Lucerne University of
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Ongoing Developments in Photon Mapping

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Outline

1. Introduction and motivation
2. RADIANCE Photon Map
3. What's new
4. What's old (current limitations)
5. Conclusion and ToDo

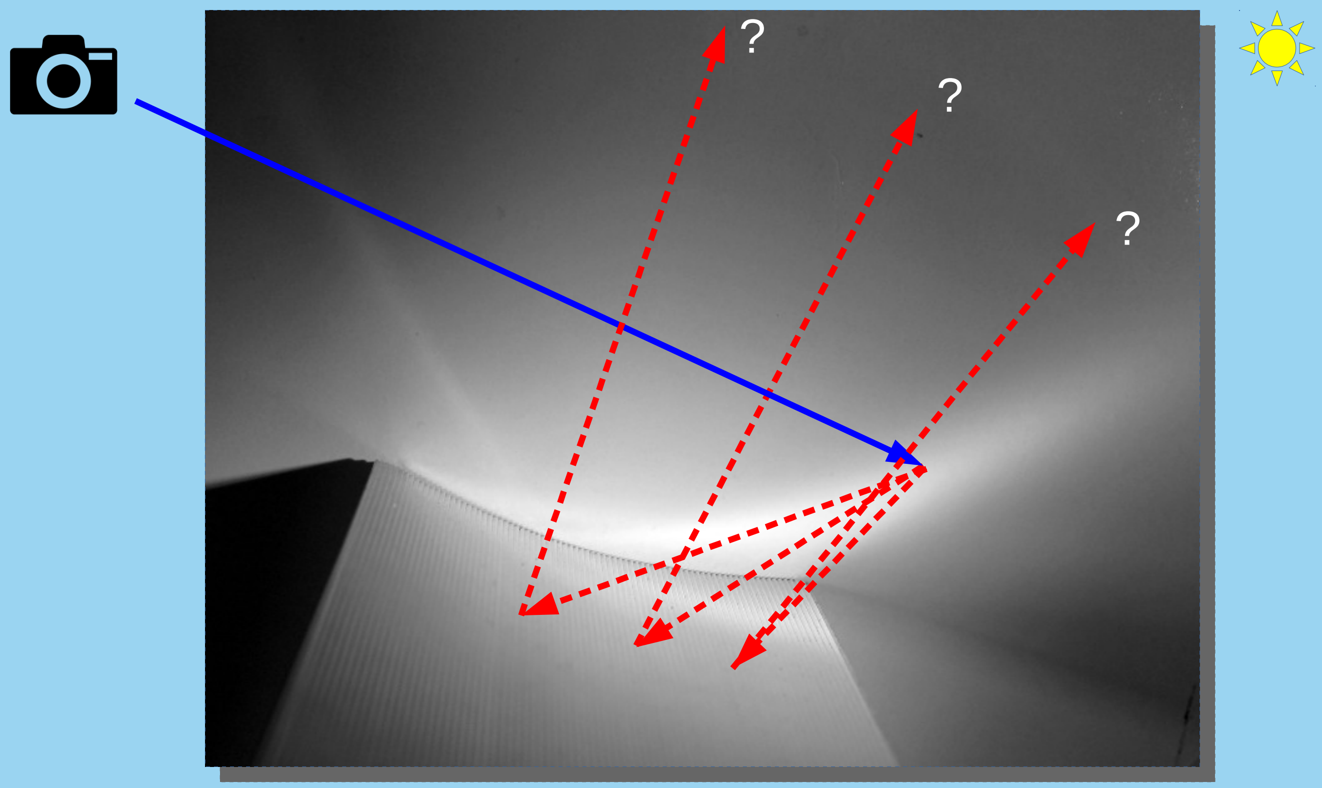
Introduction: Caustics in Daylight Redirection

Daylight redirecting systems exhibit specular reflection → caustics

Retroreflecting lamella patented by Helmut Köster

Forward vs. Backward Raytracing

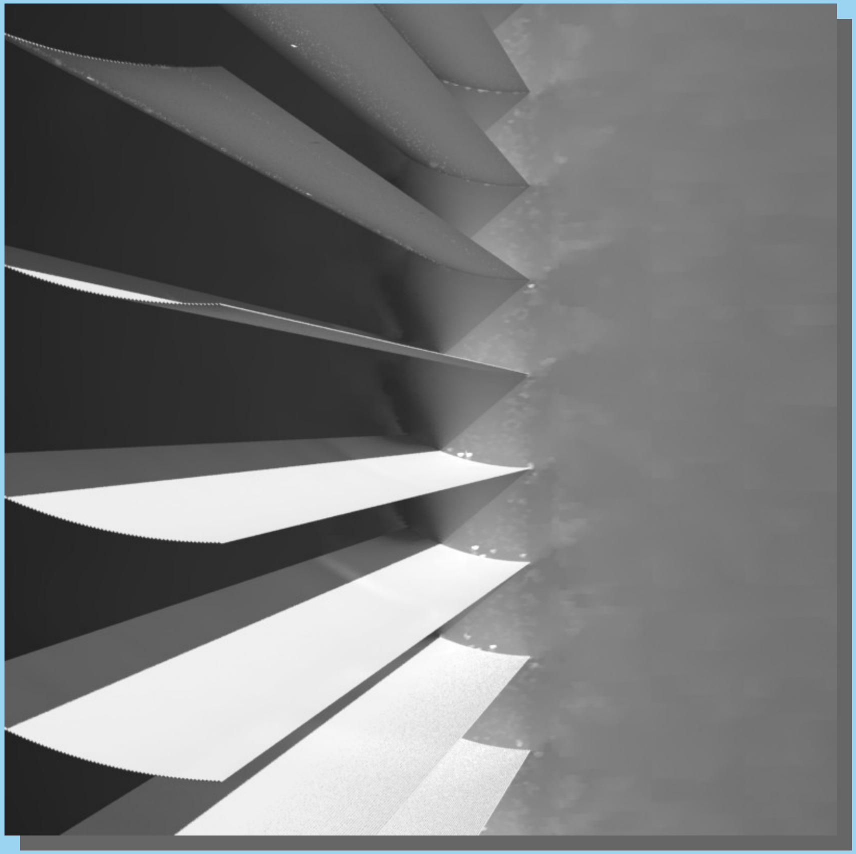
View → (Diffuse | Specular)$^+$ → Light



Which sampling direction lies within specular lobe?

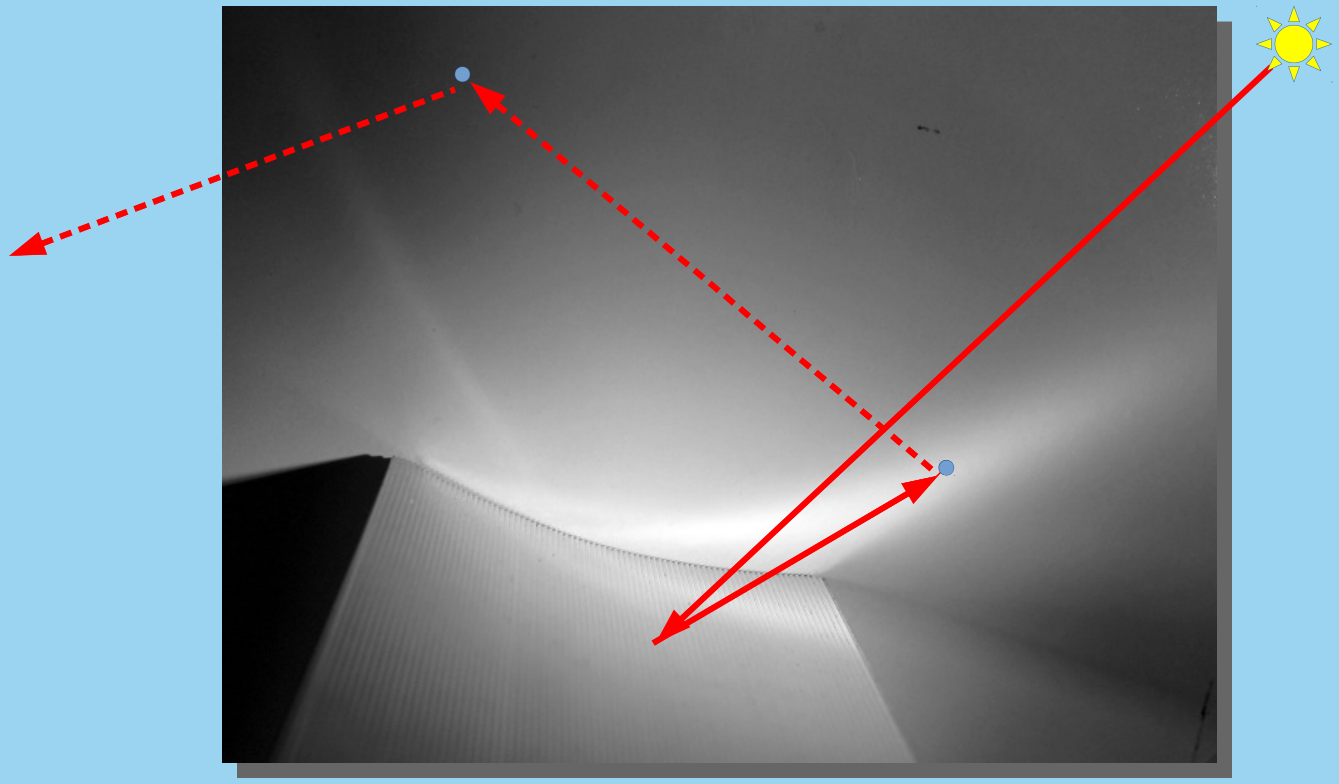
Forward vs. Backward Raytracing

Backward raytracing with RADIANCE → noisy caustics



Forward Pass

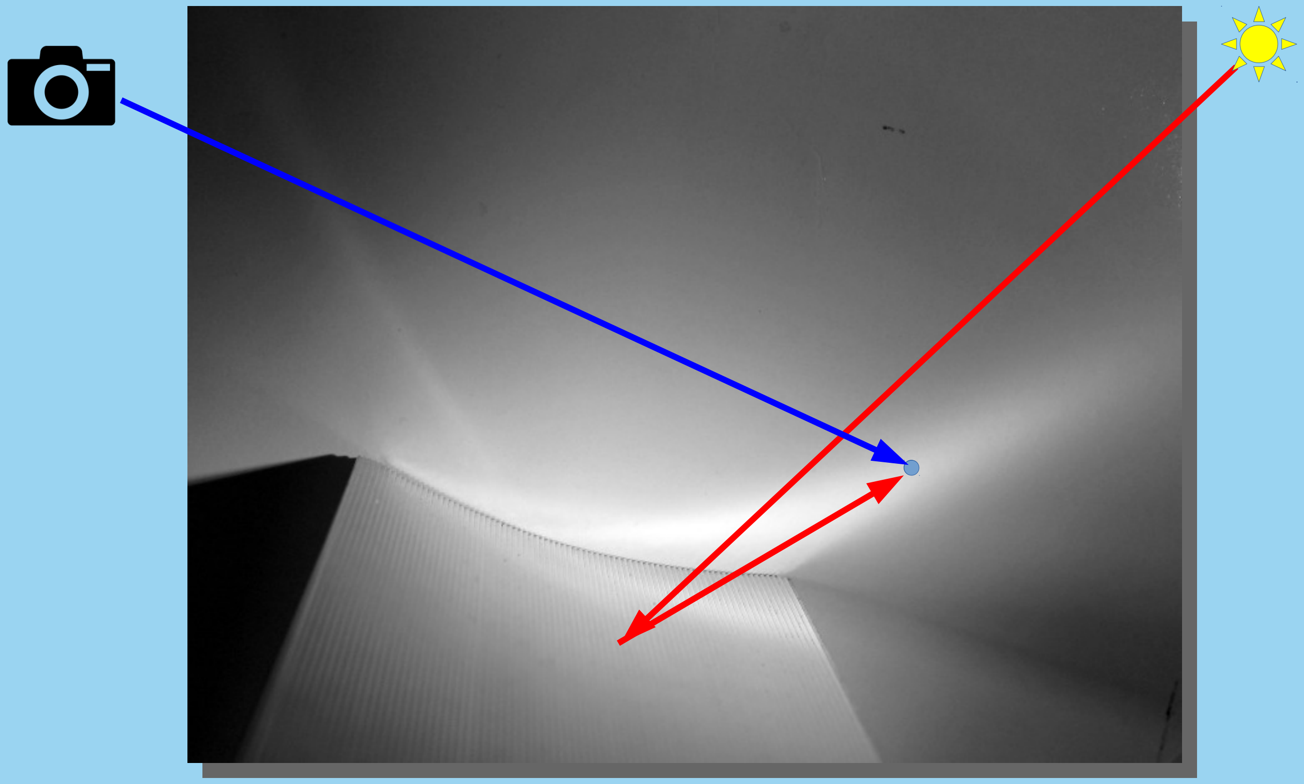
Supplement RADIANCE with forward pass: Light → (Diffuse | Specular)$^{+}$ ← View



Store indirect hitpoints and ray flux

Backward Pass

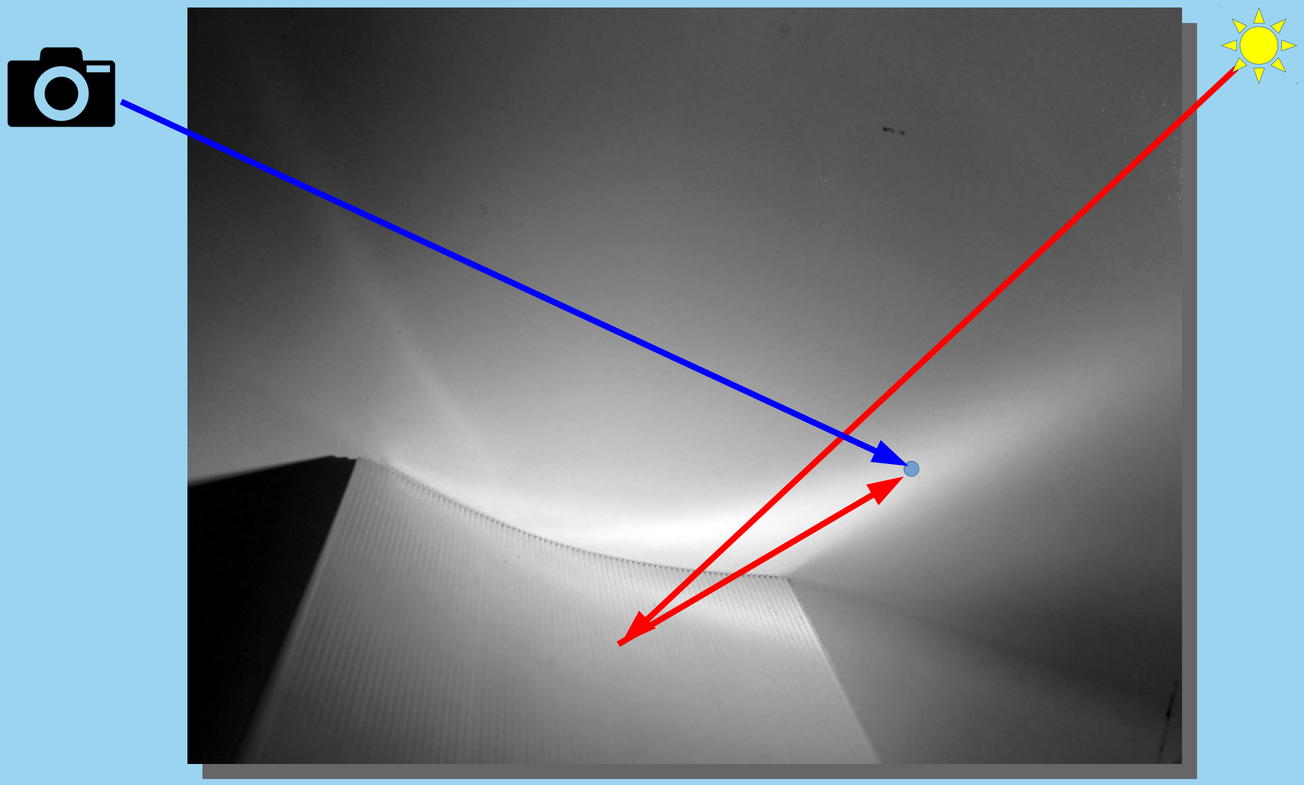
Couple to RADIANCE's backward pass: Light → (Diffuse | Specular)$^{+}$ ← View



Look up nearby hitpoints and evaluate irradiance

Backward Pass

Forward + backward = bidirectional raytracer!

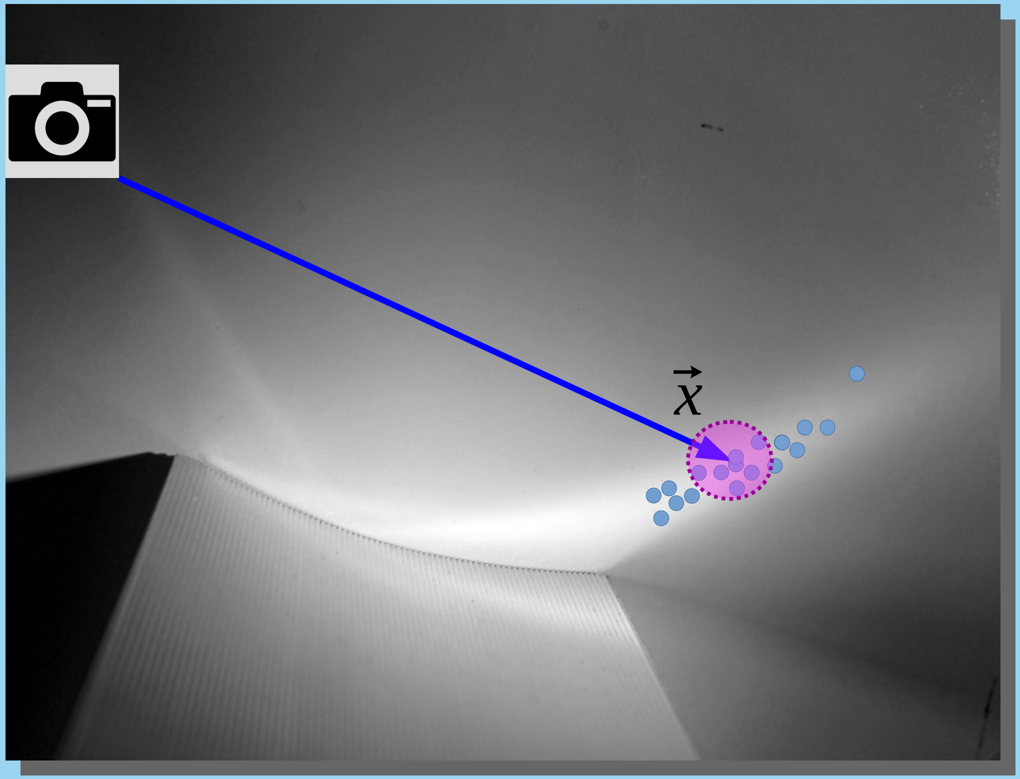


Backward Pass: Density Estimate

Irradiance *E(x,n)* at point x proportional to density of *n* nearest photons

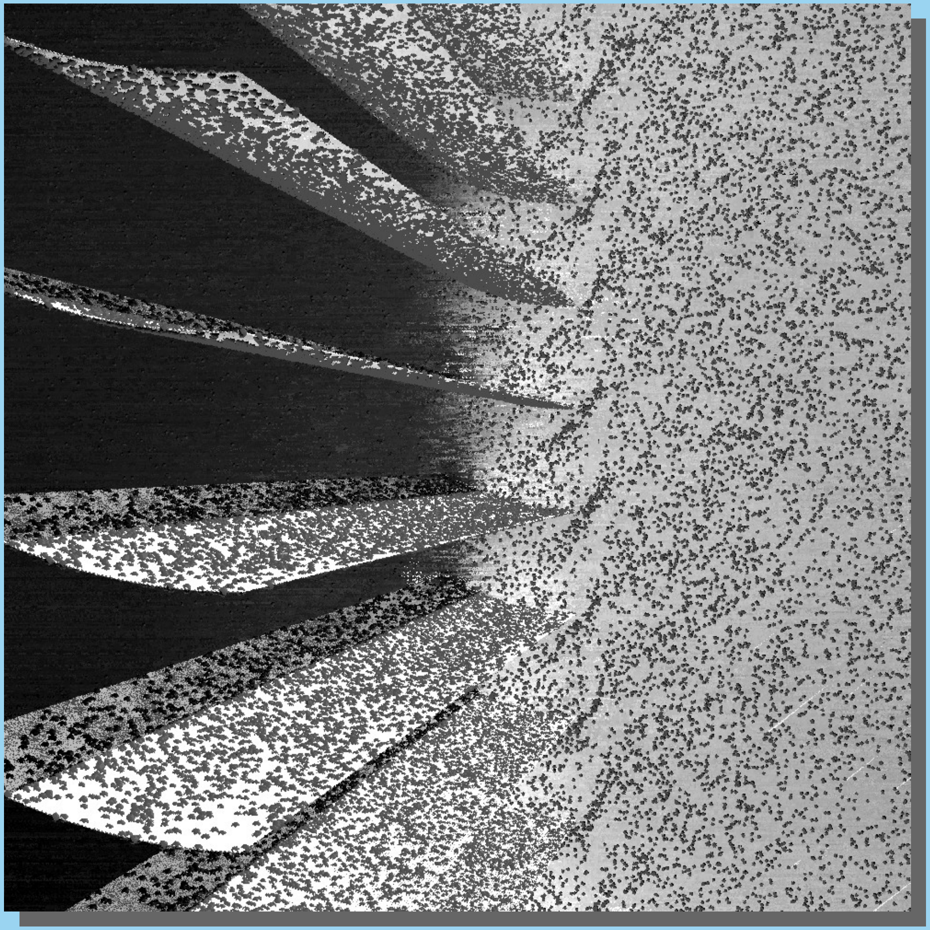
$$E(\vec{x},n) \approx \sum_i^n k(|\vec{x}-\vec{x}_i|)\Phi_i$$

$\vec{x}_i : photon\ position$
$\Phi_i : photon\ flux\,[W]$
$k : normalised\ filter$



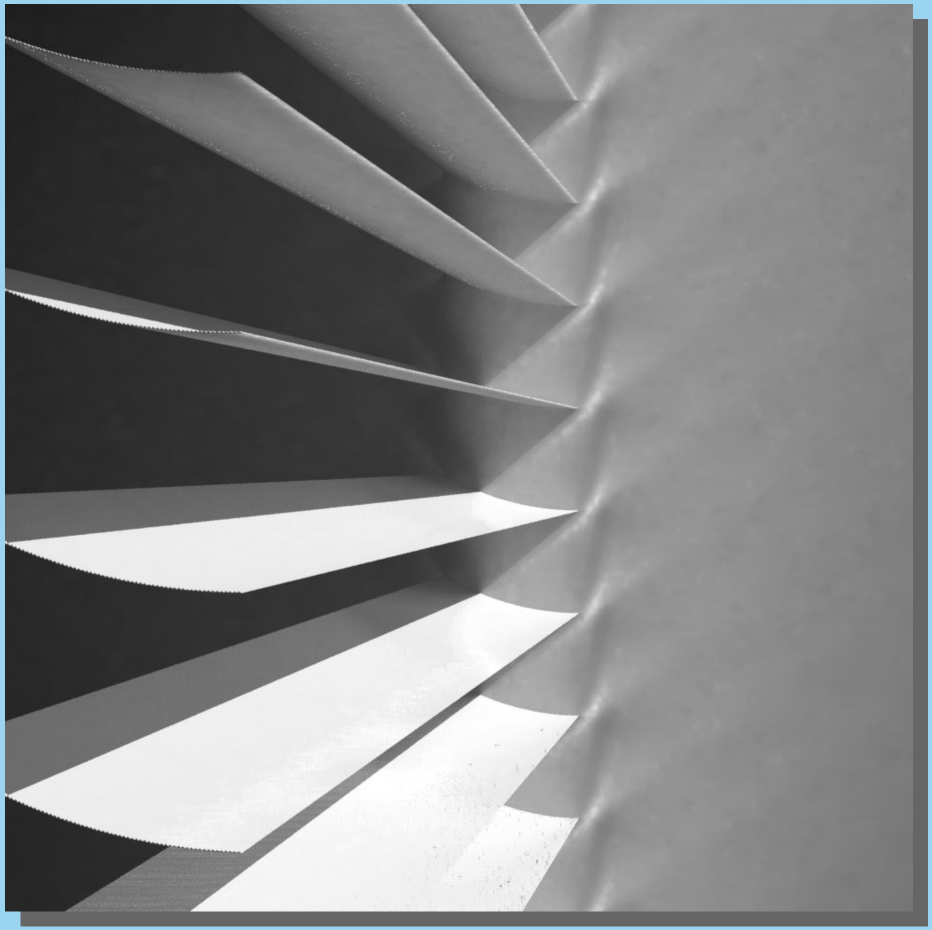
Number of nearest photons *n* characterises the density estimate *bandwidth*

RADIANCE Photon Map



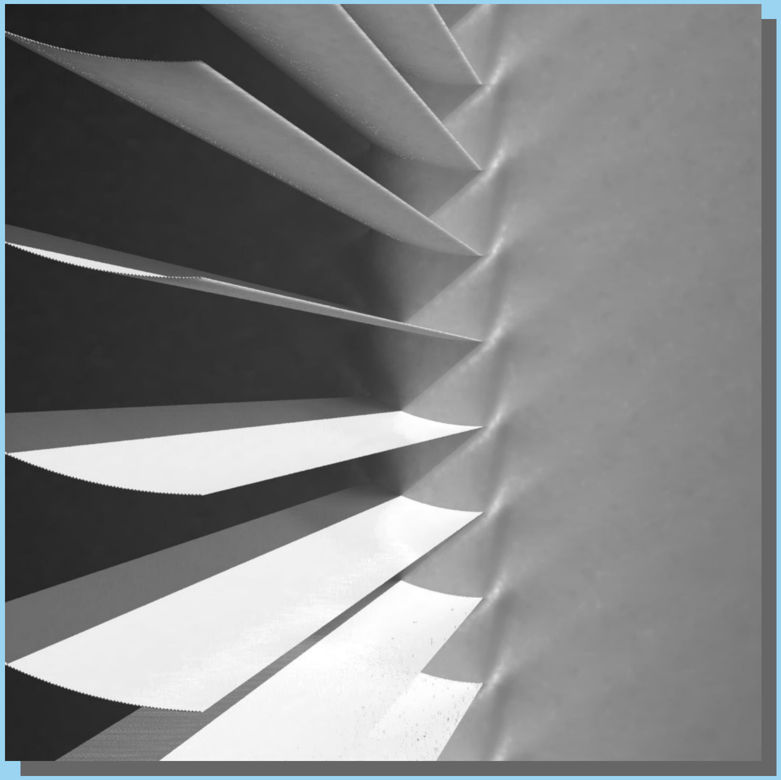
Photon distribution after forward pass (250k photons)

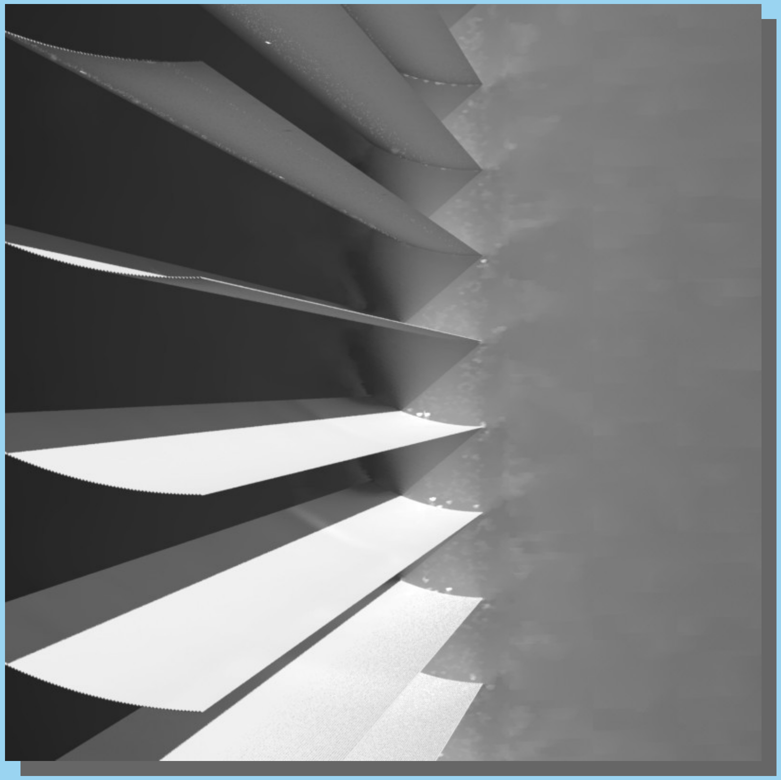
RADIANCE Photon Map



Final rendering after
backward pass (250k photons)

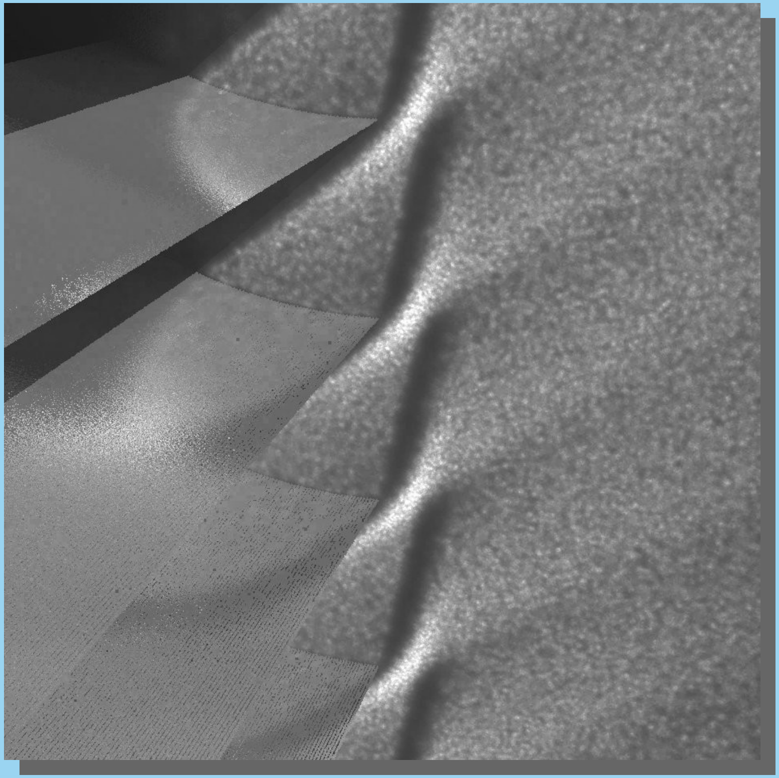
Photon Map (l) vs. RADIANCE Classic (r)



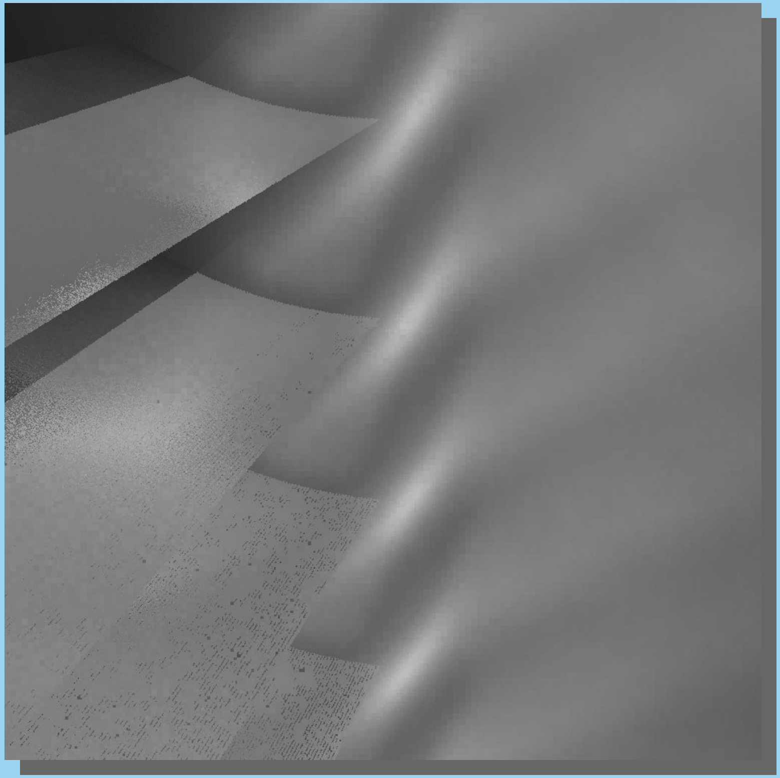


Bias vs. Noise

Inherent tradeoff between noise and bias (blurring) in density estimate



Bandwidth = 20 photons → noisy



Bandwidth = 2000 photons → biased

RADIANCE Photon Map

- Originally developed at Fraunhofer ISE 1999-2001 (FARESYS project), current development at HSLU since 2013 (DRC project)
- Monte Carlo simulation of light particle transport [Wann Jensen 1995]
- Photometrically validated [Schregle and Wienold 2004]
- **Forward pass (`mkpmap`)**
  - emits photons at light sources
  - stores hitpoints on diffuse surfaces
  - scatters photons based on BSDF **or**
  - absorbs probabilistically based on albedo (*Russian Roulette*)
- **Backward pass (`rpict/rtrace/rvu`)**
  - Irradiance estimated from density of photons in the vicinity of hitpoint

What's new in Photon Map 4.2 ?

(The short version)

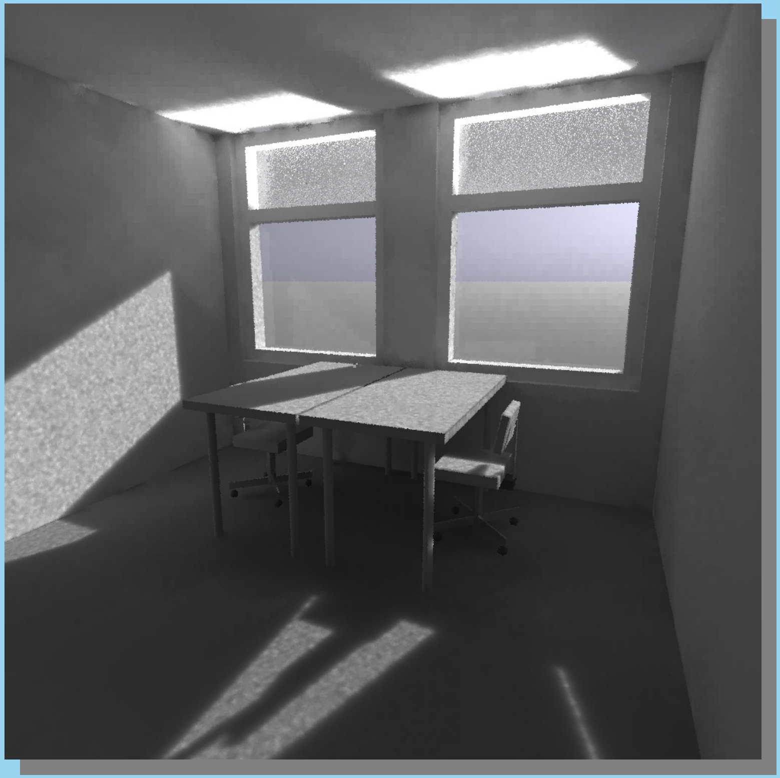
What's new in Photon Map 4.2 ?

- BSDF support → measured materials
- Progressive photon mapping → user friendlier, larger pmaps, less noise
- Support for light source contributions → climate based simulation
- Low discrepancy sampling → reduced noise, faster convergence
- Out of core photon map → load on demand, reduced memory footprint
- Integration into official RADIANCE 4.2 → no more patches (woohoo!)

What's new: BSDF Support

Scattering from measured BSDF of prismatic film

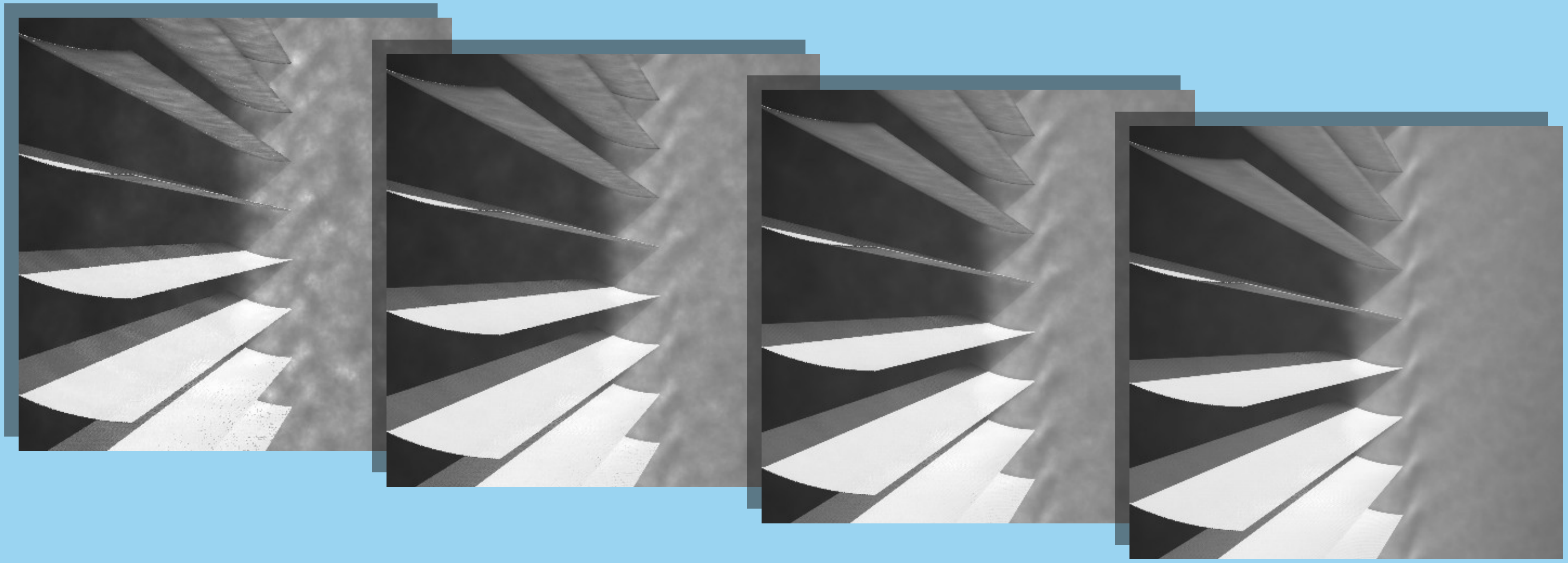
RADIANCE Classic



Photon Map

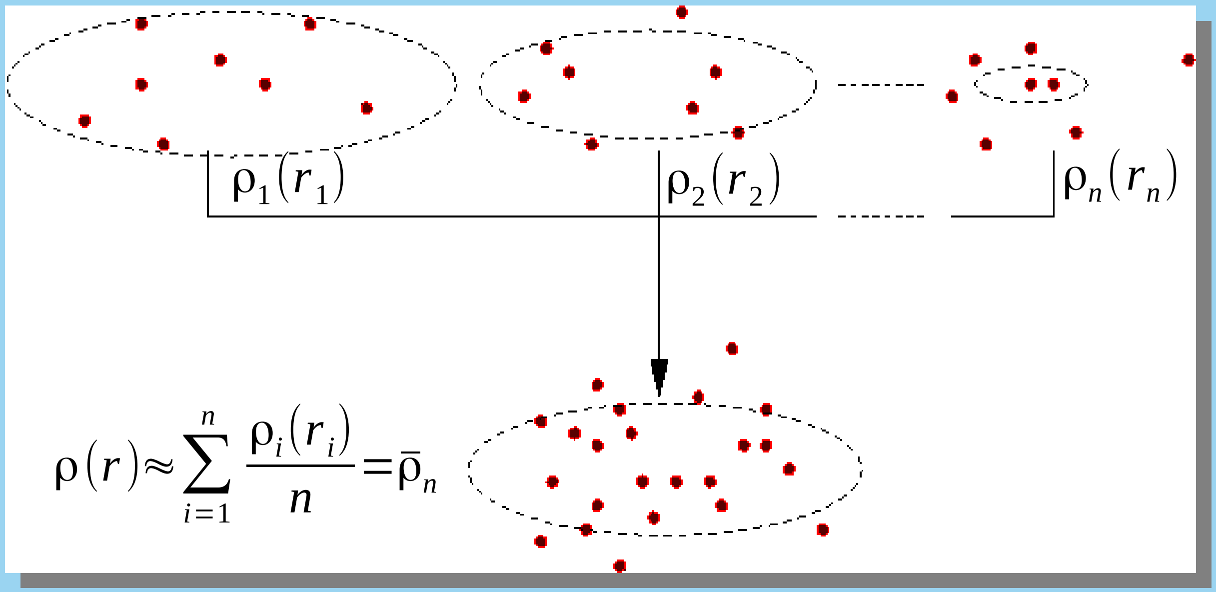
What's new: Progressive Photon Mapping

- Iterative process with preview of progressive refinement [Hachisuka 2008]
- Accumulates density estimates from multiple photon maps → noise reduction
- Reduces bandwidth at each iteration → bias reduction
- Simplified parametrisation for non-expert users (photon map size not fixed a priori)



What's new: Progressive Photon Mapping

- *n* accumulated density estimates $\rho_1 \dots \rho_n \approx$ density estimate from combined pmap
- Decreasing bandwidths $r_1 > r_2 > \dots > r_n$
- Decomposition into *n* smaller photon maps relaxes memory constraints
- Iterations are independent and can be executed in parallel [Knaus & Zwicker, 2011]



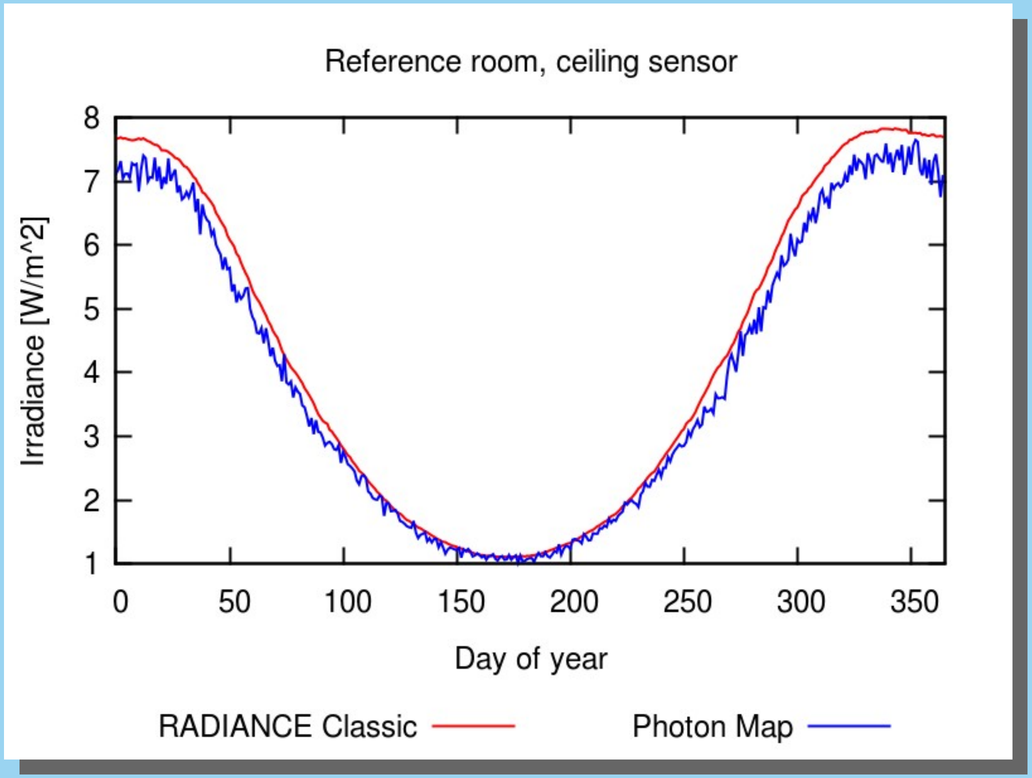
What's new: Progressive Photon Mapping

- Implemented as Perl script + Perl Data Language (PDL) for matrix ops + obscure modules from CPAN :^(
- Image based approach; iterations run as parallel instances of `mkpmap` followed by `rpict`.
- Termination criteria:
  - Error threshold
  - Max number of iterations
  - Manual override
- Saves final accumulated image optionally partial results every *n* iterations
- Cannot reuse partial photon maps
- Currently only proof of concept

What's new: Progressive Photon Mapping

What's new: Light Source Contributions

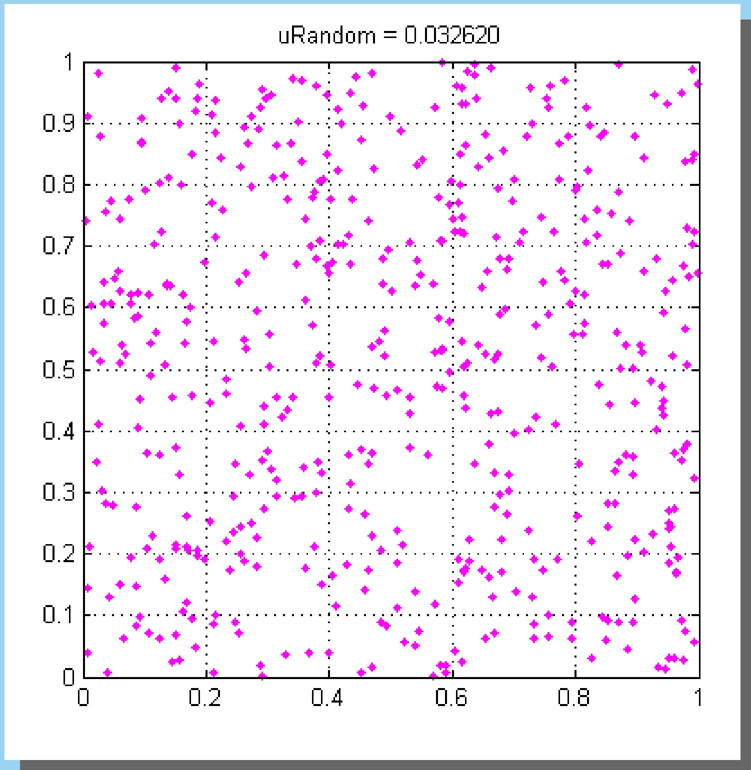
Photon map accounts for separate contributions from light sources in combined annual simulation → climate based daylight sim via `rcontrib`

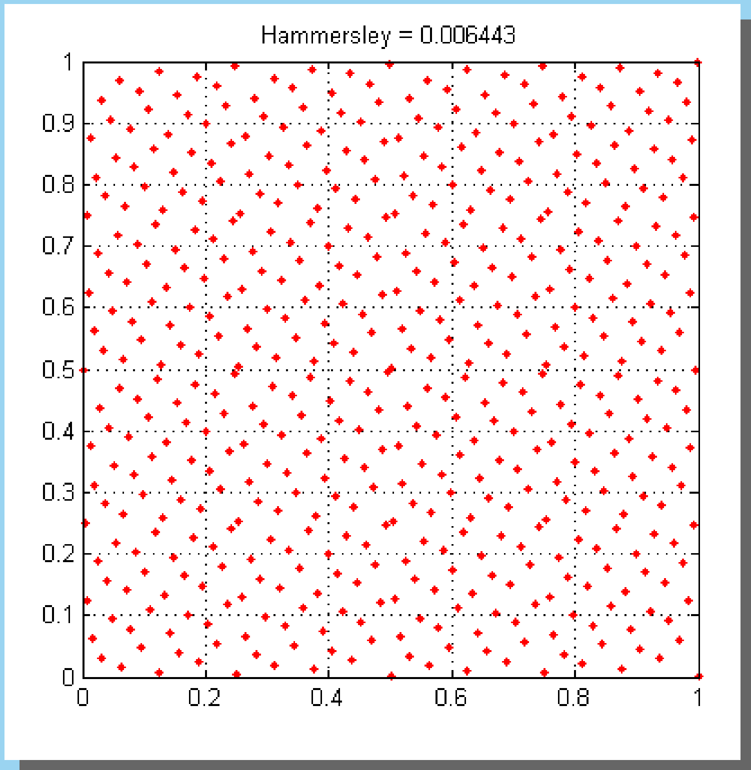


365 sun positions at reference room ceiling using `rcontrib`

What's new: Low Discrepancy Sampling

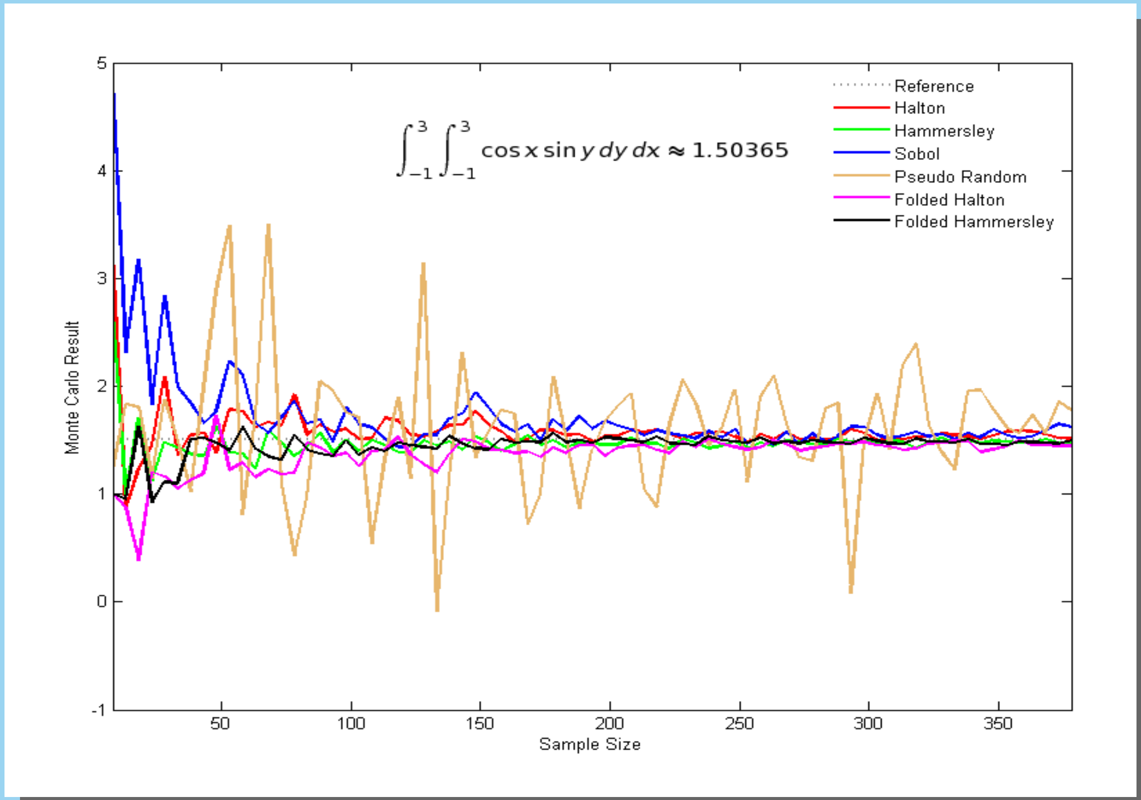
Low discrepancy sequences cover sampling space more uniformly than pseudorandom numbers → less clustering and noise





What's new: Low Discrepancy Sampling

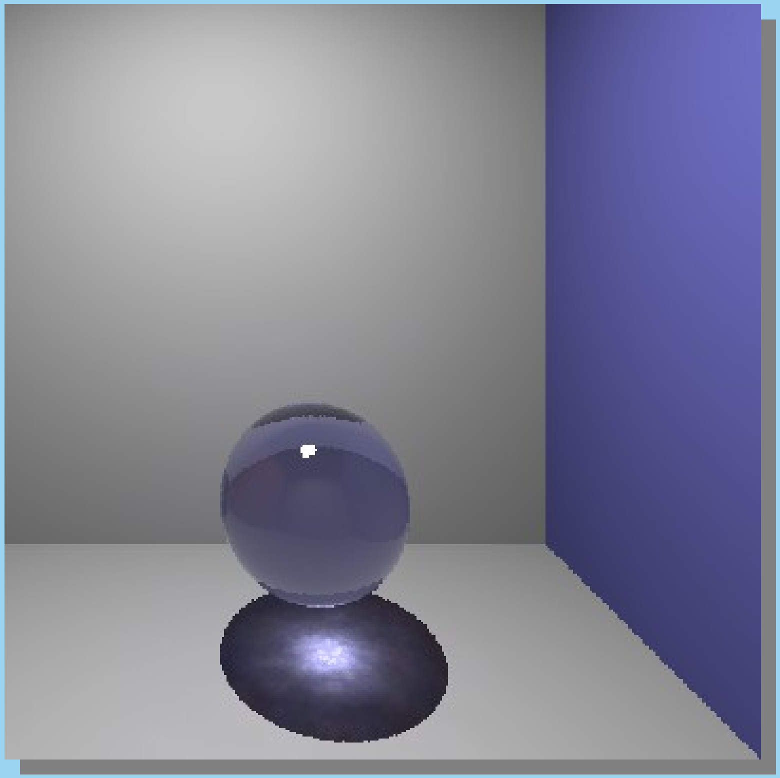
Low discrepancy sequences cover sampling space more uniformly than pseudorandom numbers → faster convergence



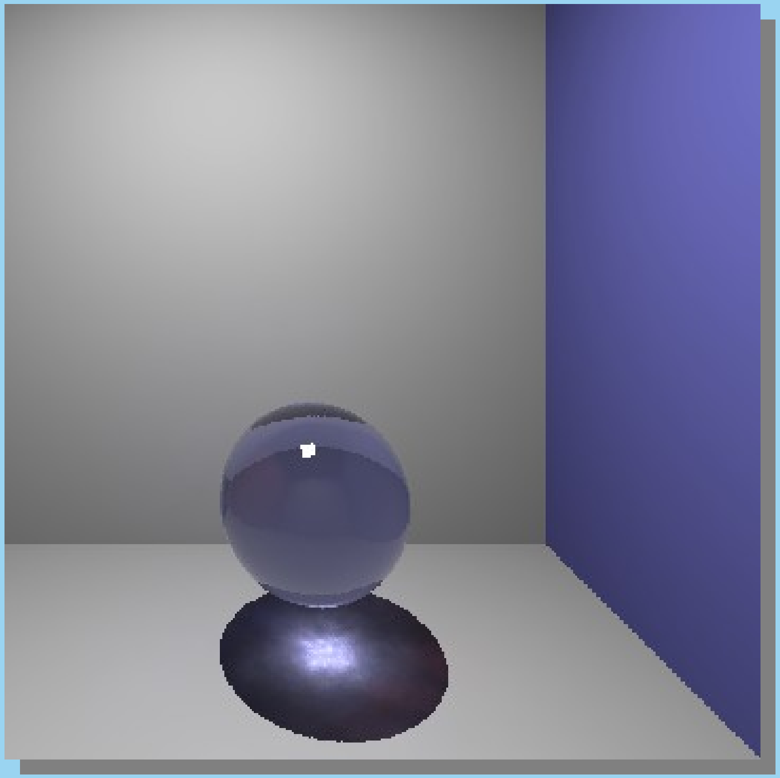
Monte Carlo integration using low discrepancy sampling (*Quasi-Monte-Carlo*) vs. reference solution

What's new: Low Discrepancy Sampling

Initial results: improved low frequency caustic



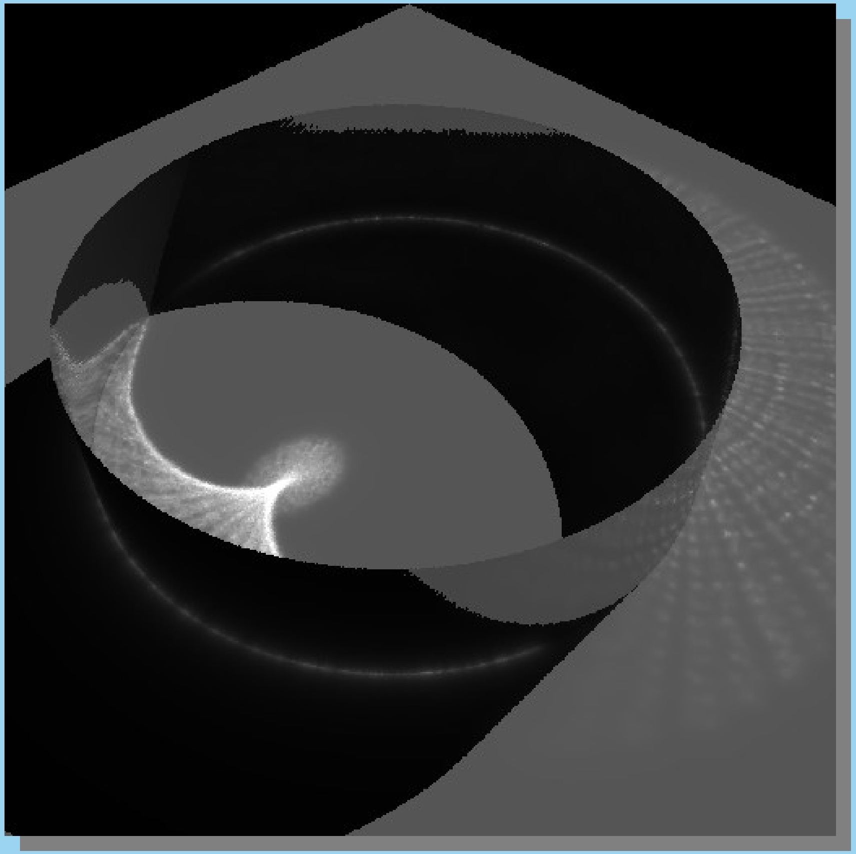
Pseudo-Random



Low Discrepancy (Halton)

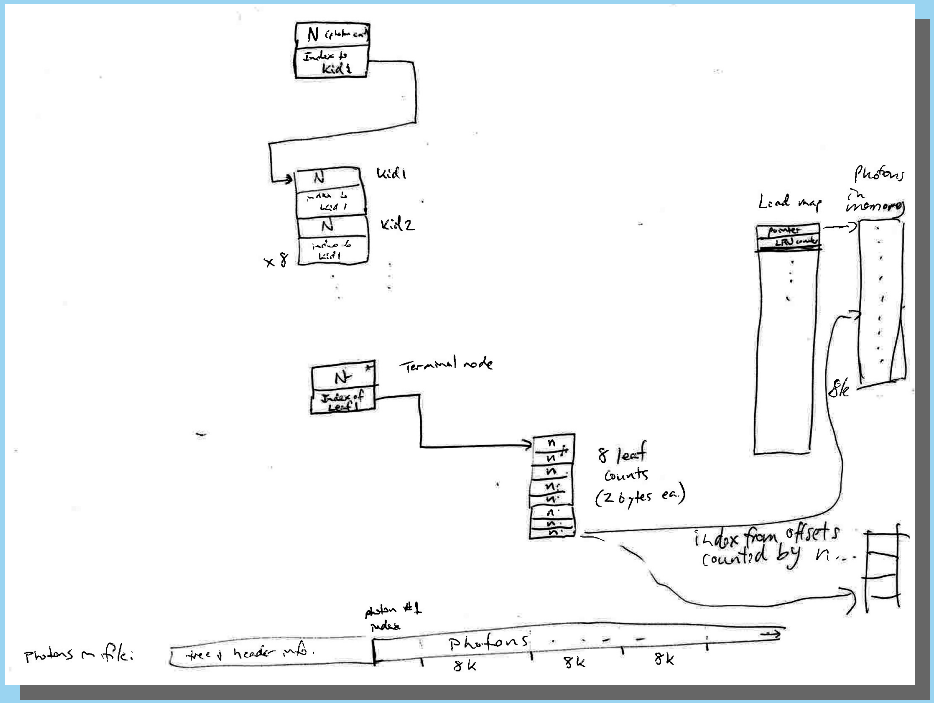
What's new: Low Discrepancy Sampling

Pitfall: correlation can lead to visible artefacts in high frequency caustics!



What's new: Out of Core Photon Map

- Allows huge photon maps which exceed RAM capacity
- Loads from disk on demand → only visible photons in memory
- Replaces kd-tree with sparse octree, built bottom-up via Hilbert indexing



Ze Plan
Greg Ward,
2014
Pencil on paper
HSLU archives

What's new: Integration with RADIANCE 4.2

- Photon map part of official RADIANCE distribution → no more patches
- Output files now comply with RADIANCE file format, photon map statistics in cleartext header → `pmapinfo` deprecated
- Isolation of photon map specific code from major RADIANCE components (ambient, direct, option parsing…) via subroutines → easier maintenance
- Double counting of paths already accounted for by photon map during backward pass currently material specific → needs more general solution
- Standard RADIANCE functionality preserved without pmap options
- Coordination of responsibility and code maintenance

What's old: Lingering Limitations

- Measurement points must still reside on receptor surfaces
- Clunky photon port workaround for distant light sources still requires user intervention
- No optimal solution to bias/noise tradeoff (inbuilt bias compensation incoherent and slow)
- Still no inbuilt parallelism or shared memory
- Photon lookups still not optimised for caching

Conclusion and ToDo

- Measured materials now supported via BSDF → needs thorough testing
- Progressive photon mapping simplifies use → needs reimplementation
- Integration into RADIANCE 4.2 distrib → testing & coordination with Greg
- Ongoing developments as part of DRC project at CC EASE
  - Climate based daylight simulation → needs (lots of) debugging
  - Low discrepancy sampling → by intern
  - Out of core photon map → partially implemented
- Update documentation!
- Beta testers?

Thank you for your attention!

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