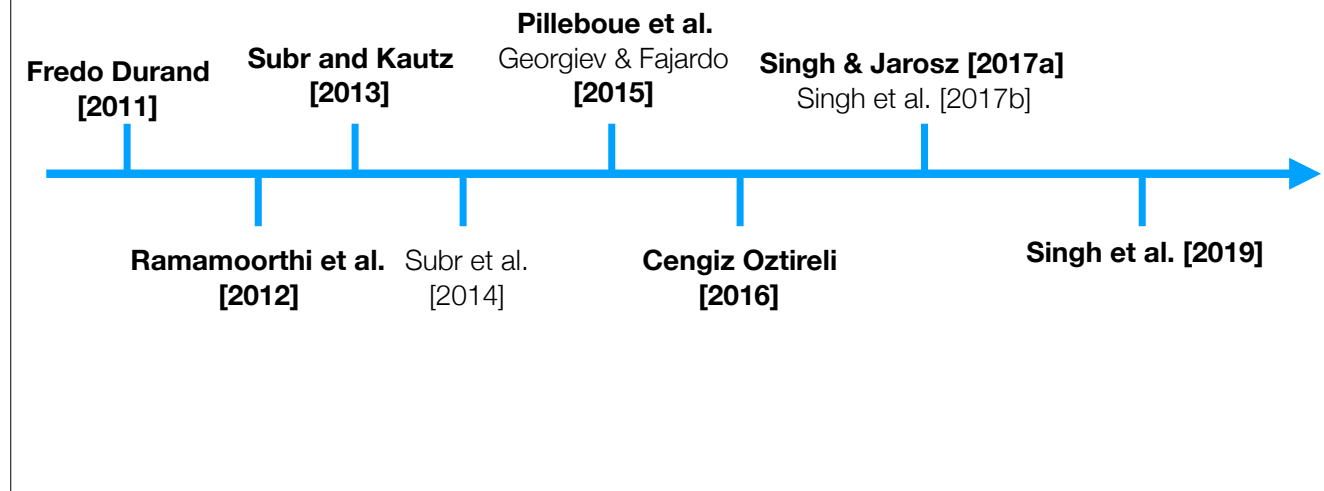
This STAR: Analyze sample correlations for MC sampling



Assessing MSE, bias, variance and convergence of Monte Carlo estimators using spatial and spectral tools

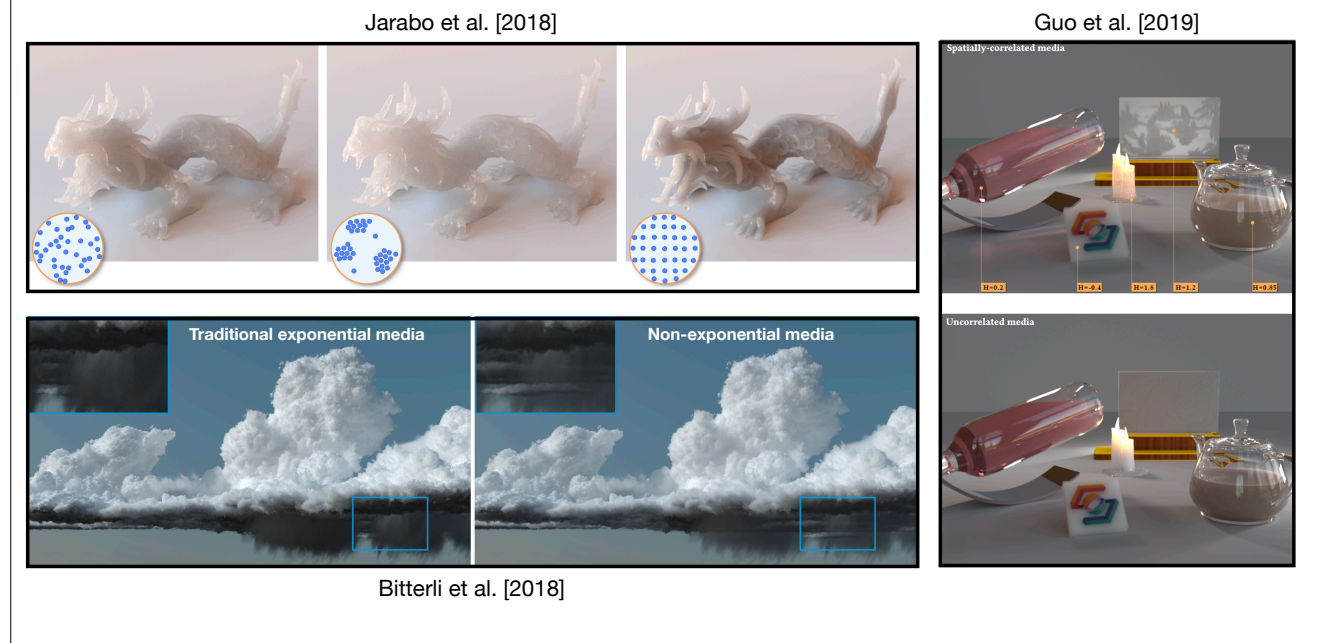
In this presentation, we are actually interested in the projection or the integration aspect of these path space samples. We would like to assess the error in the form of variance and bias due to different sampling strategies used during Monte Carlo estimation techniques (that will be introduced in the next part of the presentation by Cengiz) using spatial and spectral tools.

This STAR: Analyze sample correlations for MC sampling



We will survey the works done in this past decade, starting from [CLICK] Fredo Durand's tech report in 2011 to this year's paper that makes the first attempt in analyzing importance samples using Fourier tools.

Sample correlations affect light transport / appearance



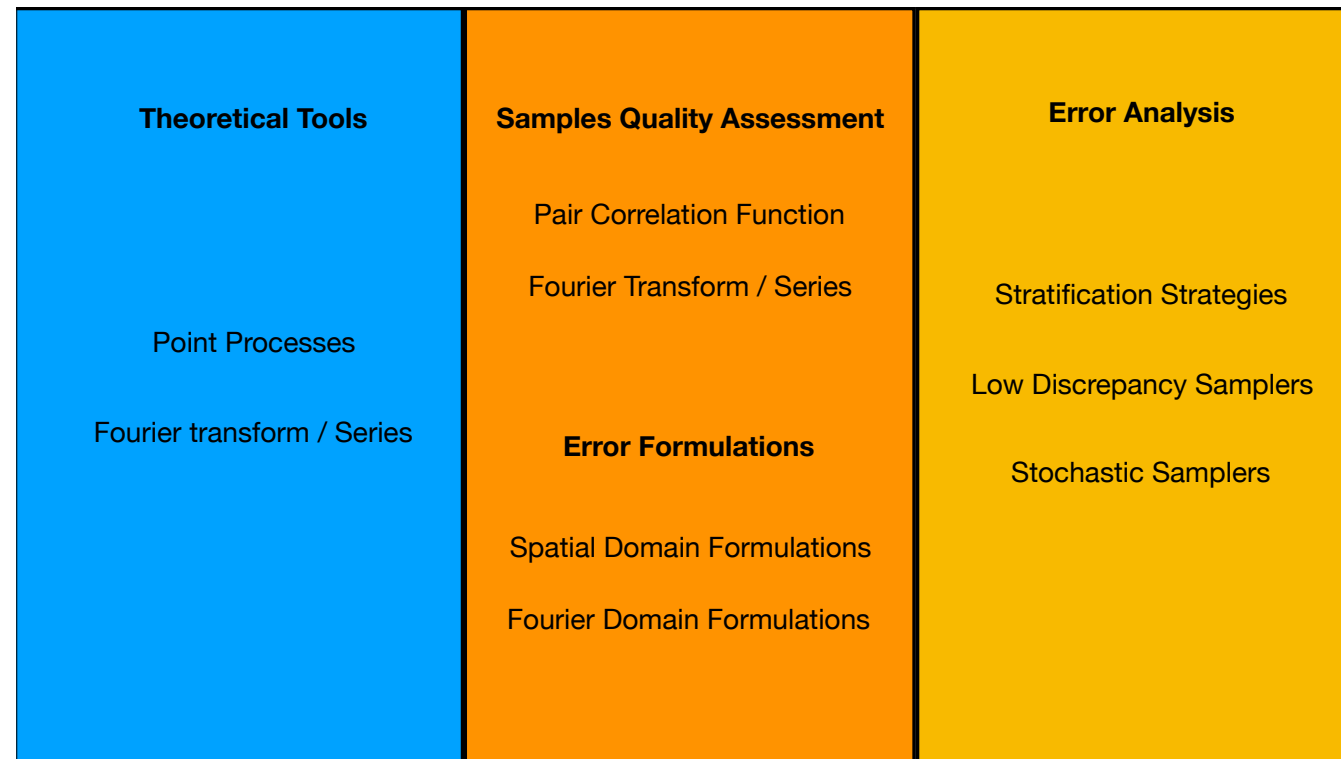
One quick impact of these correlations could be scene on appearance rendering.

When propagating through a participating medium, light is scattered

and absorbed in a very complicated way, and this transmission through a spatially-correlated media has demonstrated deviations from the classical exponential law of the corresponding uncorrelated media. And as you can see, these correlations can affect the overall appearance of the object.

This hints towards a new paradigm where we need to explore other sample correlations that could be useful in tailoring new appearances for artistic purposes.

However, in this talk...



...we will confine ourselves to the following topics.

[CLICK] We first overview the theoretical tools from the stochastic point processes and the Fourier literature.

[CLICK] We then see different ways to assess sample correlations using these spatial and spectral tools. We then present the error formulations developed using these tools.

[CLICK] In the last section, we overview how different sampling strategies affect error during Monte Carlo integration for rendering purposes.

With this, I handover the stage to Cengiz...