Photon Relaxation

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State of the Art in Photon Density Estimation

Modified slides and presentation by Toshiya Hachisuka

Introduction

Photon relaxation is a contribution to the area of error minimization in photon density estimation:

- Estimate error is the sum of bias and noise.
- Goal is to reduce noise without increasing bias.
- Problem often addressed at the kernel level with filters/intelligent bandwidth selection.
- Photon relaxation is different in that it directly manipulates the underlying point dataset.

Background

Challenges facing kernel-based noise removal:

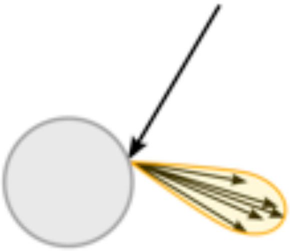
- Tricky to preserve high-frequency detail – particularly at sub-kernel scales – while ensuring adequate smoothing; noise removal and bias are correlated.

- Wide bandwidths required to effectively filter all-frequency noise – increases rendering cost.

Photon relaxation addresses both of these points. Salient features of caustics can be preserved on a fine scale while allowing noise removal on a broader scale due to diffusion.

Furthermore, the relaxed distribution allows the use of very low-bandwidth kernels.

Background

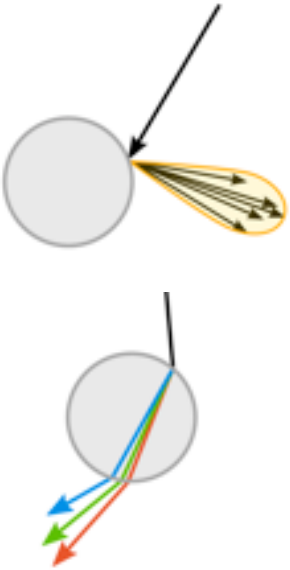


What causes noise?

Two factors:

- Point discrepancy. Caused by stochastic processes (e.g. scattering) and photon decoherence (geometry) during the particle tracing step.

Background



What causes noise?

Two factors:

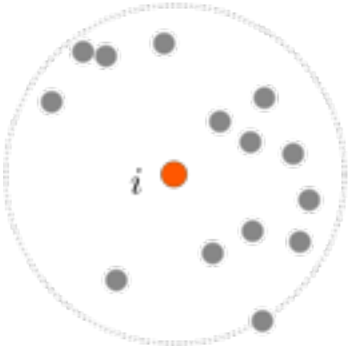
- Point discrepancy. Caused by stochastic processes (e.g. scattering) and photon decoherence (geometry) during the particle tracing step.
- Variance in photon flux. This can be caused by absorption, attenuation, dispersion through dielectric media, etc.

Photon Relaxation

Basic principles:

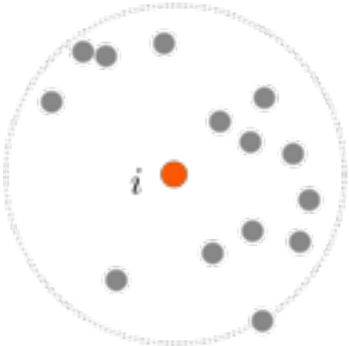
- Use point repulsion to minimize local discrepancy.

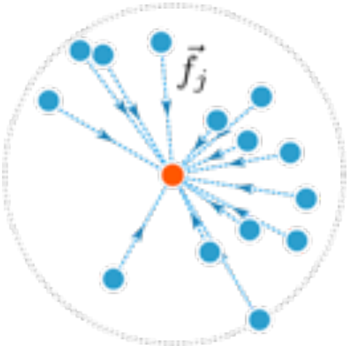
Photon Relaxation



1. For each photon, **i**, gather K-nearest neighbours to **i**.

Photon Relaxation

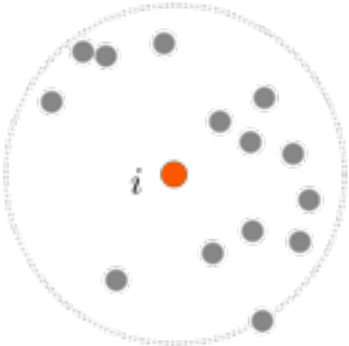




1. For each photon, **i**, gather K-nearest neighbours to **i.**

2. Compute individual repulsive forces on **i** from members, **j**, of K.

Photon Relaxation



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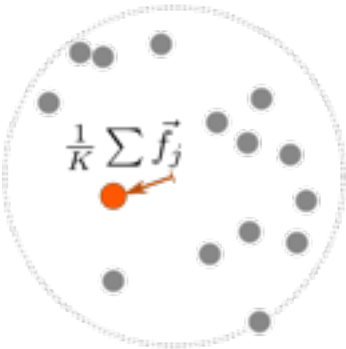

3. Apply mean of forces to position of **i.**

Photon Relaxation

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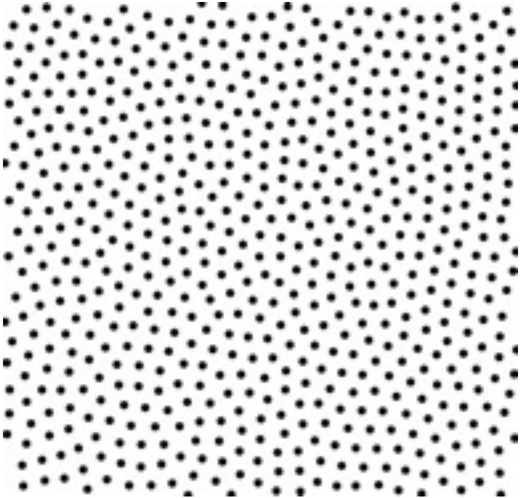
Photon Relaxation



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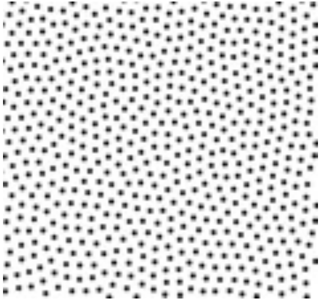
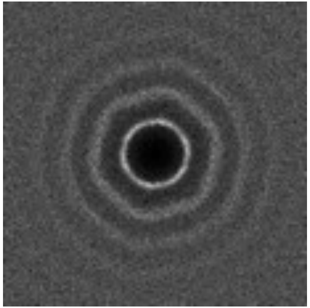
Photon Relaxation

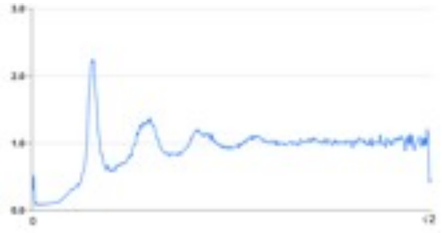




Basic principles:

- Use point repulsion to minimize local discrepancy.
- Aim to relax distribution so it exhibits a blue noise spectral signature and low angular anisotropy.

Photon Relaxation



Radially-averaged power spectrum

Angular anisotropy

Basic principles:

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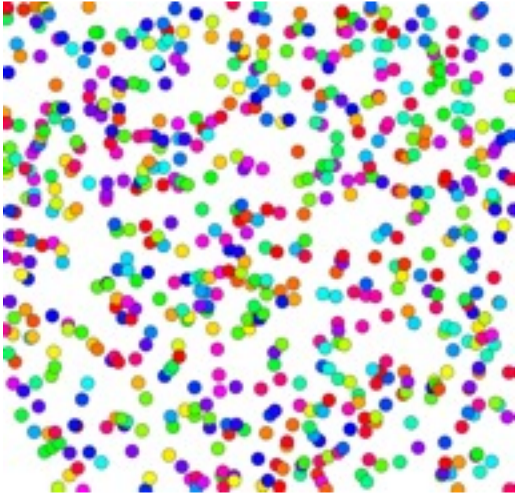
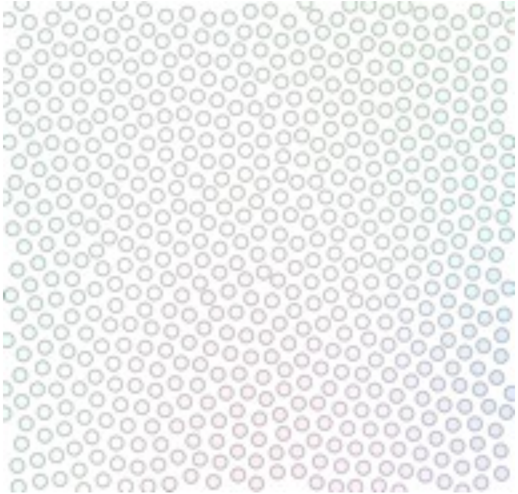
Photon Relaxation



Basic principles:

- Use point repulsion to minimize local discrepancy.
- Aim to relax distribution so it exhibits a blue noise spectral signature and low angular anisotropy.
- Use diffusion to homogenize flux between photons.

Photon Relaxation



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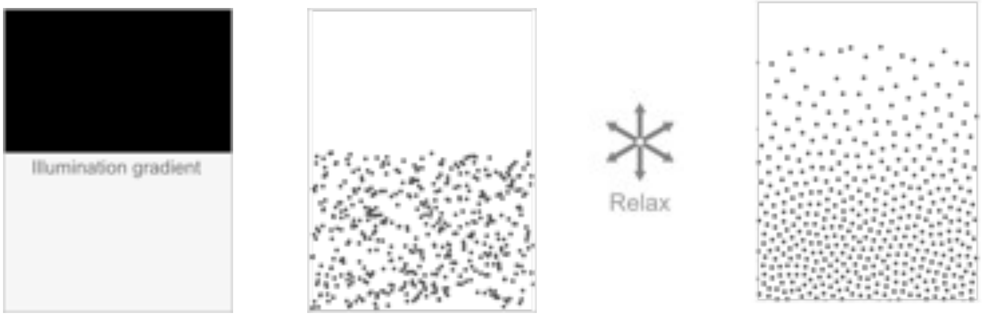
Feature Detection and Preservation

Relaxation removes noise effectively, but photon diffusion also degrades larger-scale features of the distribution.



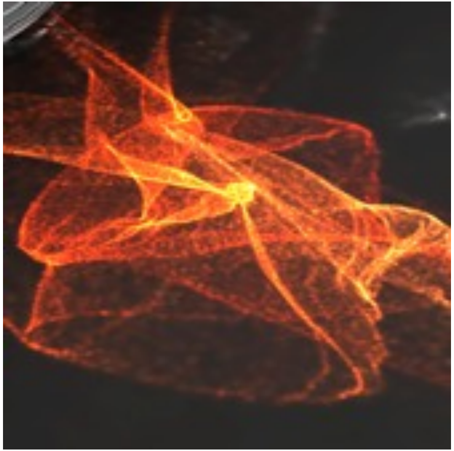
Sample PDF

Stochastically-seeded photon distribution

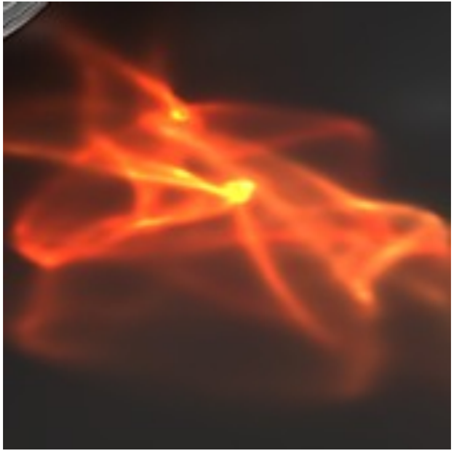
Diffusion results in degraded reconstruction

Feature Detection and Preservation

Feature Detection and Preservation



Caustic before relaxation



After relaxation. High-frequency detail has been lost due to diffusion.

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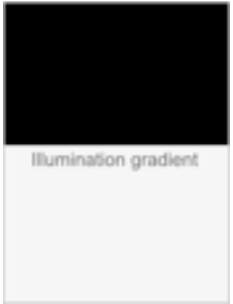
Can we do better?

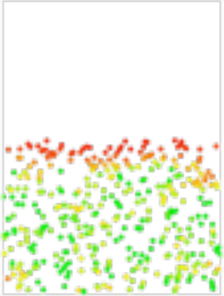
Feature Detection and Preservation

Feature detection aims to preserve these features by detecting and inhibiting motion in the direction of migration.

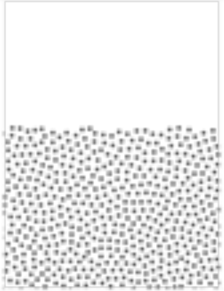


Sample PDF

Photons migrate along direction of density derivative.

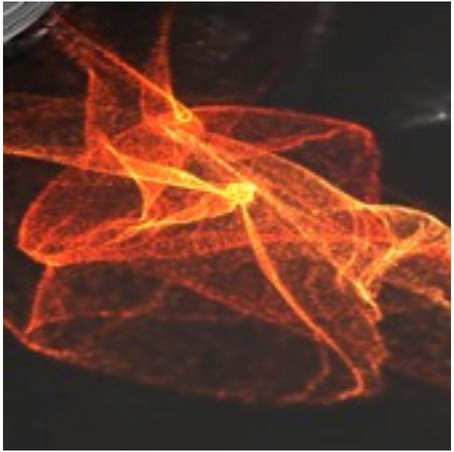


Feature detection constrains photons in the direction of migration (red = constrained).

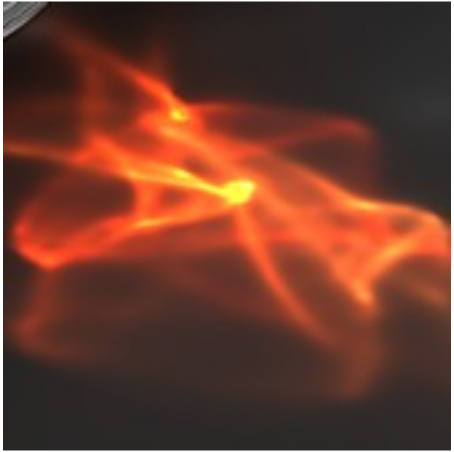


Reconstructed distribution better preserves PDF.

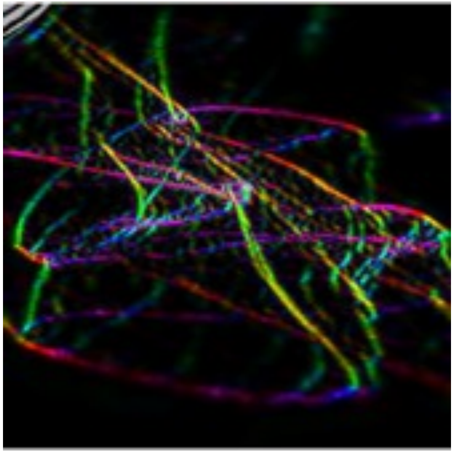
Feature Detection and Preservation



Original

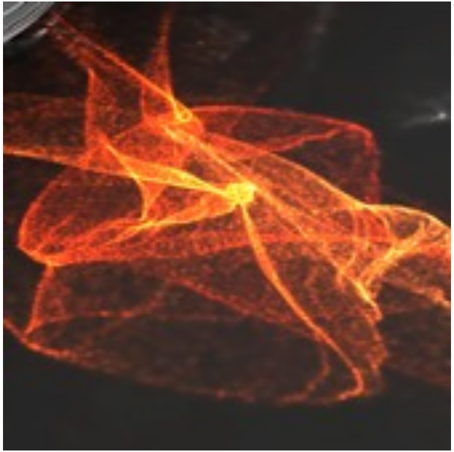


Naive relaxation

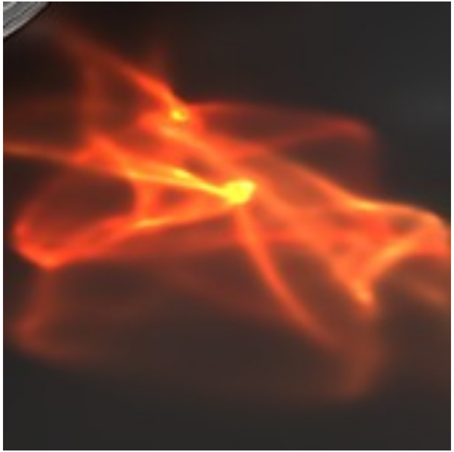


Constraints

Feature Detection and Preservation



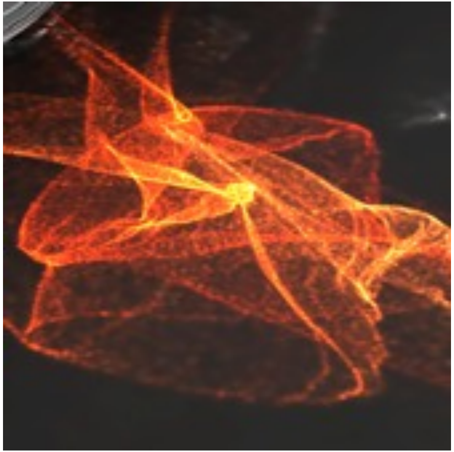
Original



Naive relaxation

Constrained relaxation

Feature Detection and Preservation



Original

Constrained relaxation

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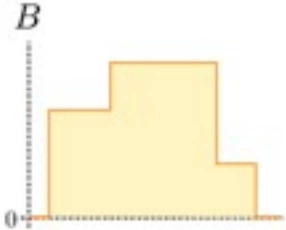
Can we do even better?

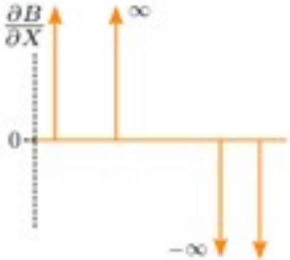
Parameterization of Photons

Using the flux density gradient to constrain photons is sound in principle, but hampered in practice by bias from the kernel estimator.

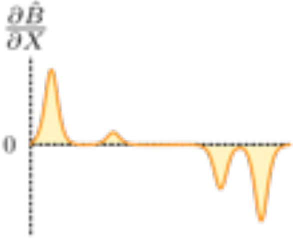
Sample flux density function



Cross-section of flux density



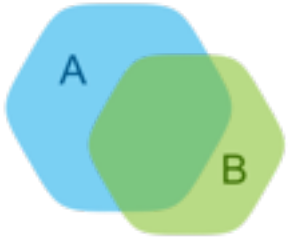
Analytical derivative



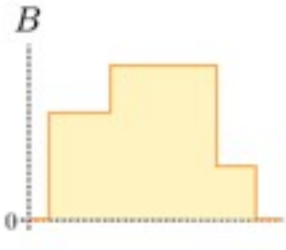
Estimated derivative is biased and so contains error.

Parameterization of Photons

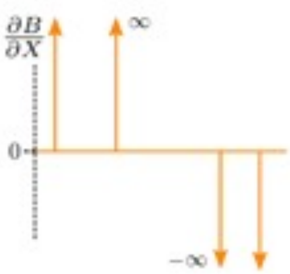
Introducing a parameterisation to the density function separates each element into individual domains and makes gradient estimation more consistent.



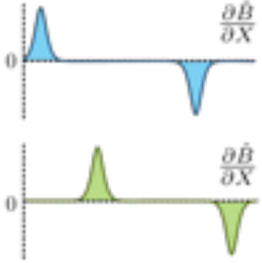
Flux density parameterised into sets A and B.



Cross-section of flux density



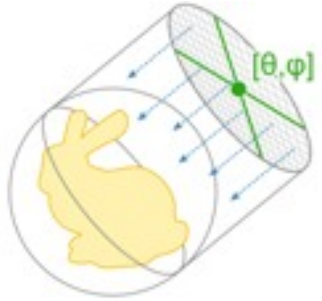
Analytical derivative



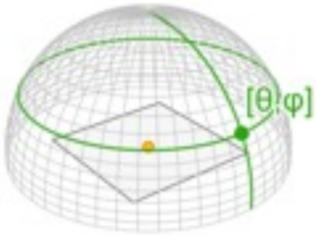
Parameterised querying yields more consistent estimates.

Parameterization of Photons

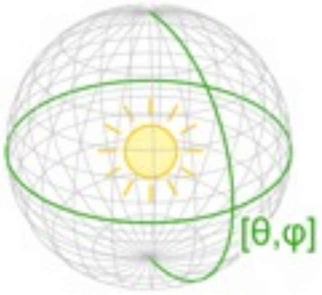
Different real-world emitters require different parameter spaces.



Collimated emitter (eg. sunlight)
2-D space derived from photon origin



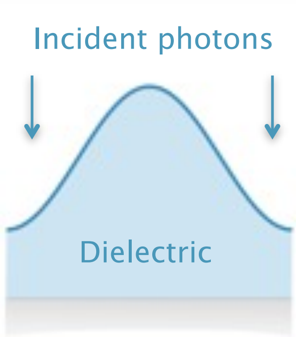
Lambertian emitter
2-D space derived from photon primal trajectory

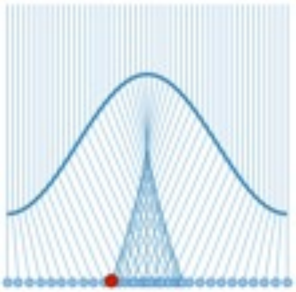


Omni-directional emitter
3-D space derived from photon primal trajectory

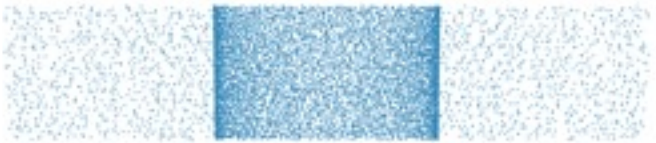
Parameterization of Photons

Structure within the photon map can be dissociated in a similar fashion by defining photon positions in a parameter space derived from their origin or primal trajectory.





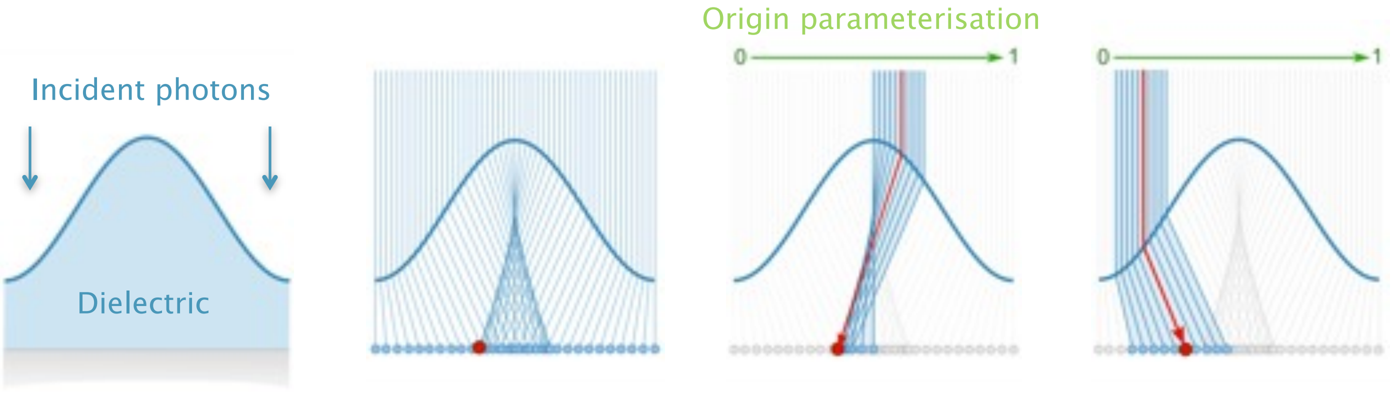
In this example, collimated photons are refracted by a dielectric and absorbed by diffuse surface.



This results in a discontinuous, refracted caustic.

Parameterization of Photons

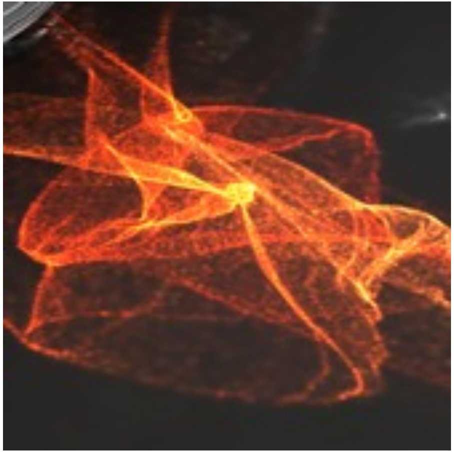
Gradient querying and relaxation within this high-dimensional space prevents photons from interlaced or overlapping structures interfering with one another.



Suppose we want to estimate the gradient at the point marked in red.

Restricting the query to a range in parameter space reveals two separable components.

Results

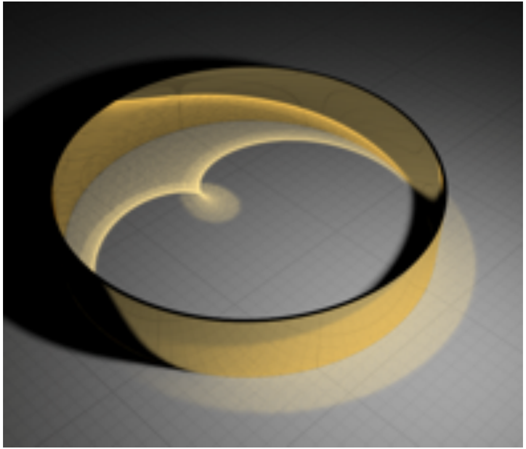


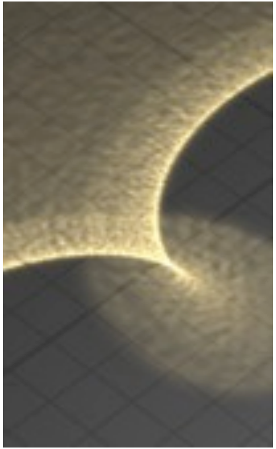
Original

Density constraints

Parametric constraints

Results





Original

Density

Parametric

Next talk

- Different approach of density estimation