Progressive Photon Mapping Extensions

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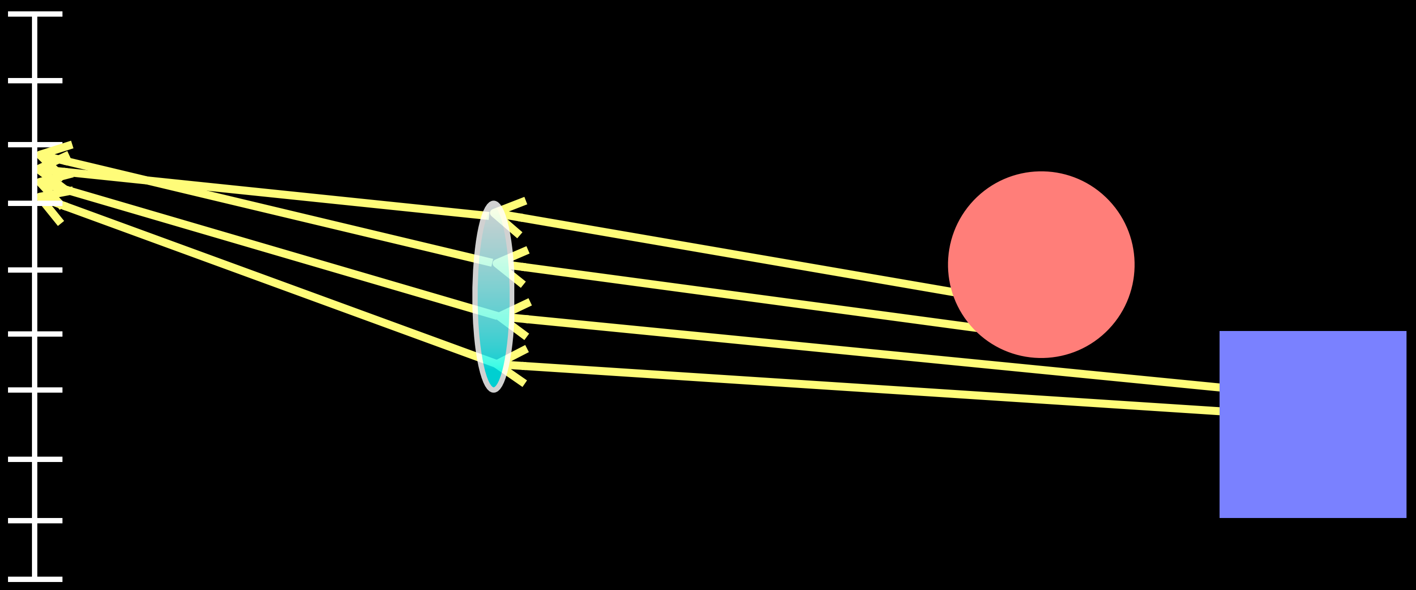
State of the Art in Photon Density Estimation

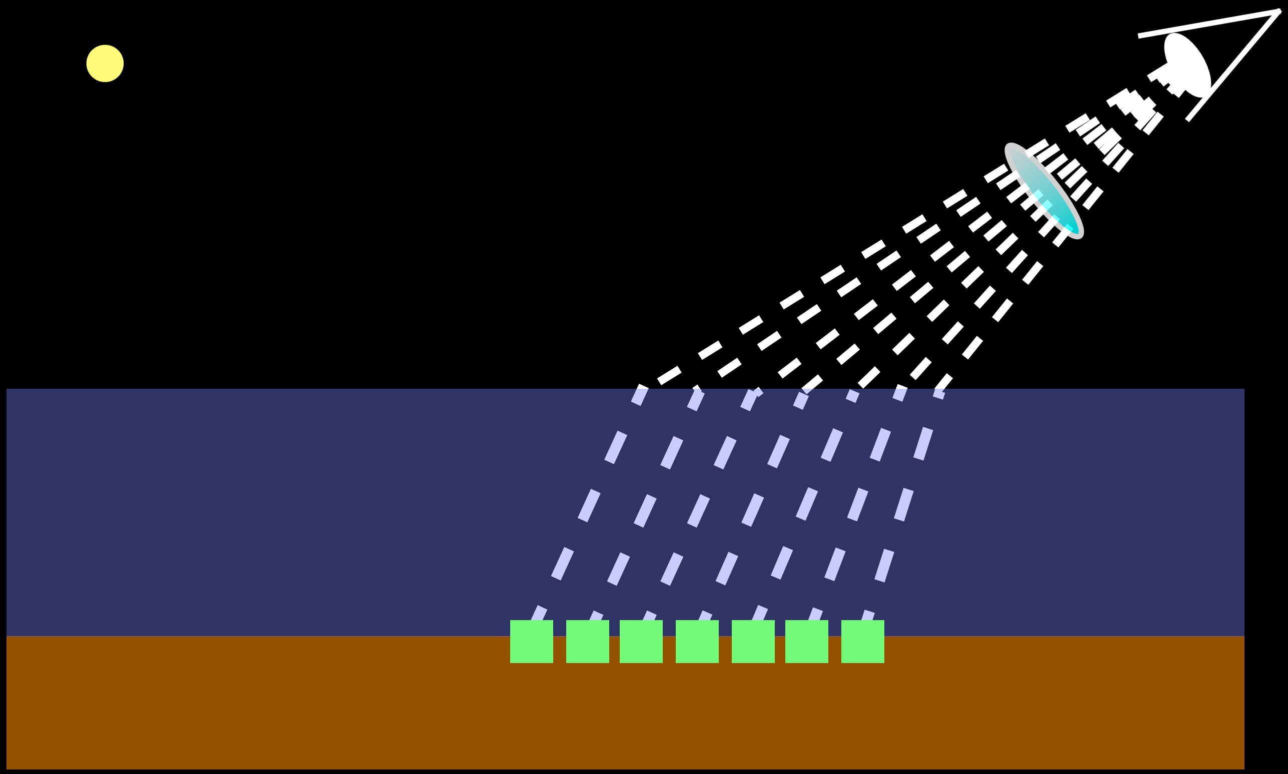

SANDY
contractors
594461

Distribution Ray Tracing

- Computes average illumination [Cook et al. 84]



Lens Simulation with PPM



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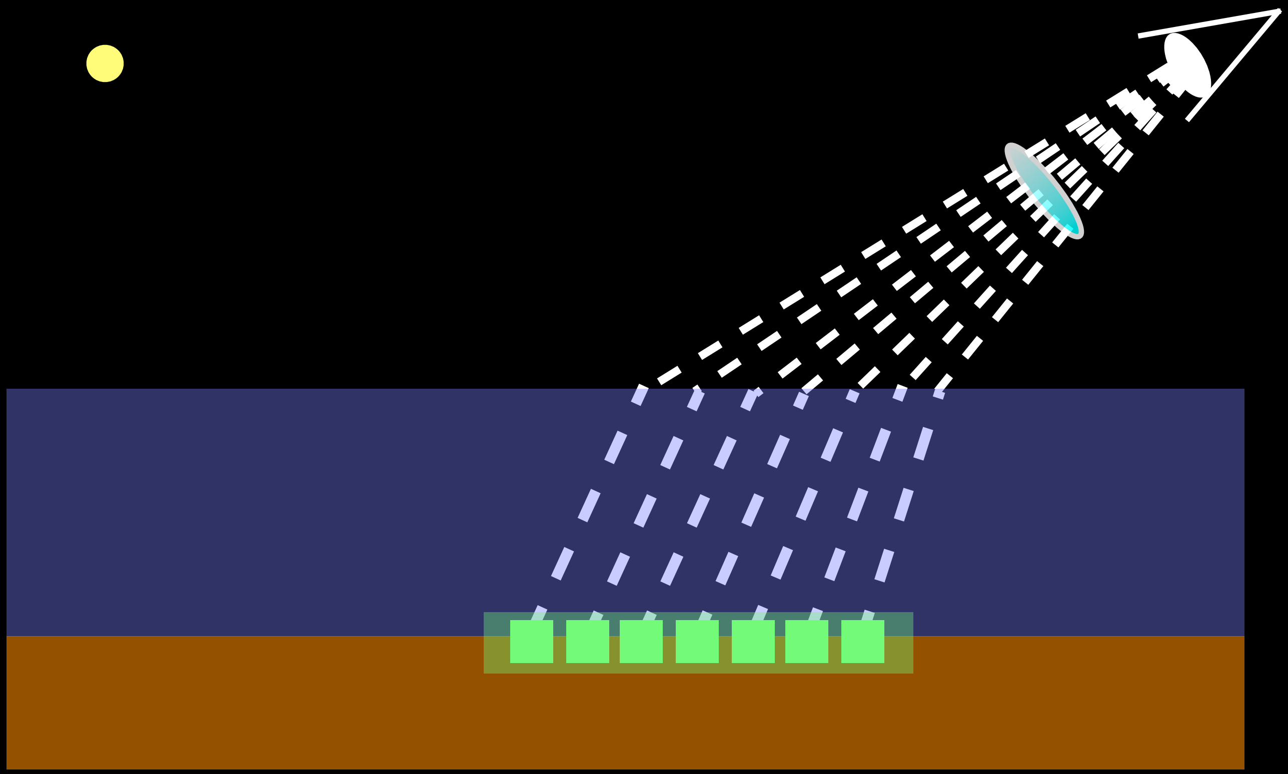
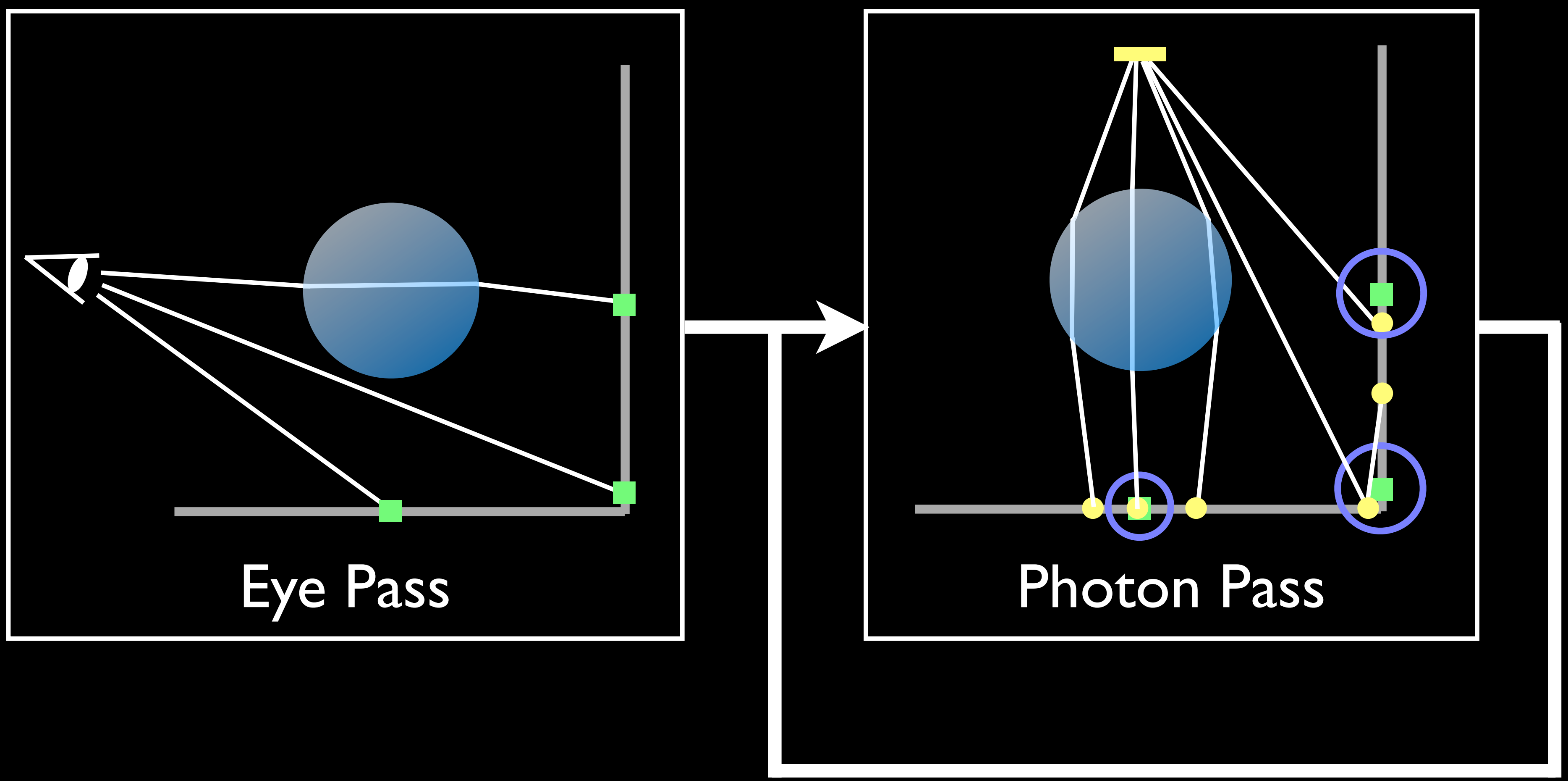
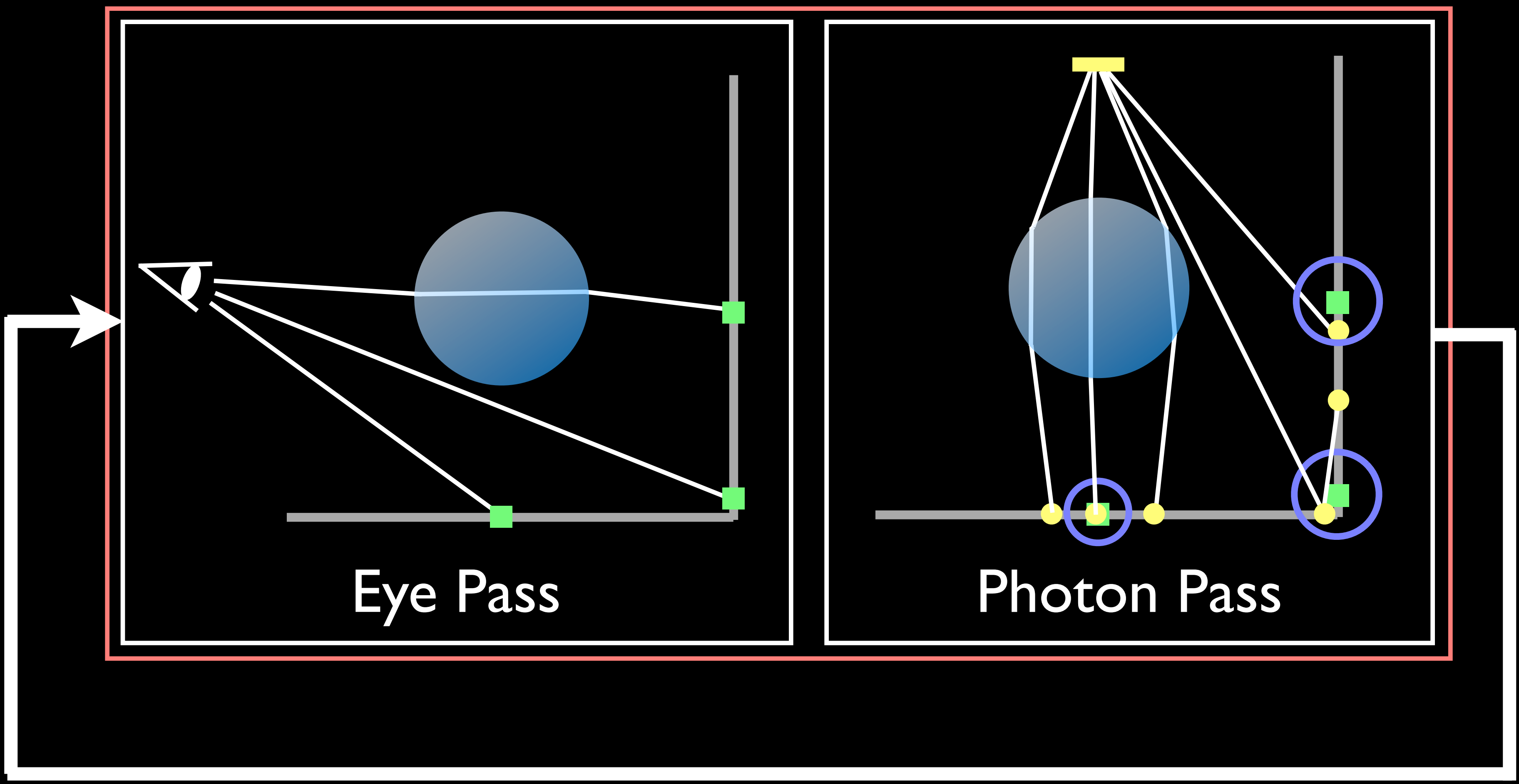


Infinite number of measurement points

PPM



Stochastic PPM



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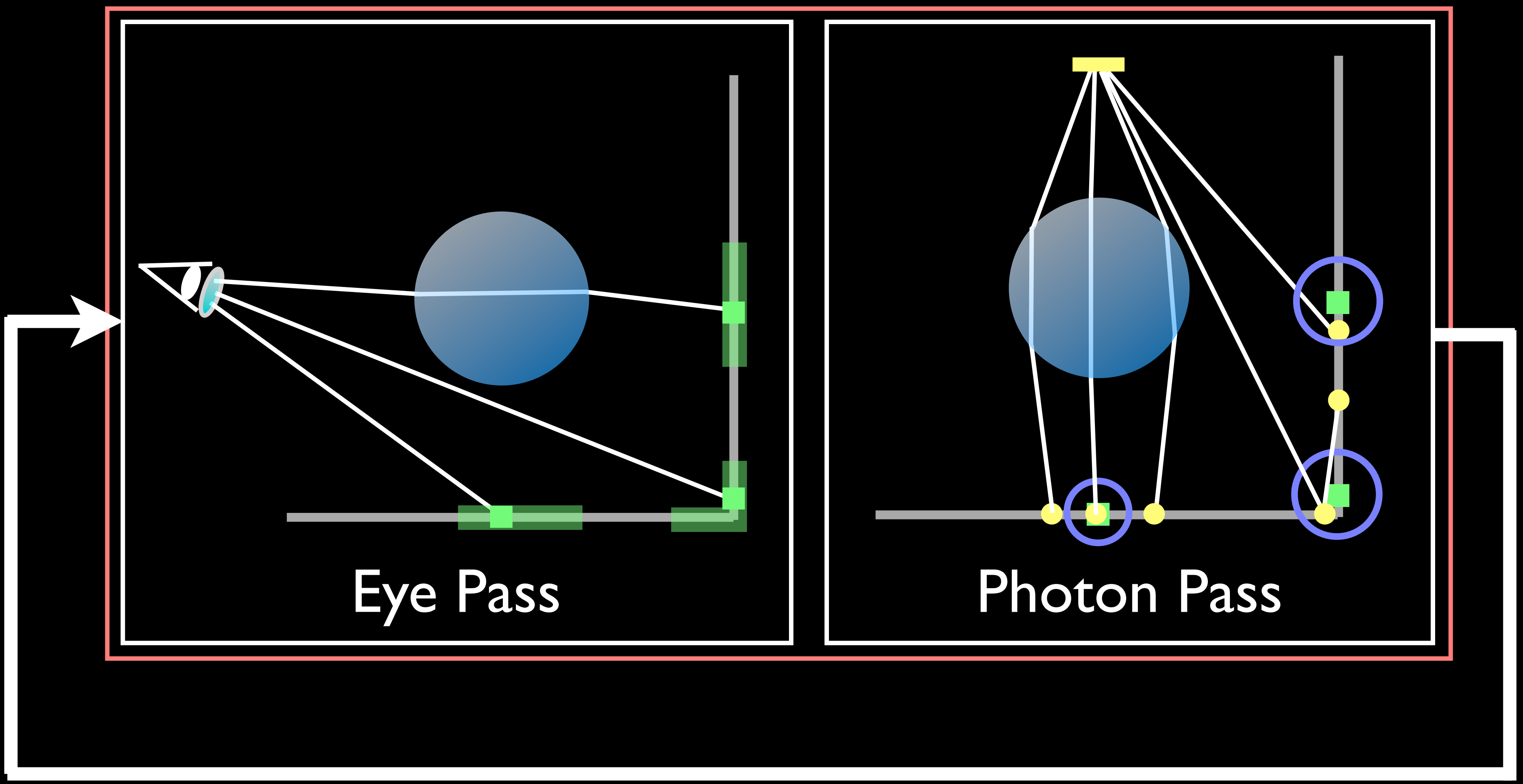

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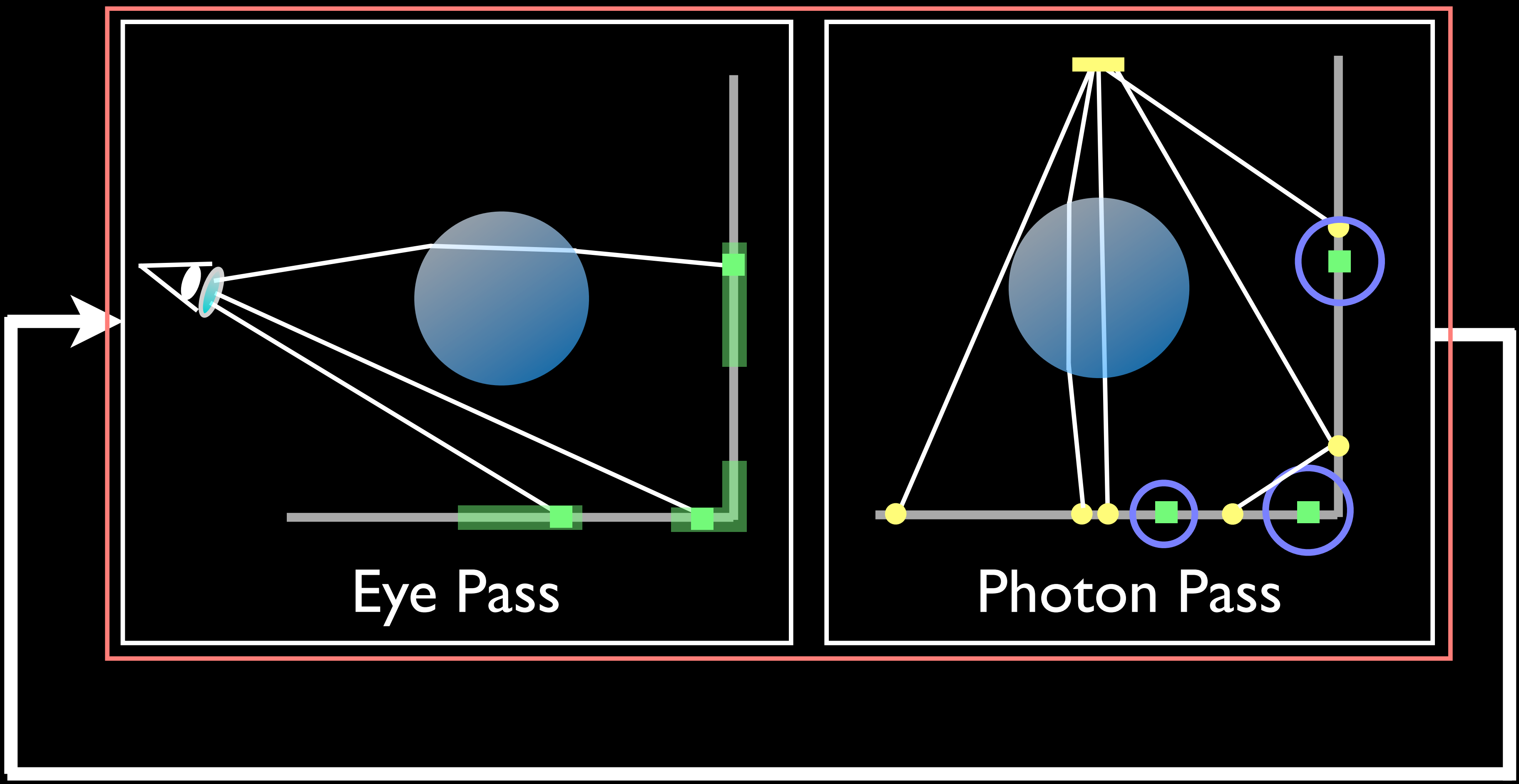

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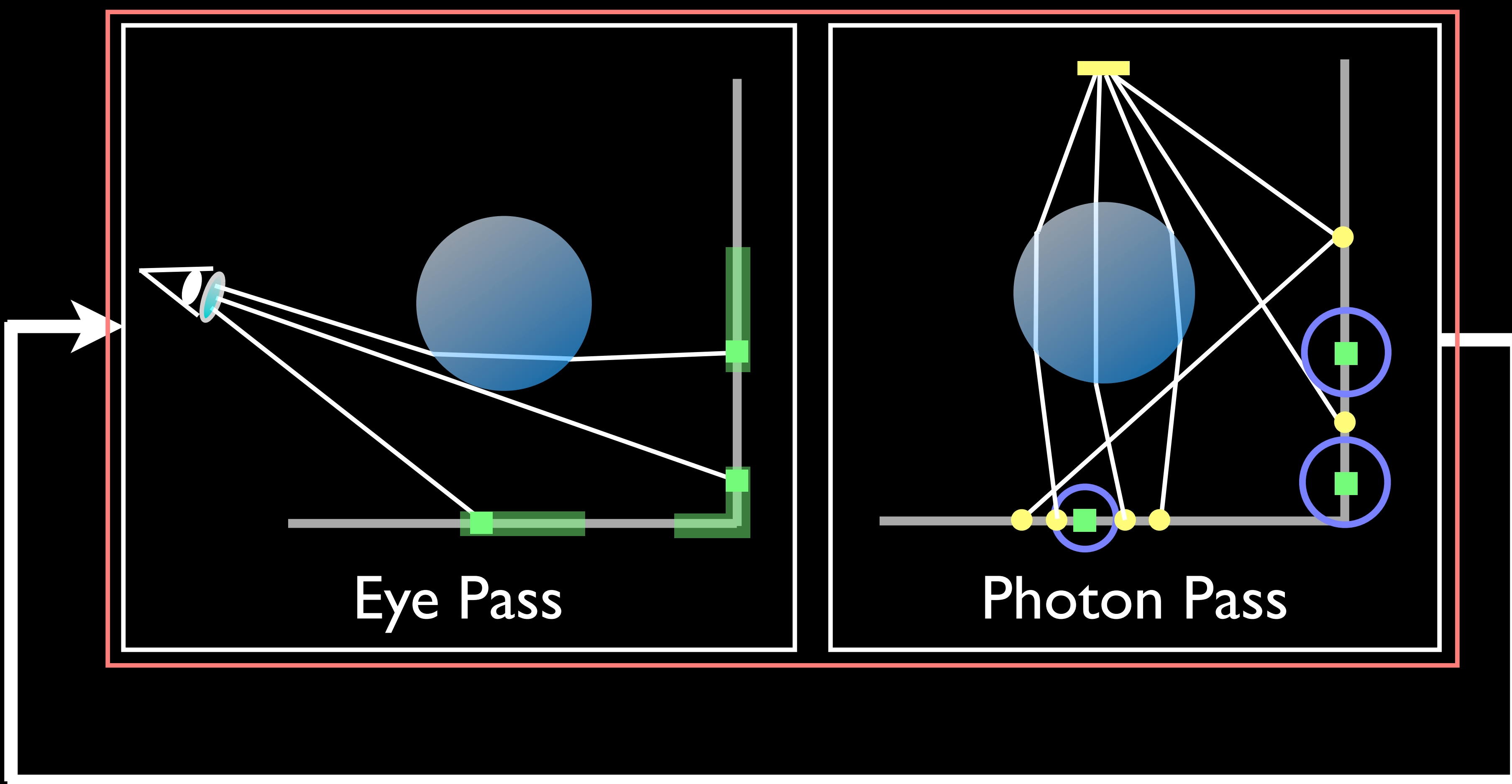


Stochastic Progressive Density Estimation

$$L_i\left(S,\vec{\omega}\right) = \frac{\tau_i\left(S,\vec{\omega}\right)}{\pi R_i\left(S\right)^2 N_e(i)}$$

$$\boxed{\lim_{i\to\infty} L_i\left(S,\vec{\omega}\right) = L\left(S,\vec{\omega}\right)}$$

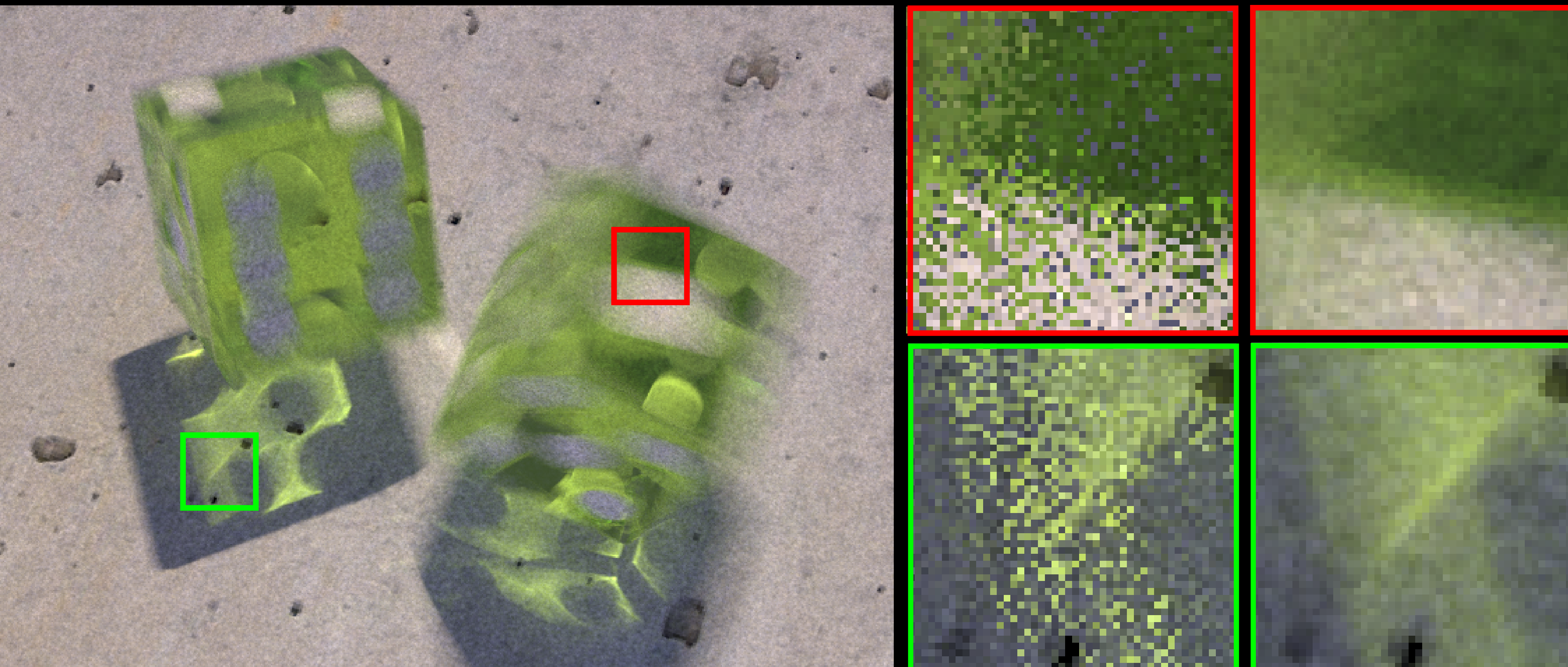
Provable convergence to
average photon density over a region S

Bidirectional Path Tracing

Original PPM

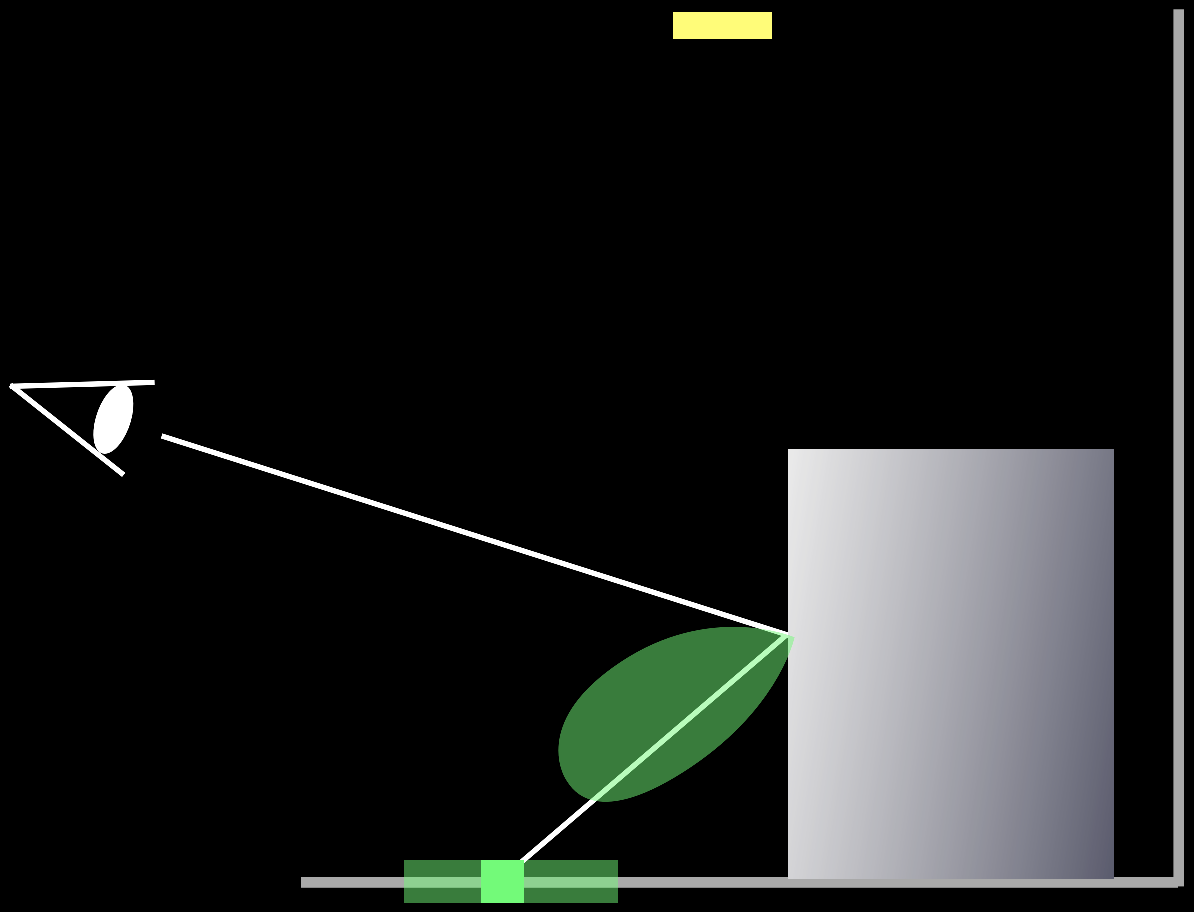
Stochastic PPM

Motion Blur



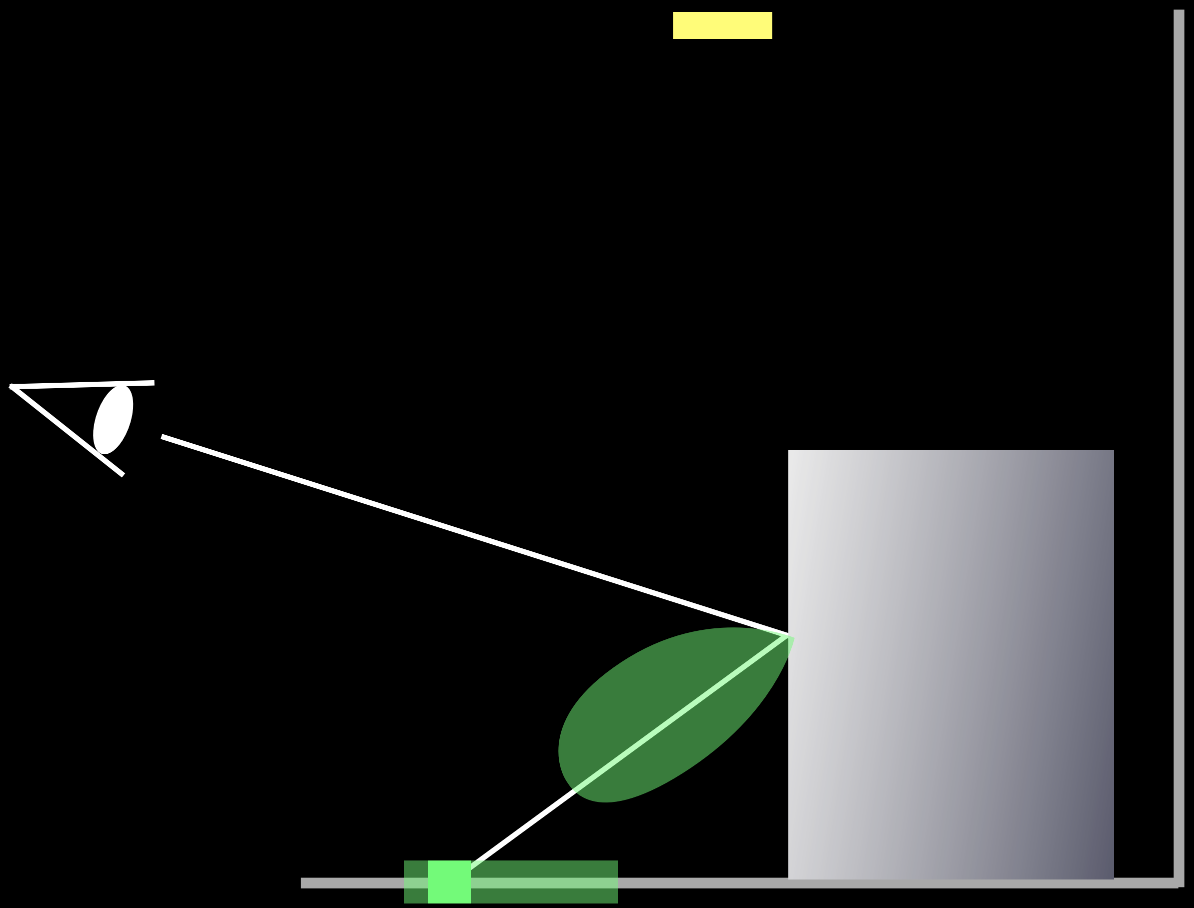
Equal time, Equal memory PPM SPPM

Glossy Materials with SPPM



Trace one bounce rays

Glossy Materials with SPPM



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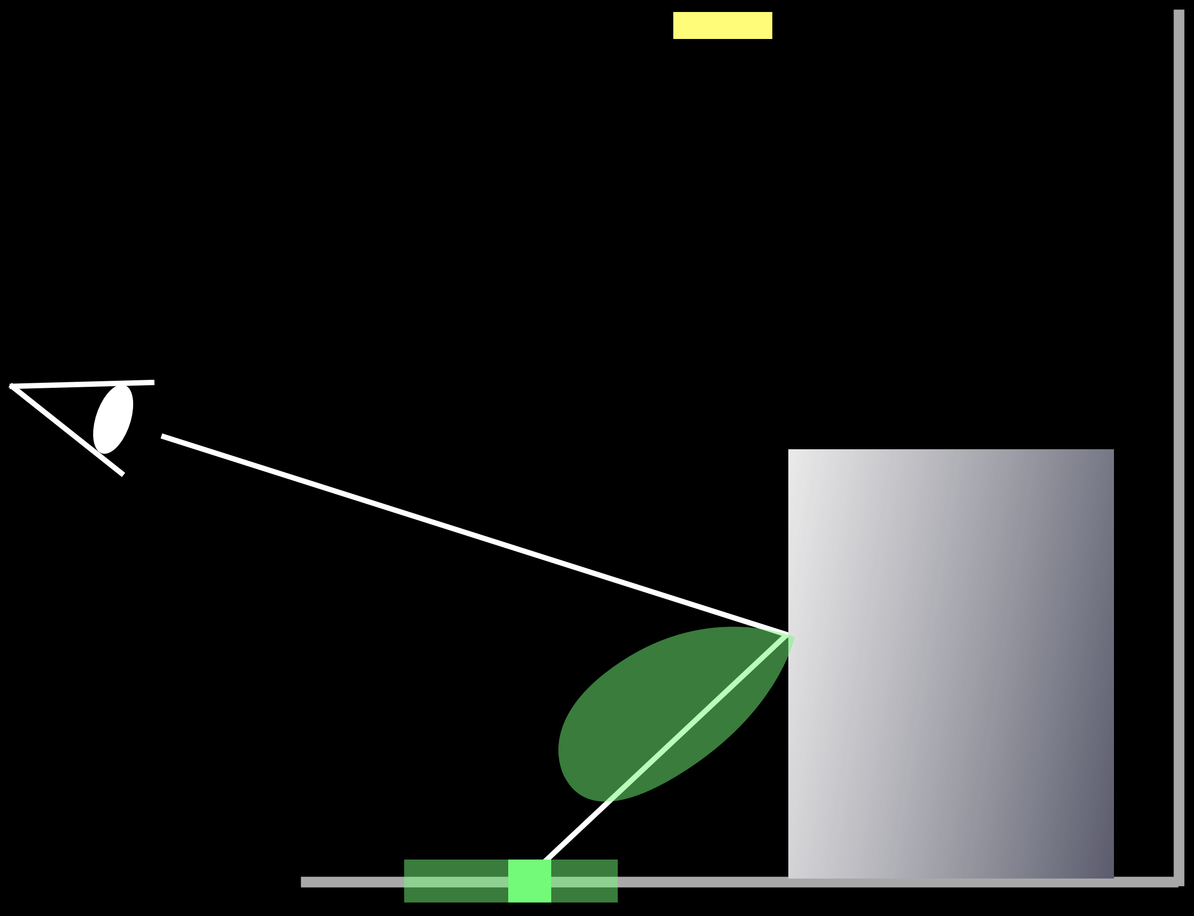
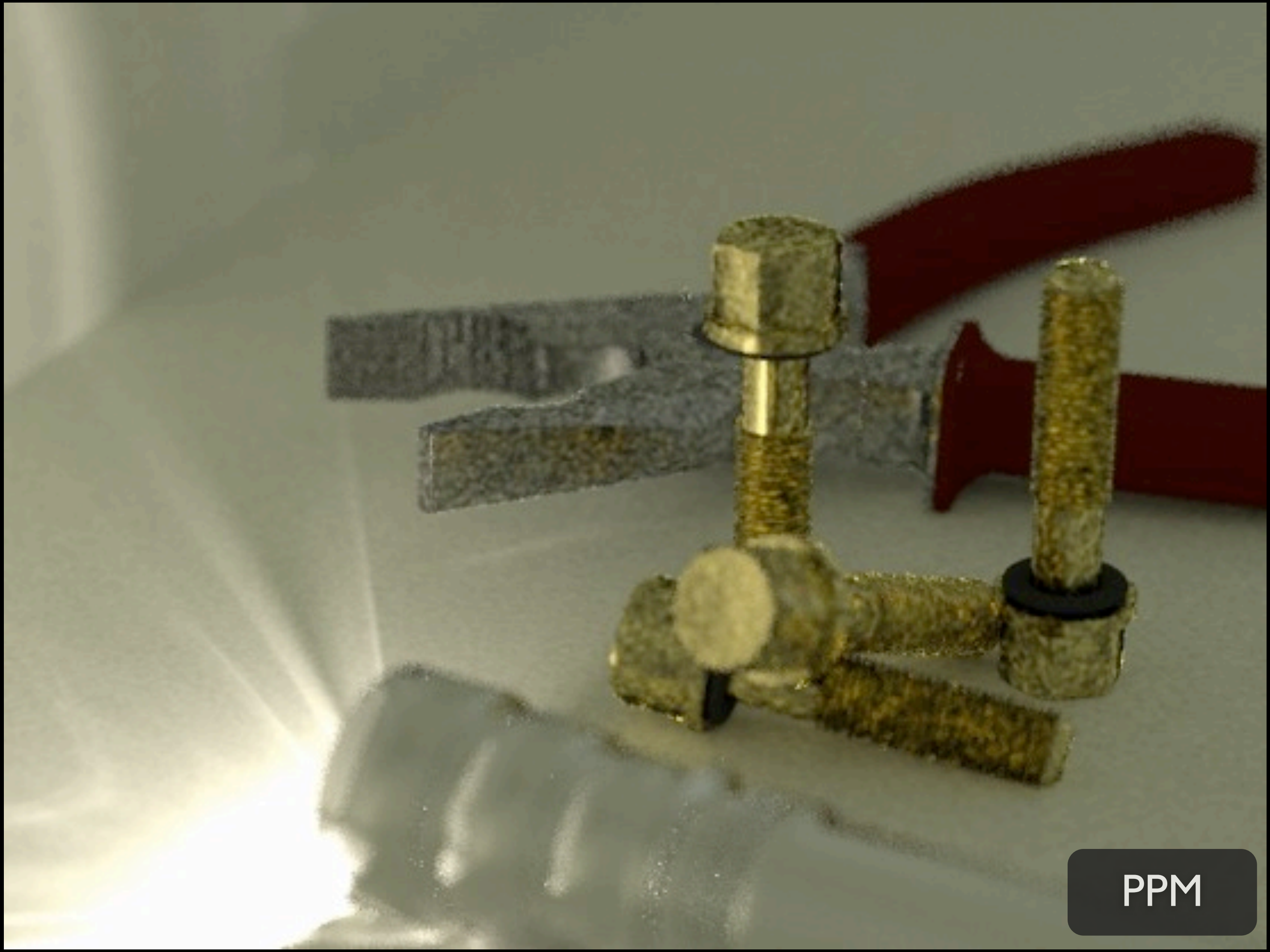


Trace one bounce rays

DOF + Glossy Reflection + Caustics



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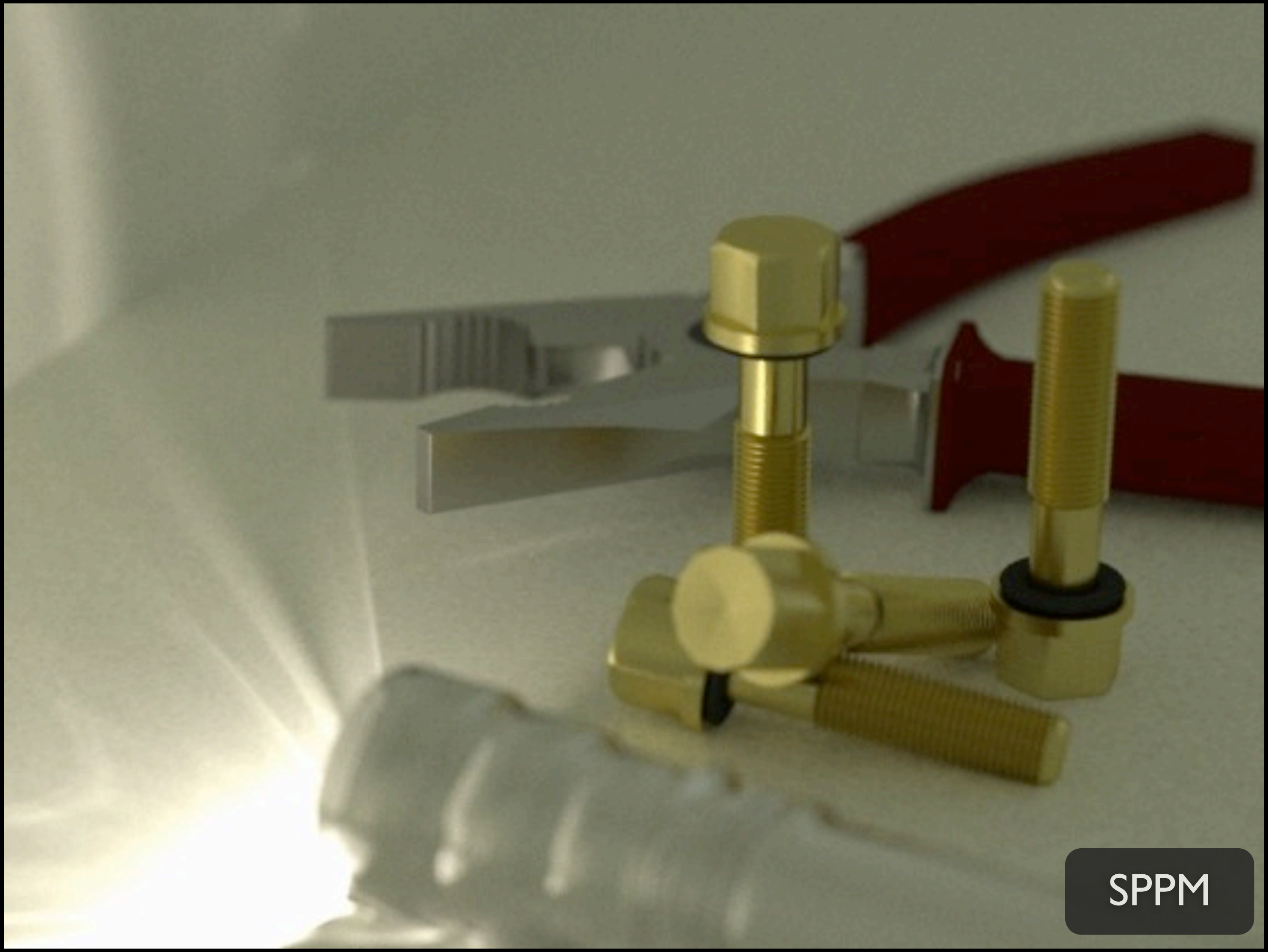
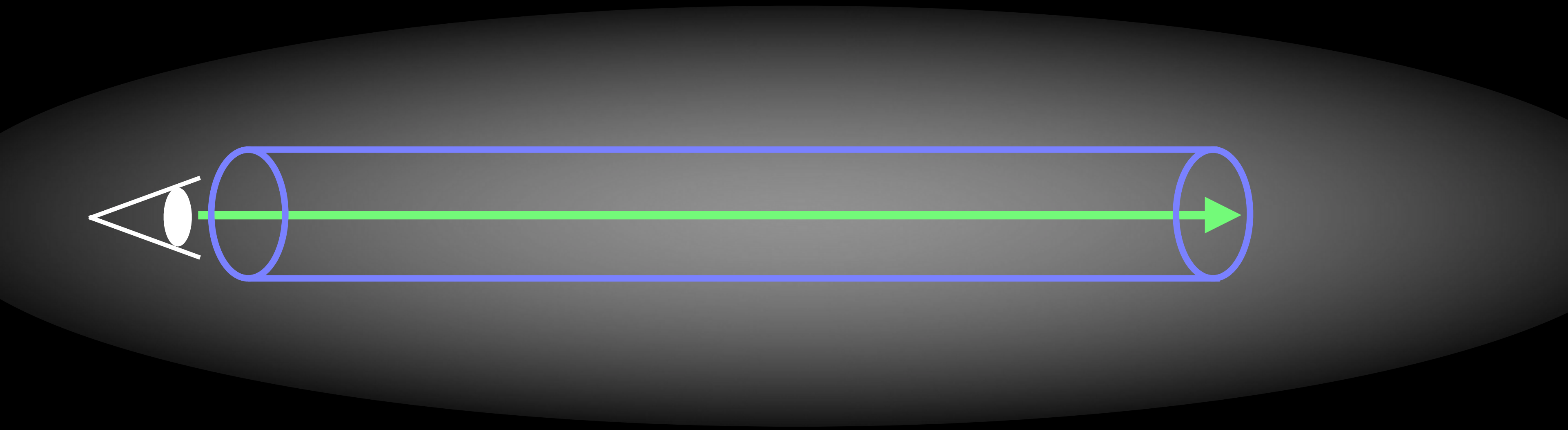


Participating Media

- Two basic approaches
  - Progressive beam radiance estimate (PPM)
  - Stochastically sample a point along eye ray (SPPM)



PPM style: cylinder progressive estimate

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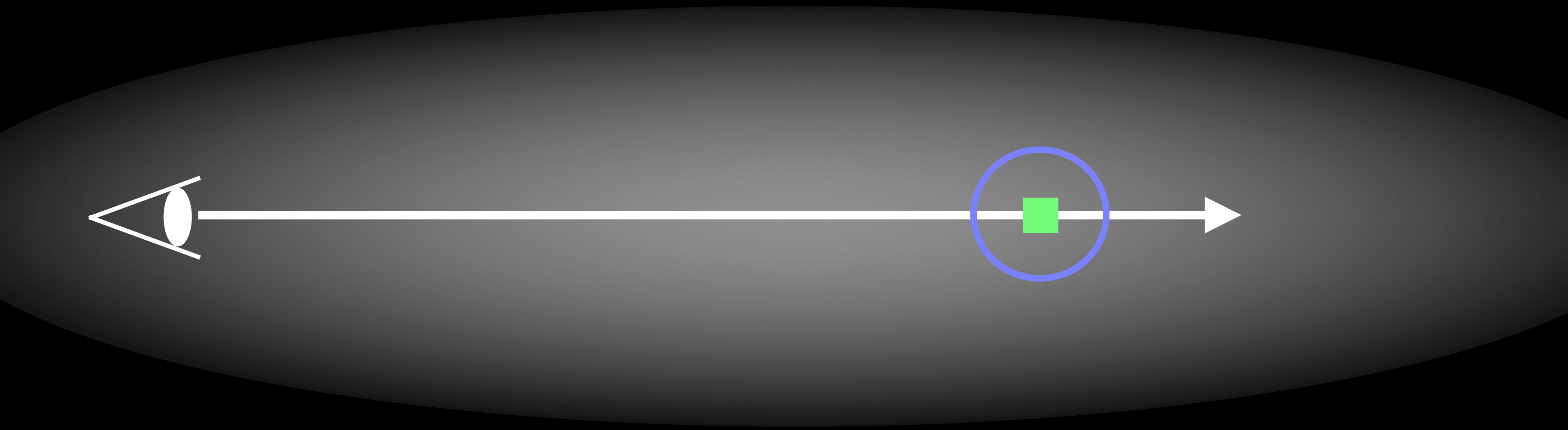

SPPM style: stochastic sampling along a ray

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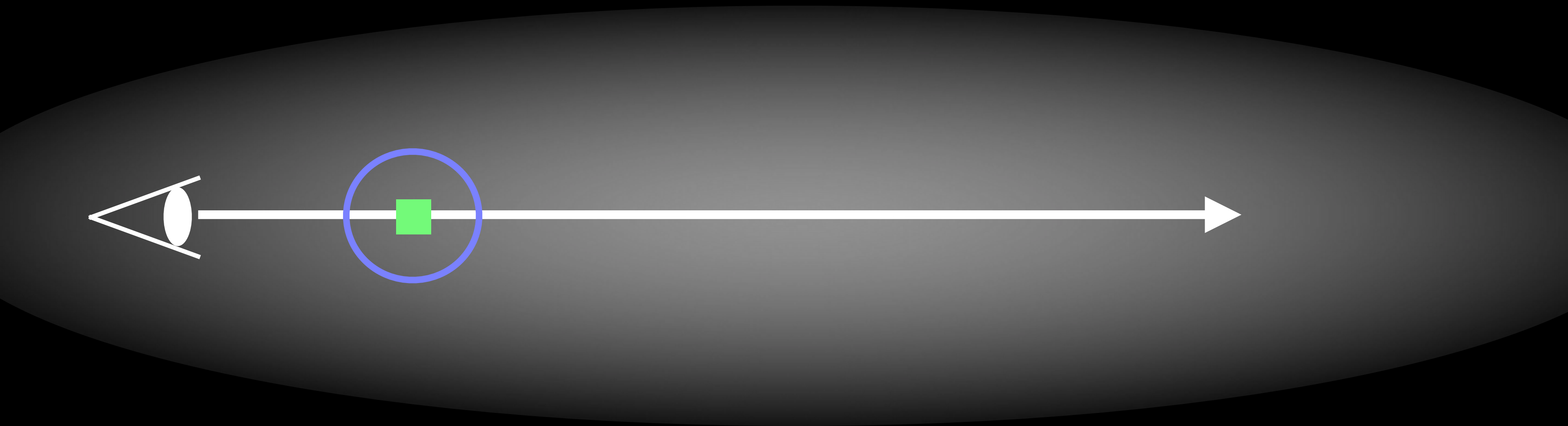

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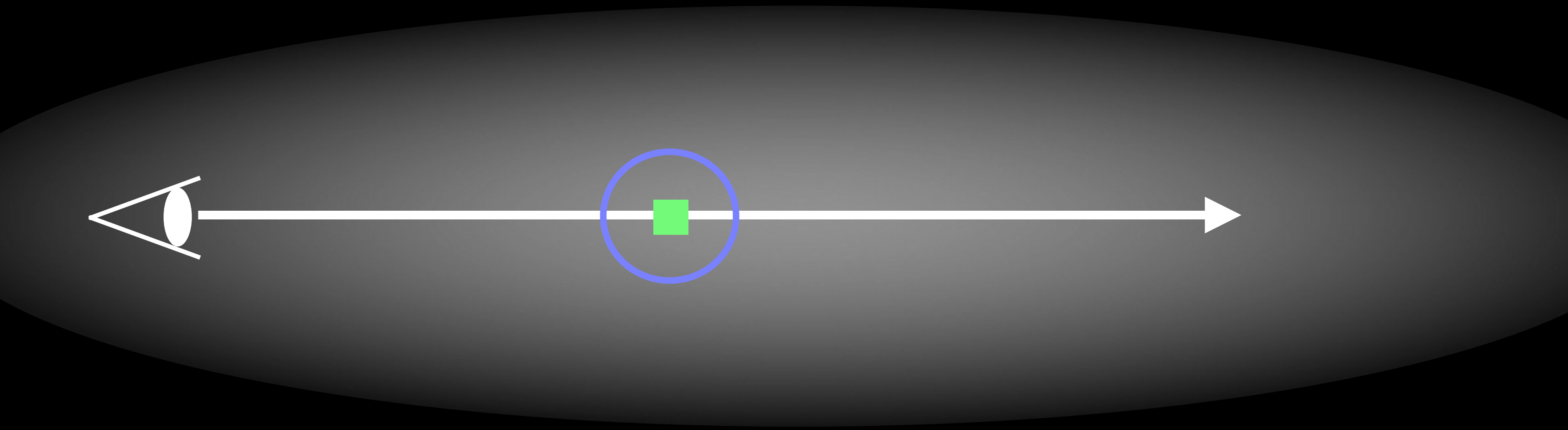
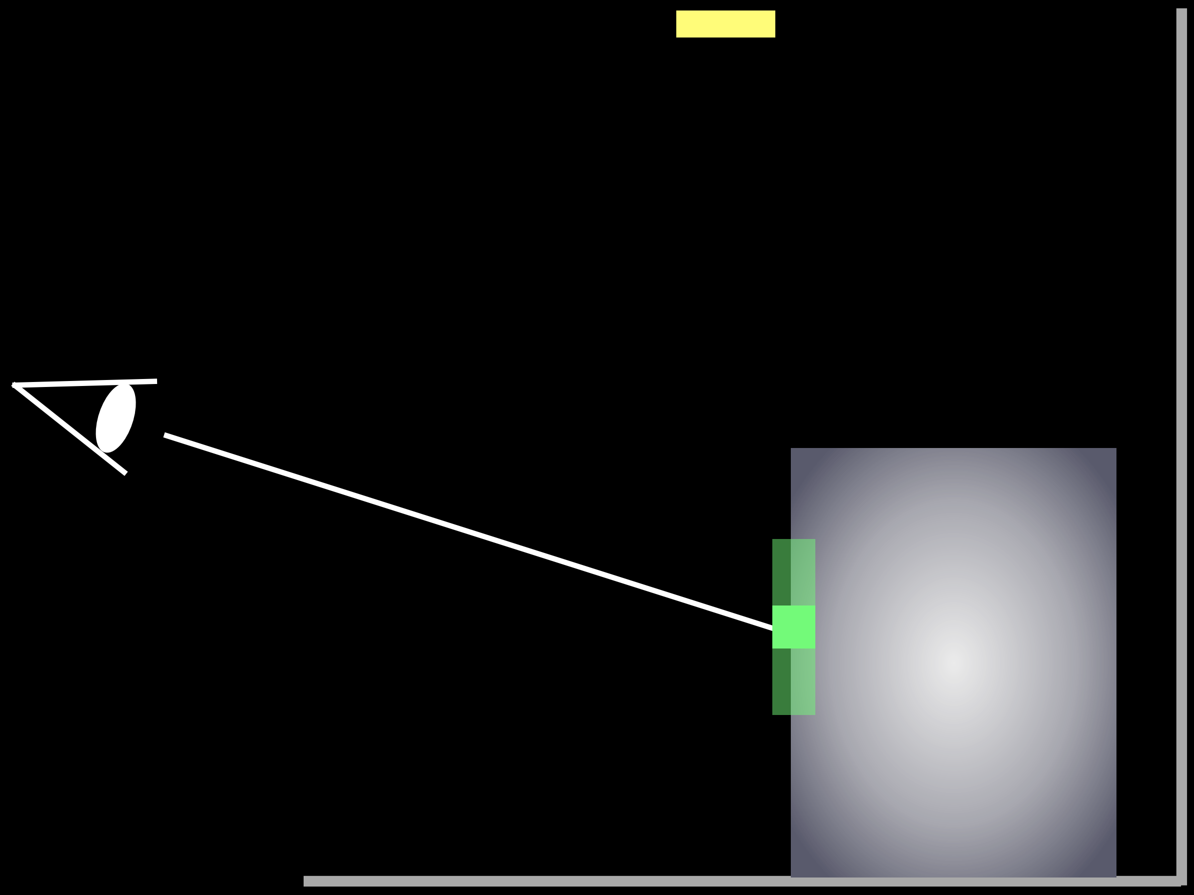


SPPM style: stochastic sampling along a ray

BSSRDF with PPM

- Stochastically sample a disc around the original location
  - e.g., BSSRDF Importance Sampling [King et al. 2013]



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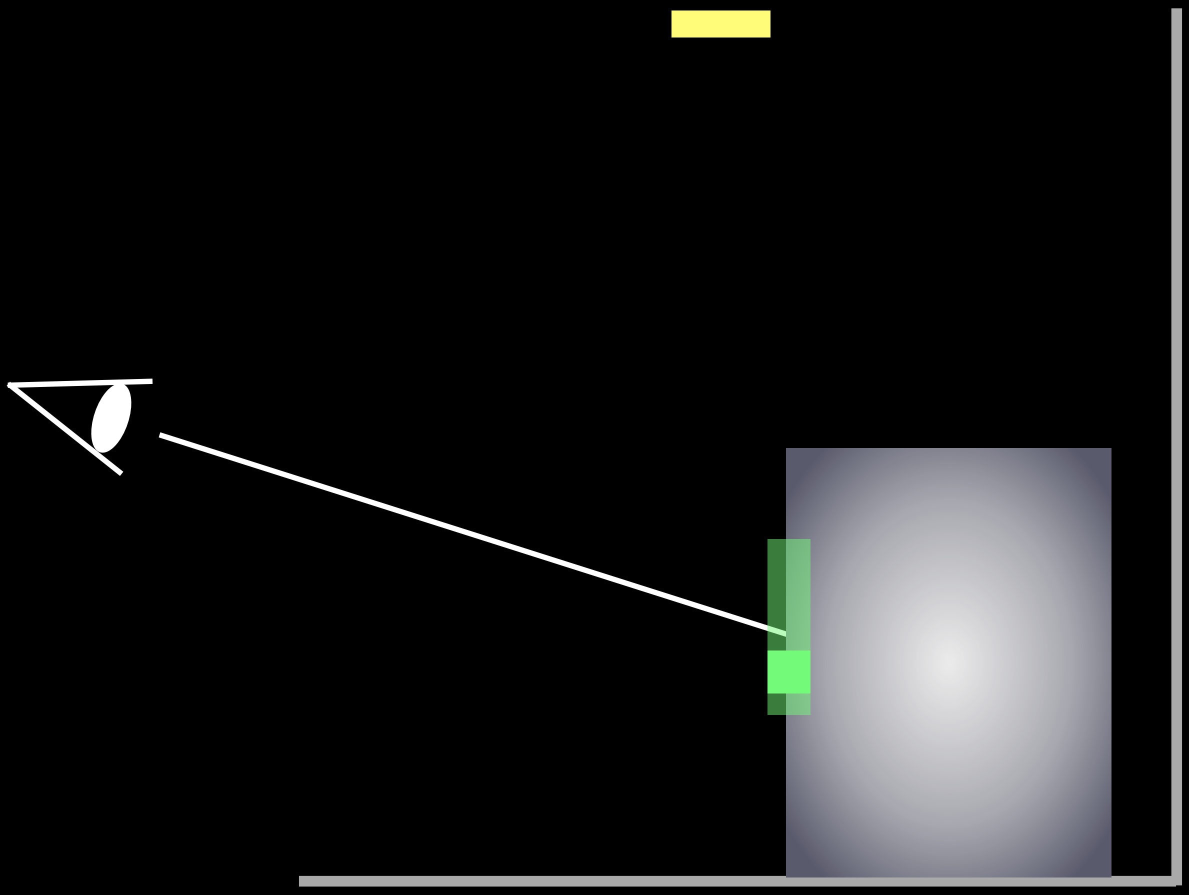

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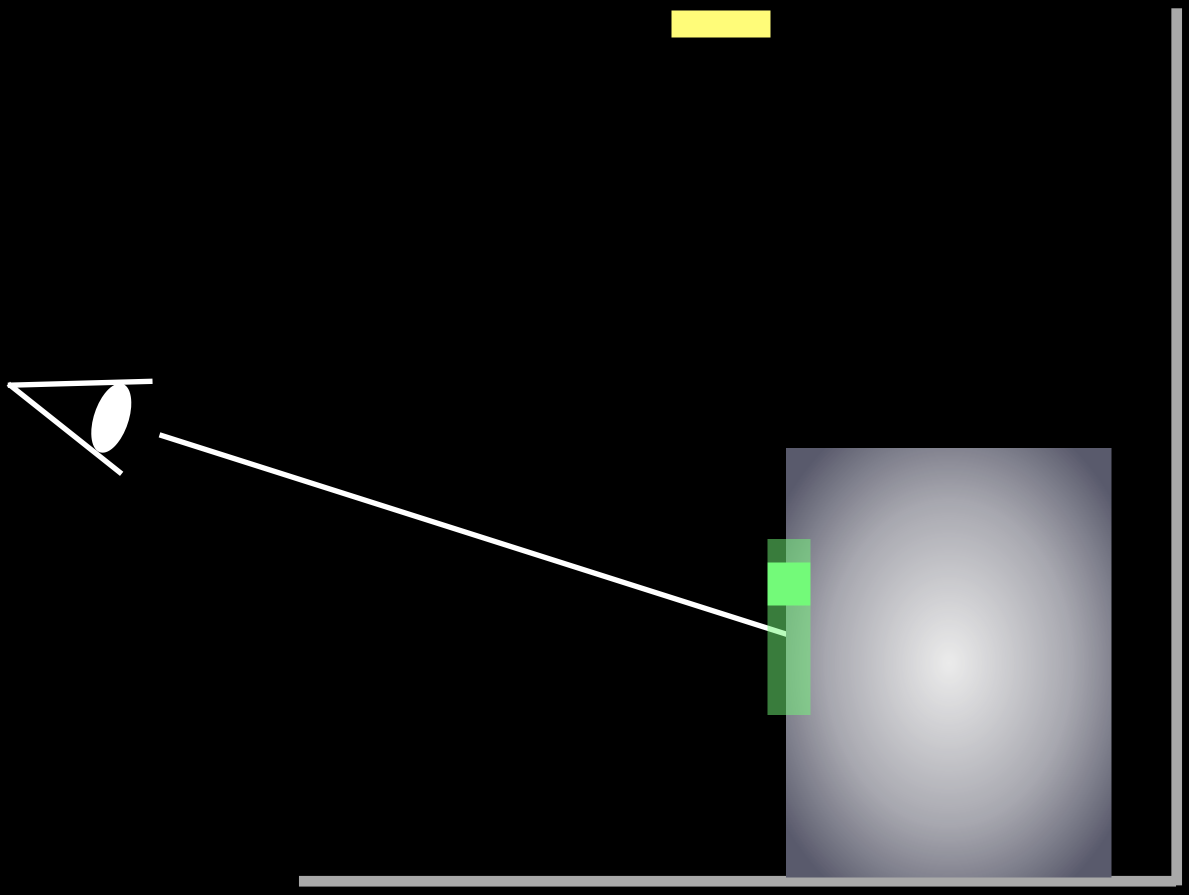

BSSRDF with PPM

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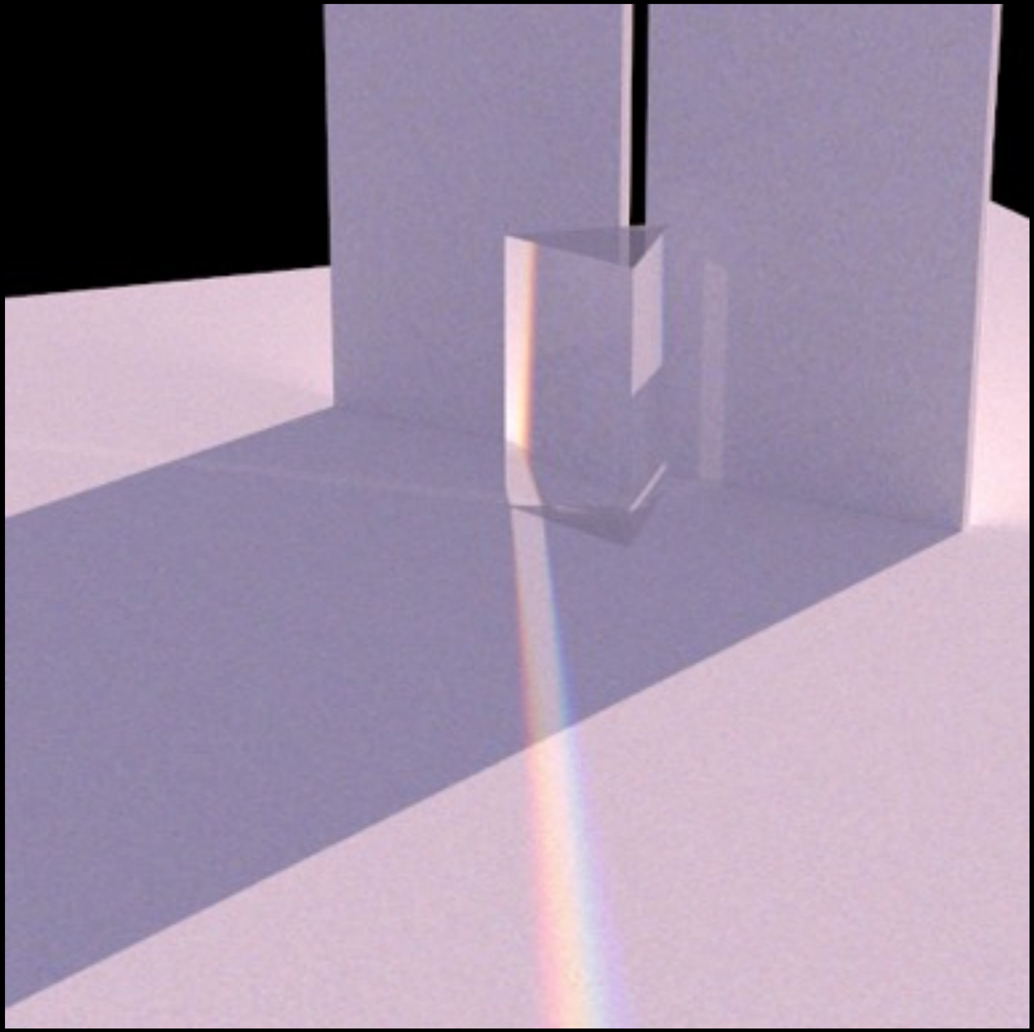
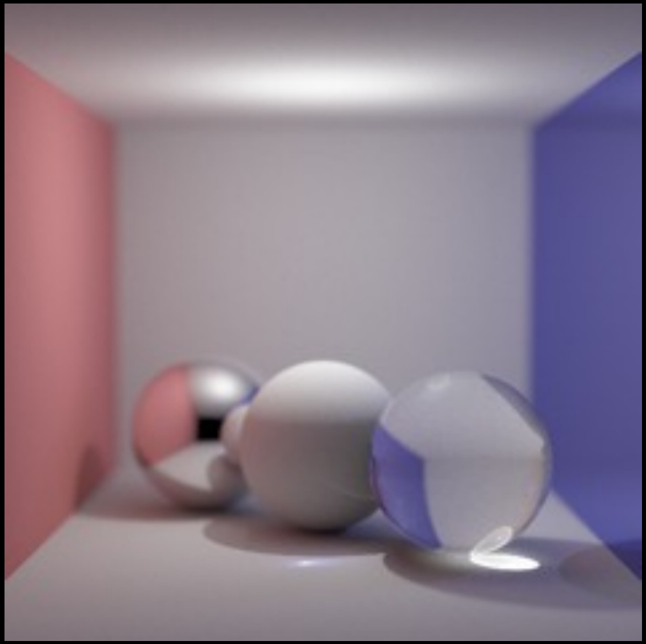
Full Spectrum Rendering

- Pick one random wavelength per iteration



GPUSPPM

- SPPM implementation using GLSL
  - Based on smallppm
  - DOF, motion blur, glossy reflection, full spectrum
  - Stochastic hashing for accel. data structure
    "Parallel Progressive Photon Mapping on GPUs", 2010



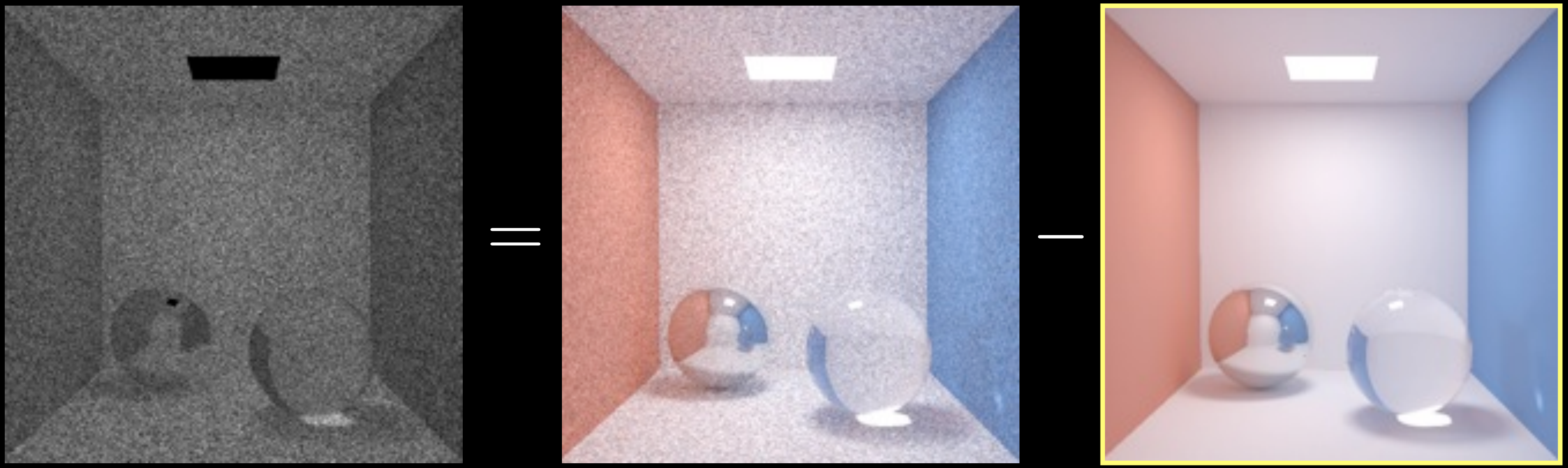
cs.au.dk/~toshiya/gpusppm.zip

How much computation is enough?

Definition of Error

- Difference between computed and exact

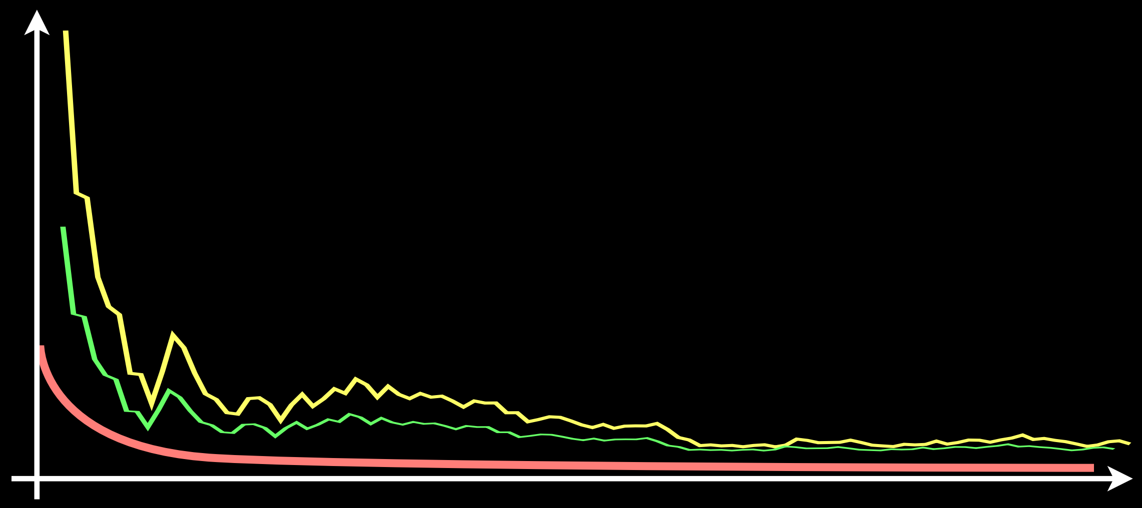
$$E_i = L_i - \boxed{L}$$ Unknown



Decomposition of Error

- Bias-Noise decomposition

$$E_i = L_i - L = B_i + N_i$$



Stochastic Error Bound Derivation

$$E_i = L_i - L = B_i + N_i$$

User-defined Probability

Stochastic error bound

$$\boxed{P(|E_i| \leq E_{b,i})} \leq \boxed{1 - \beta}$$

$$E_{b,i} = C_{i,1-\frac{\beta}{2}} \sqrt{\frac{\text{Variance}}{i}} + |B_i|$$

Stochastic Error Bound Derivation

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Error due to Noise

Stochastic Error Bound Derivation

$$E_i = L_i - L = B_i + N_i$$

$$P(|E_i| \leq E_{b,i}) \leq 1 - \beta$$

$$E_{b,i} = C_{i,1-\frac{\beta}{2}} \sqrt{\frac{\text{Variance}}{i}} + \boxed{|B_i|}$$

Error due to Bias

Bias Estimation

- Bias can be approximated by Laplacian
- Progressive estimation of Laplacian (and any derivatives)

$$B_i \approx k_2 R_i^2 \Delta L$$

k_2 constant

R_i search radius

ΔL Laplacian of radiance

Kernel

$$L_i(x) = \frac{\sum \boxed{K(x_p - x)} f_r(x, \omega, \omega_p) \Phi(x_p, x)}{\pi R_i^2}$$

Bias Estimation

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$$B_i \approx k_2 R_i^2 \Delta L$$

k_2 constant

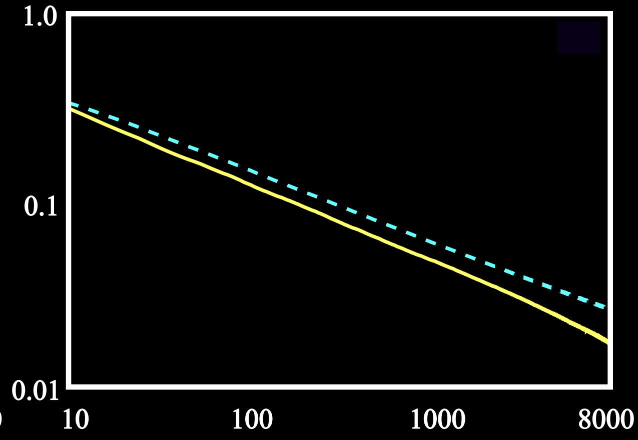
R_i search radius

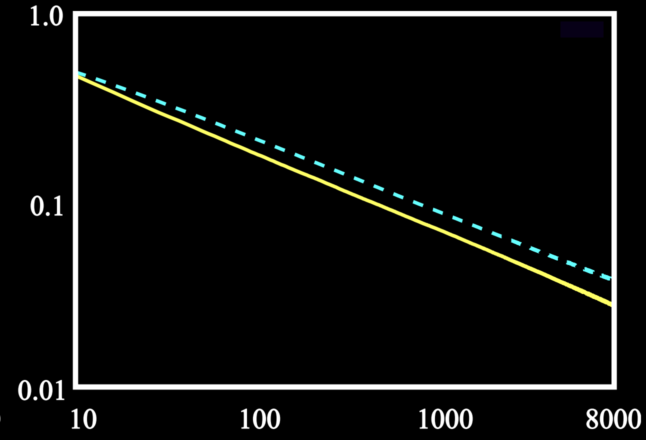
ΔL Laplacian of radiance

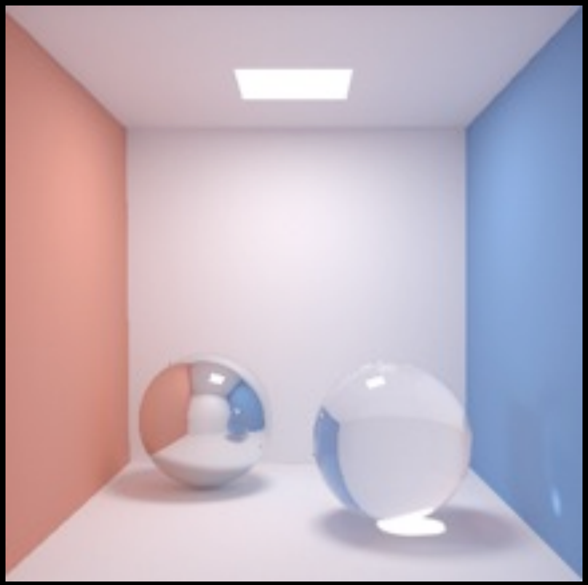
Laplacian of the kernel

$$\Delta L_i(x) = \frac{\sum \boxed{\Delta K(x_p - x)} f_r(x, \omega, \omega_p) \Phi(x_p, x)}{\pi R_i^2}$$

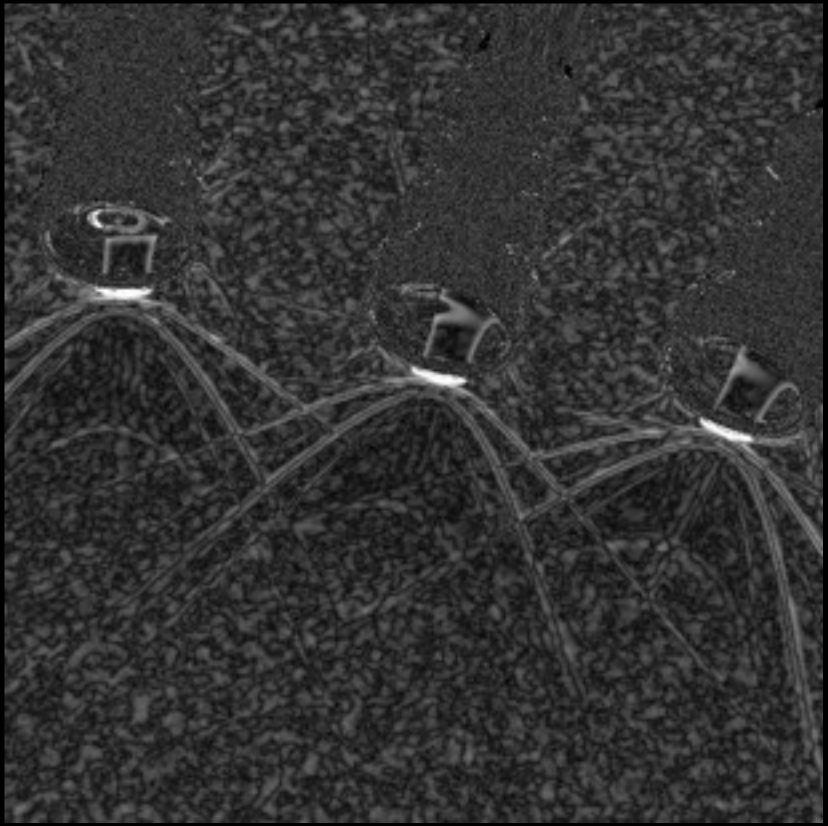
Error Estimation



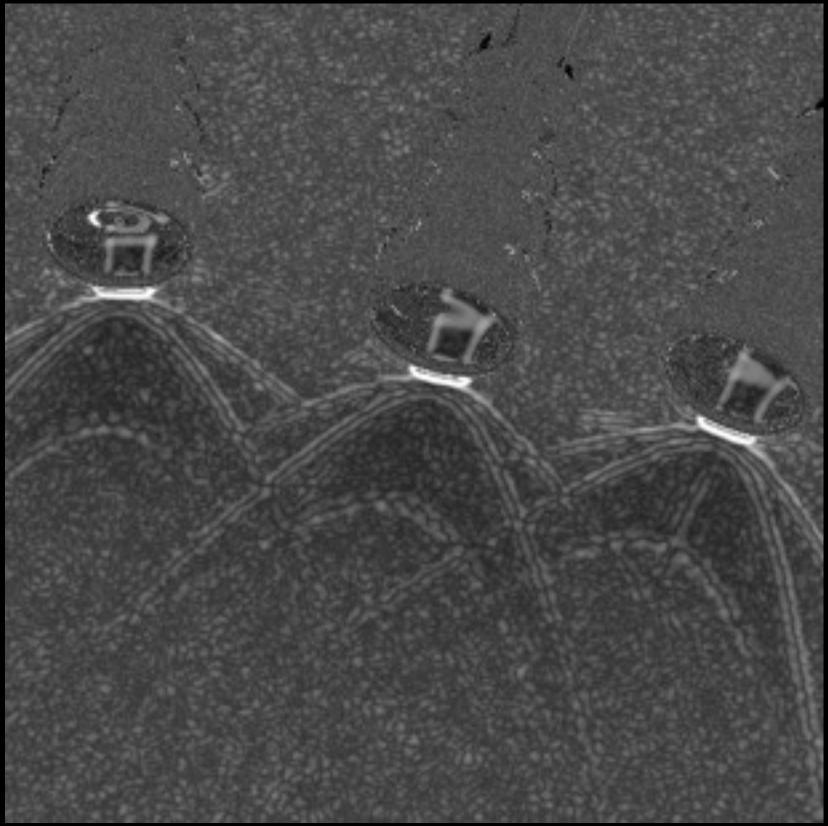




Error Estimation

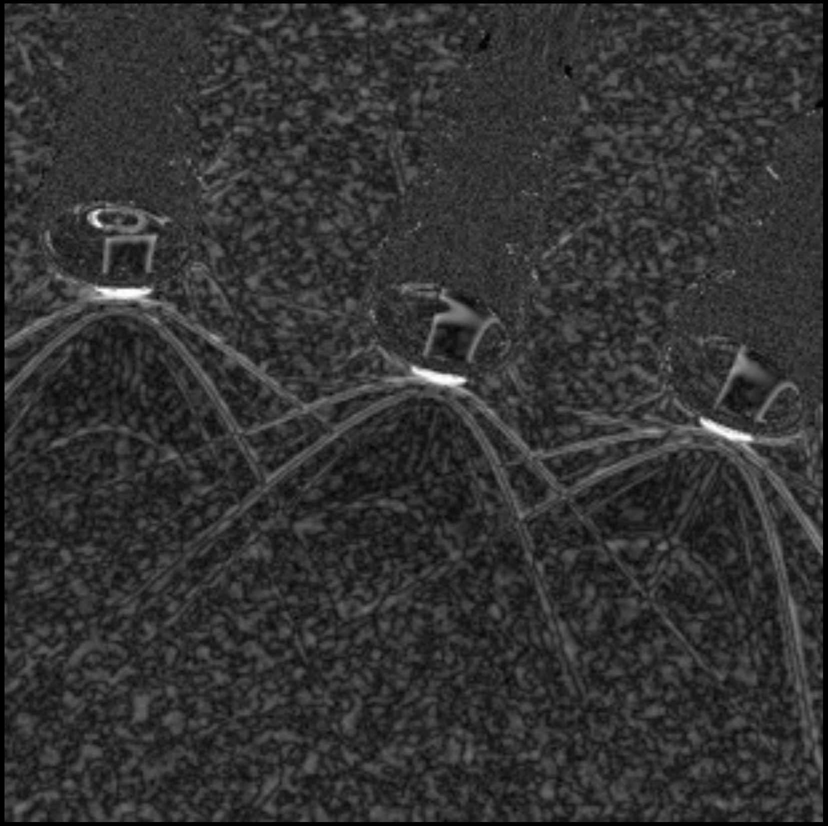


Actual Error

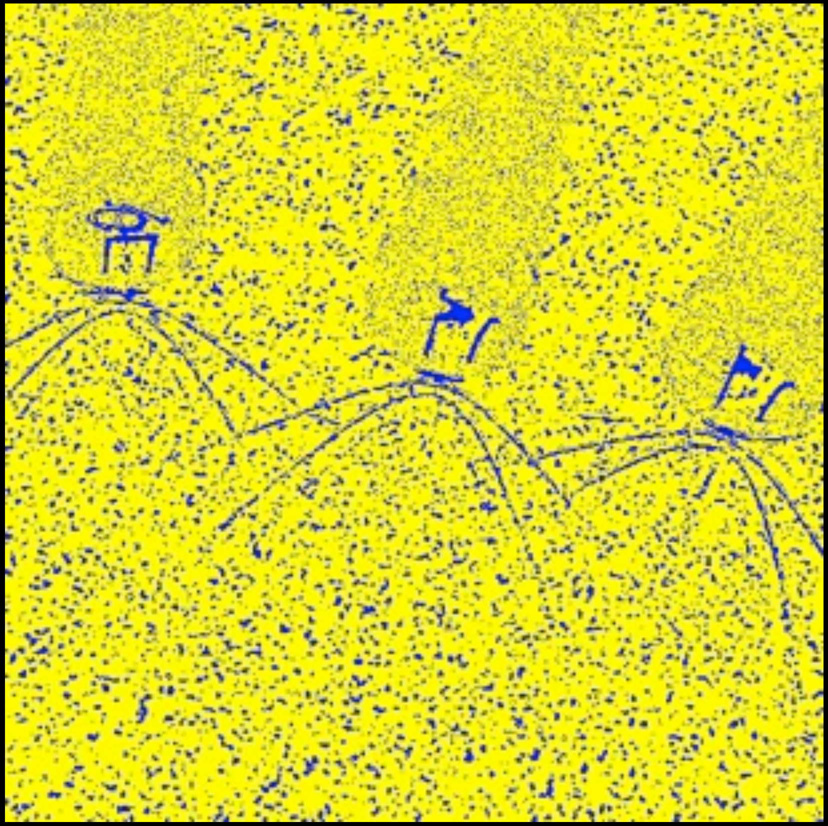


Estimated Error Bound

Error Estimation



Actual Error

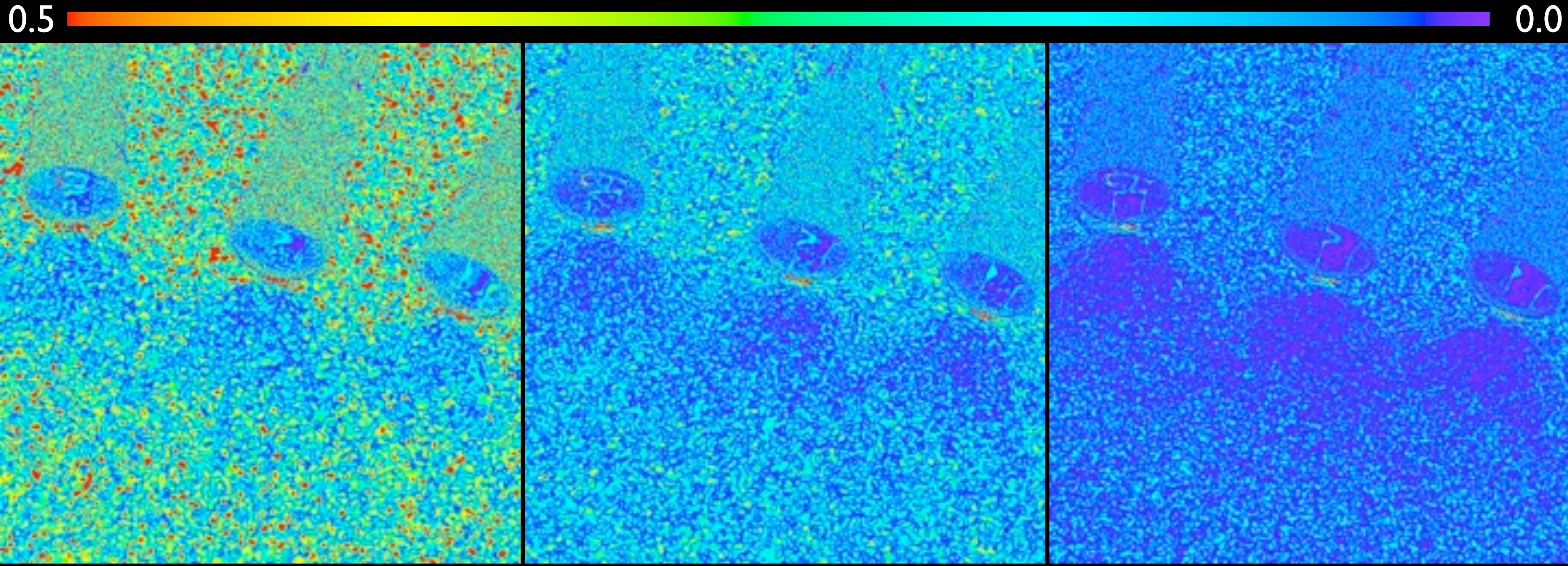


Bounded/Not bounded

Specified: 90%   Actual: 85%

Automatic Rendering Termination

SIGGRAPHASIA2013



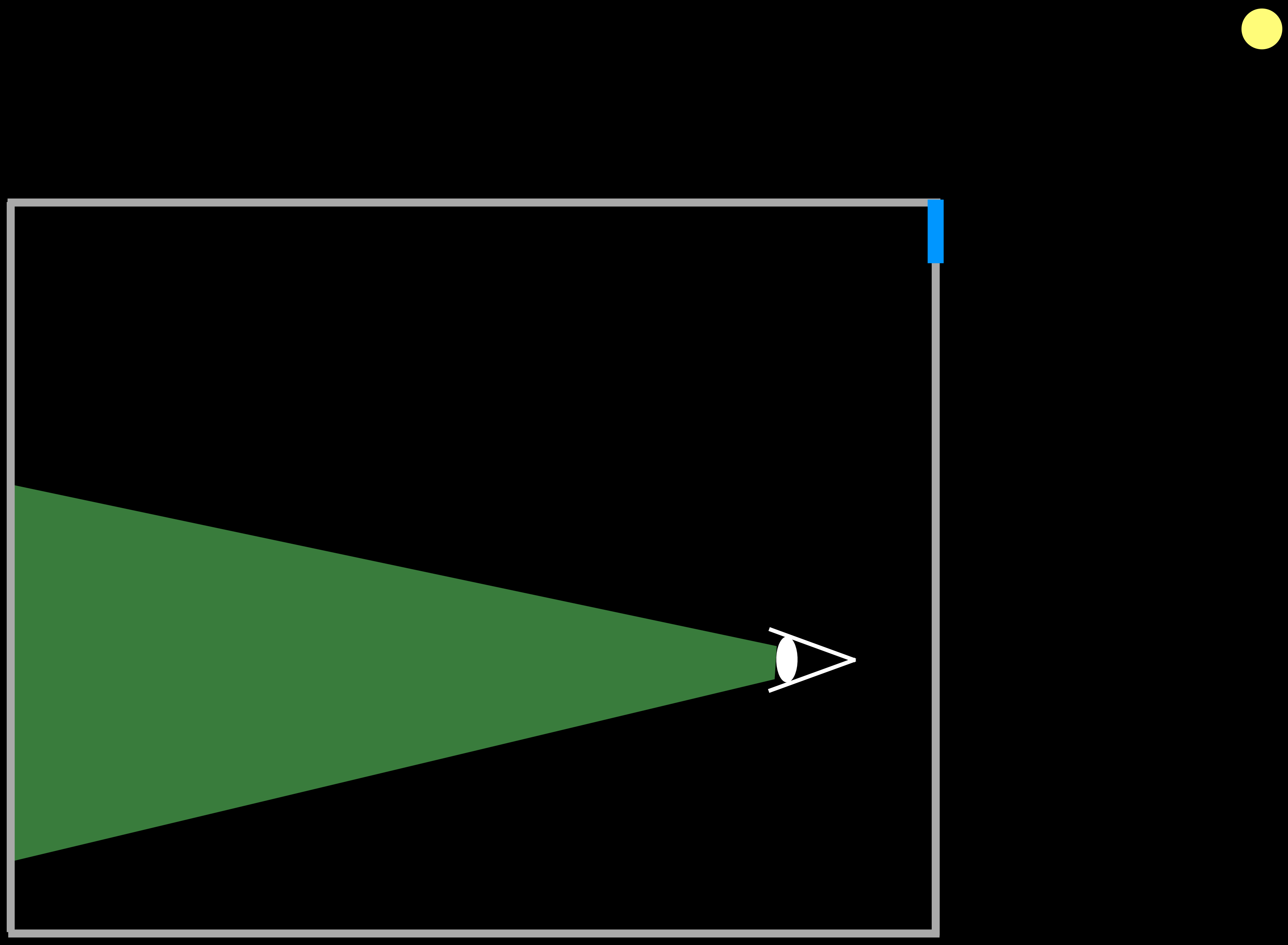
specified: 0.25
actual: 0.1916

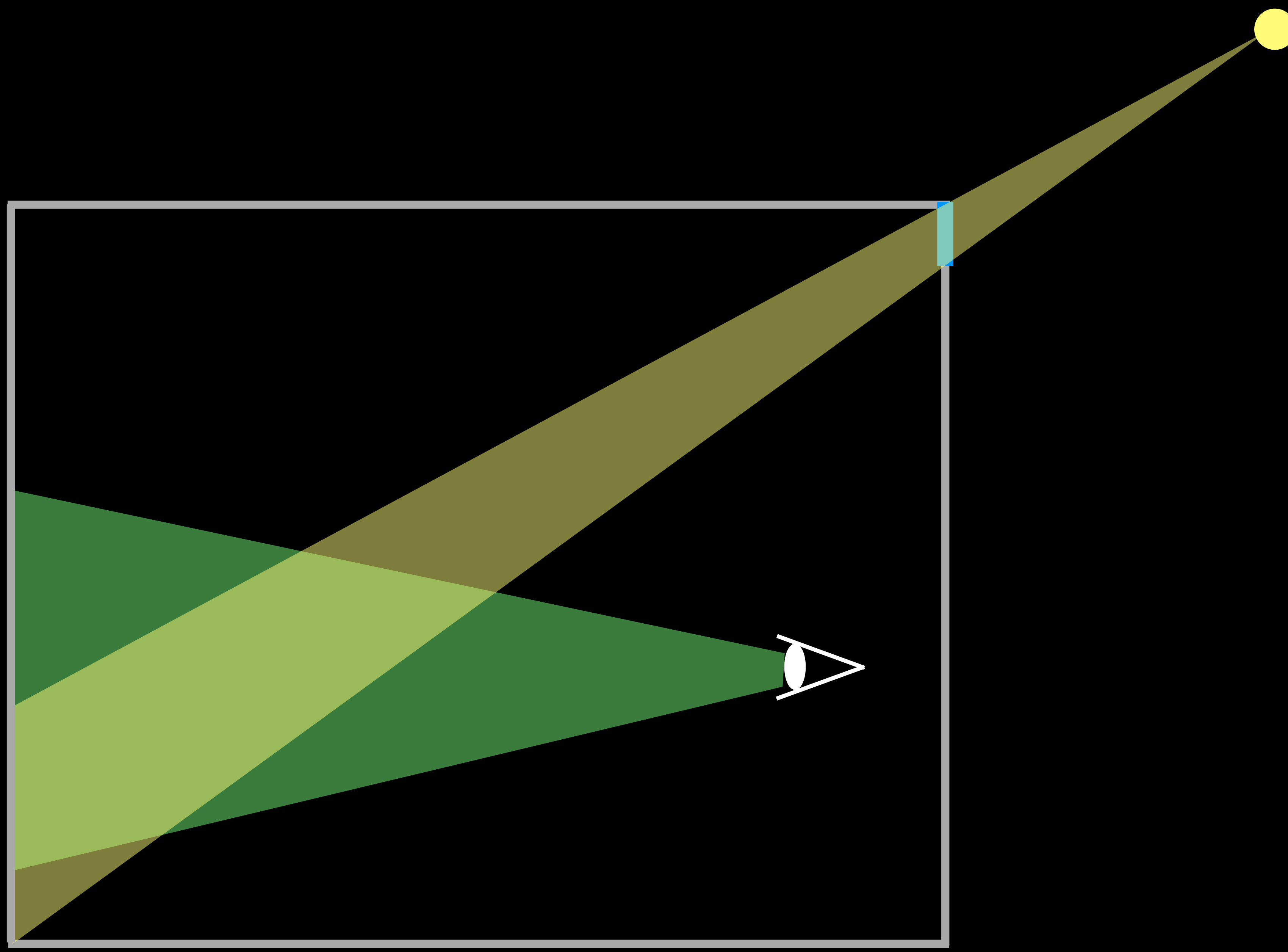
specified: 0.125
actual: 0.09294

specified: 0.0625
actual: 0.04482

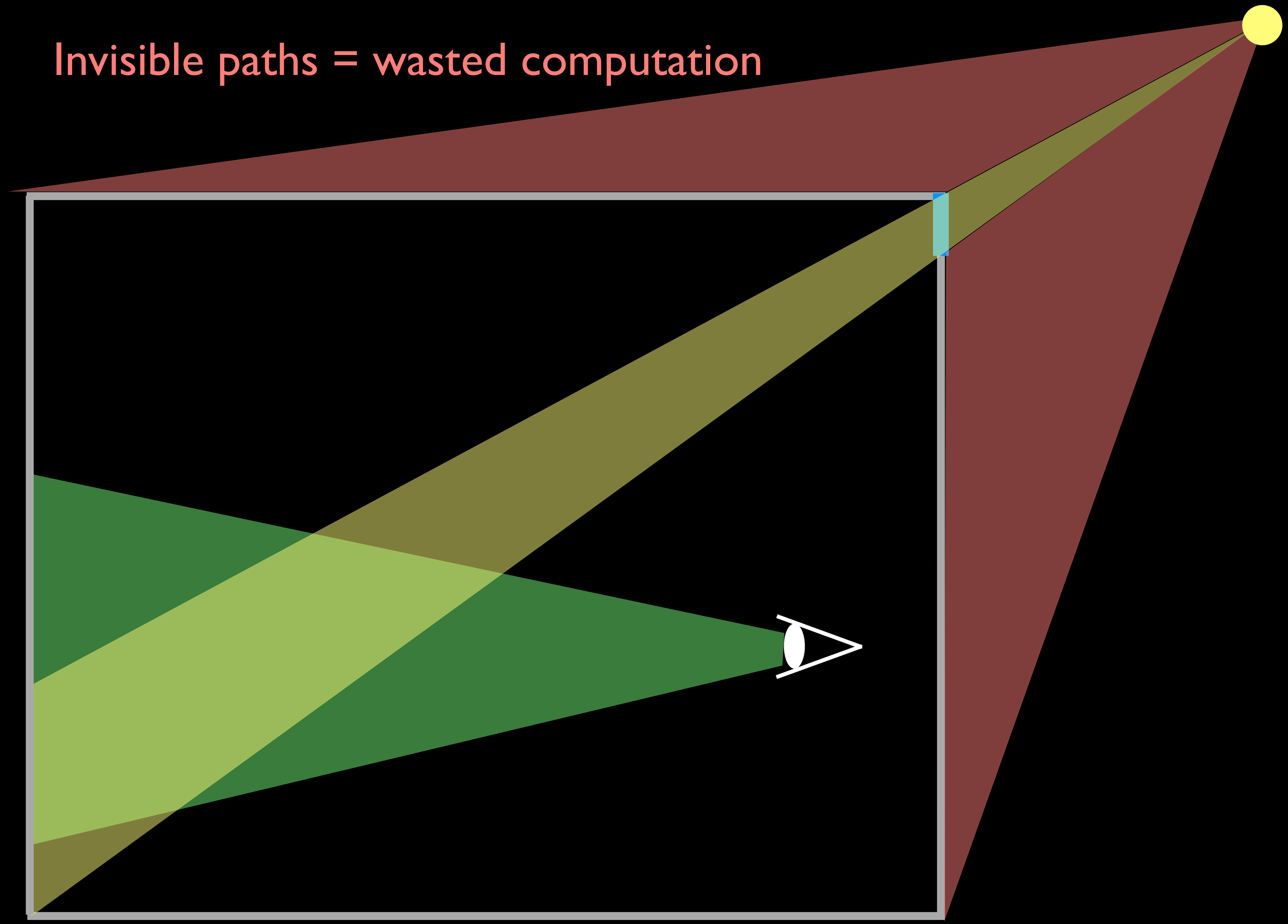
1.3 times overestimation on average


Light source
Window
Eye





Invisible paths = wasted computation



Metropolis Light Transport

Ideal

- Can we combine these two algorithms?
  - MLT: Efficient for difficult lighting scenarios
  - PPM: Robust to complex types of light paths

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  - MLT: Efficient for difficult lighting scenarios
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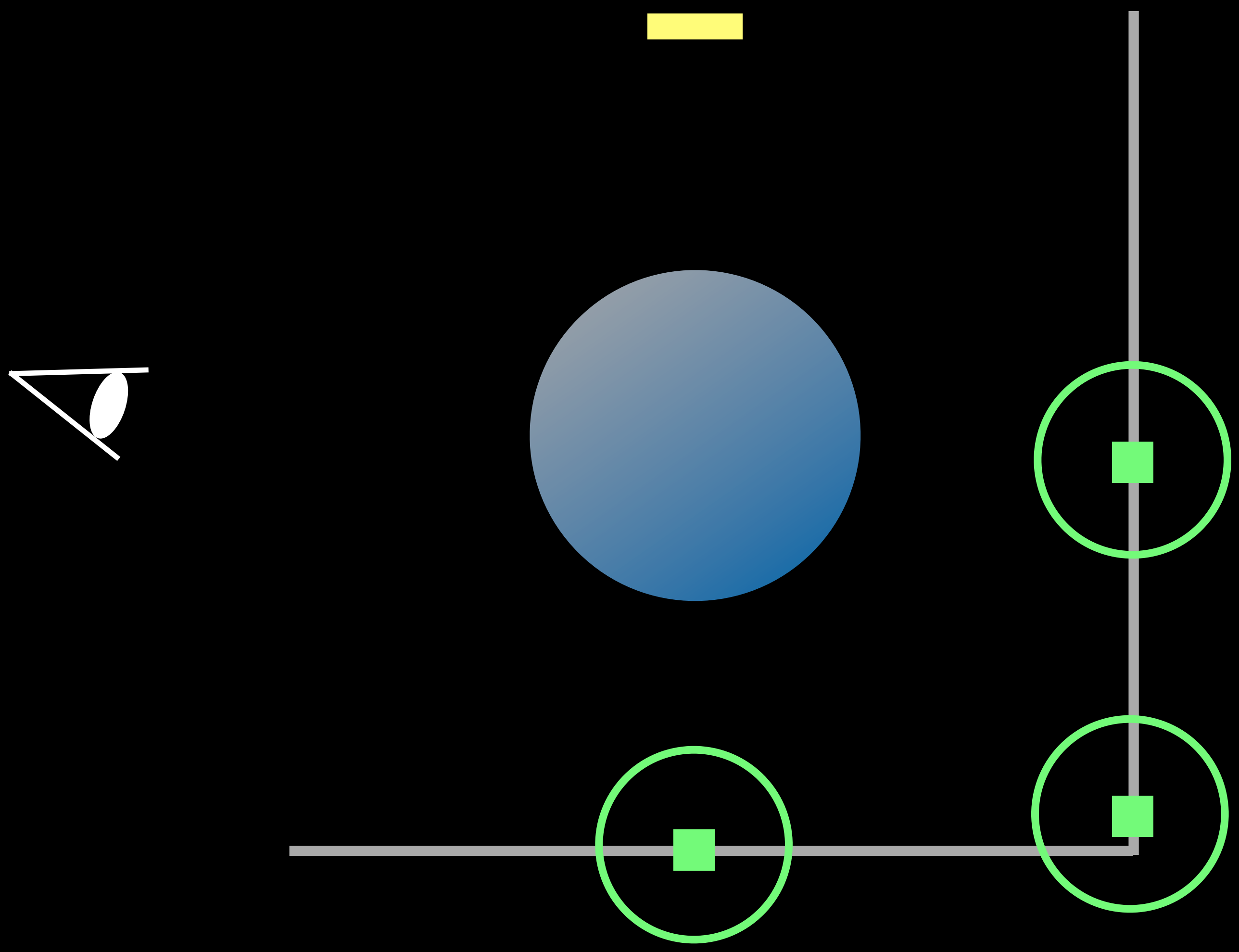
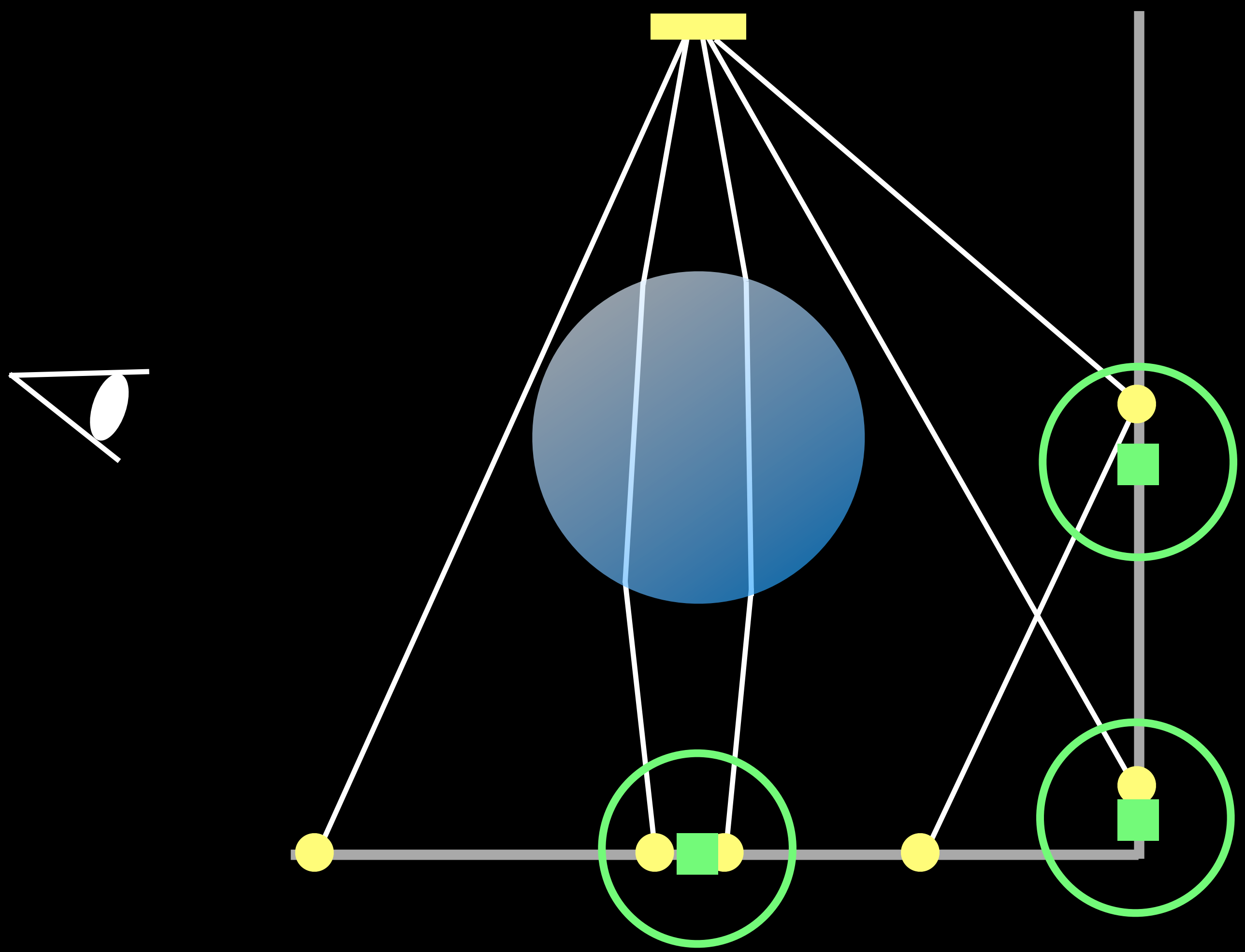
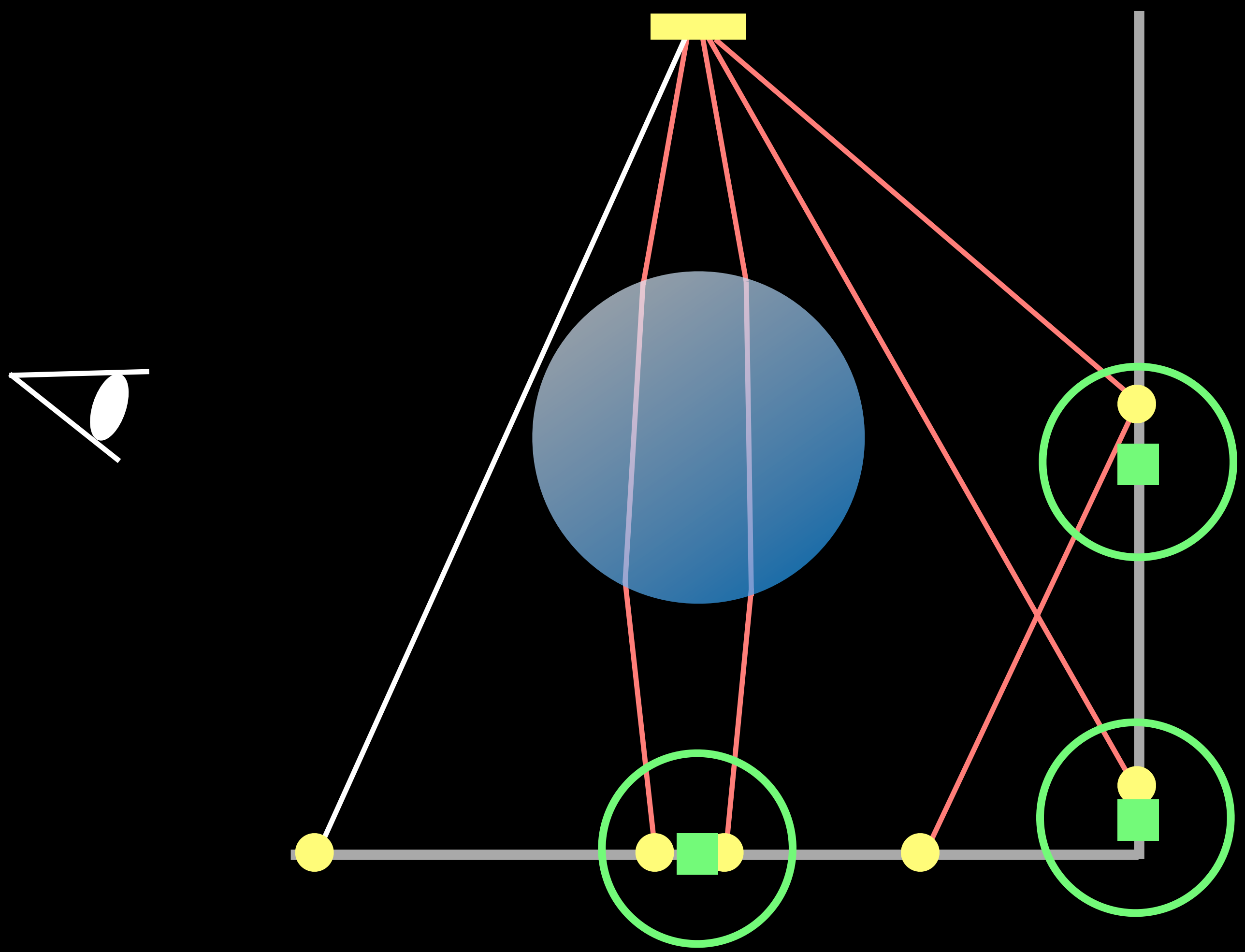
MLT + PPM

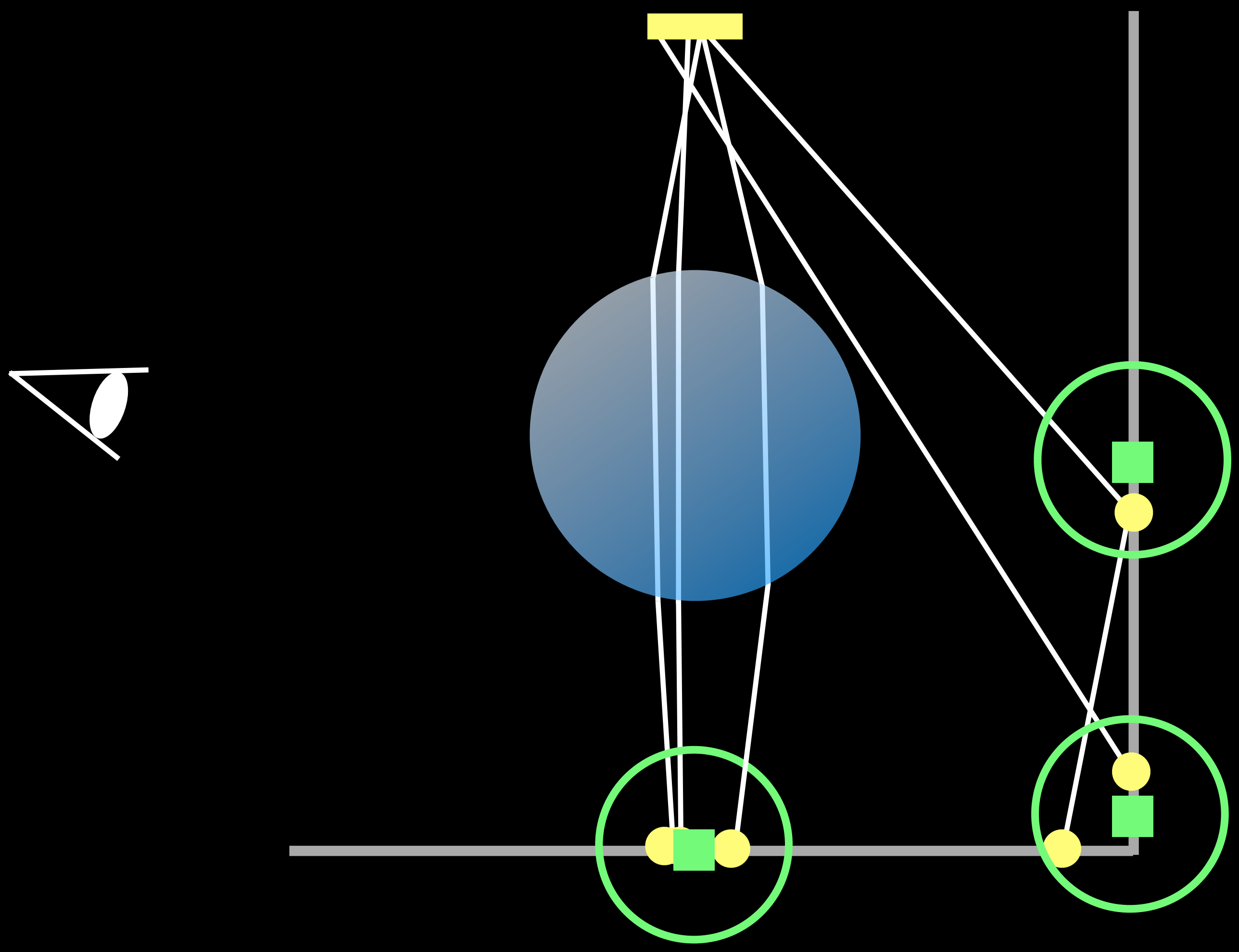
Key Observation

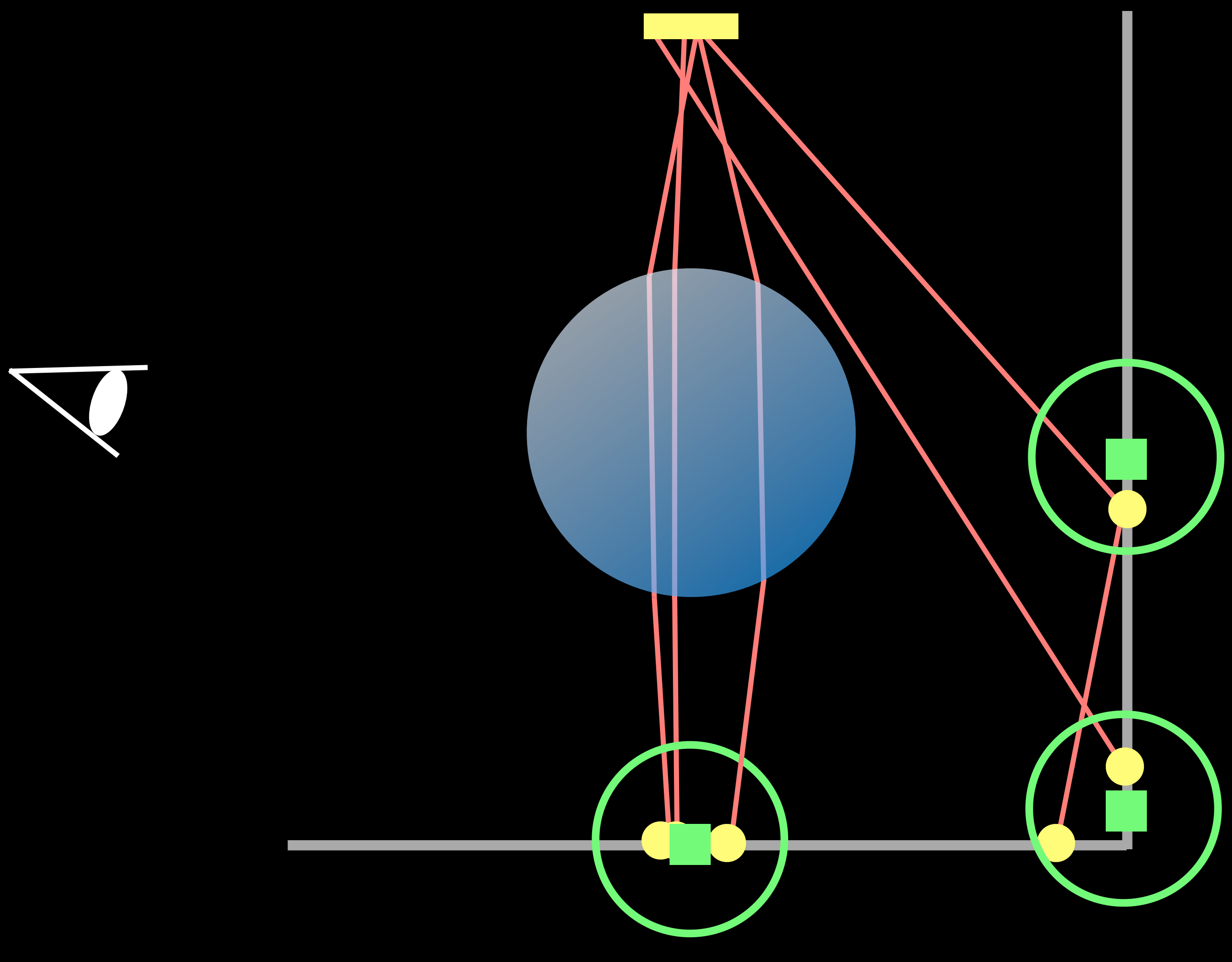
- We can determine whether a photon path is visible or not
  - Because PPM stores visible points from the eye
  - Contributed to at least one visible point = visible





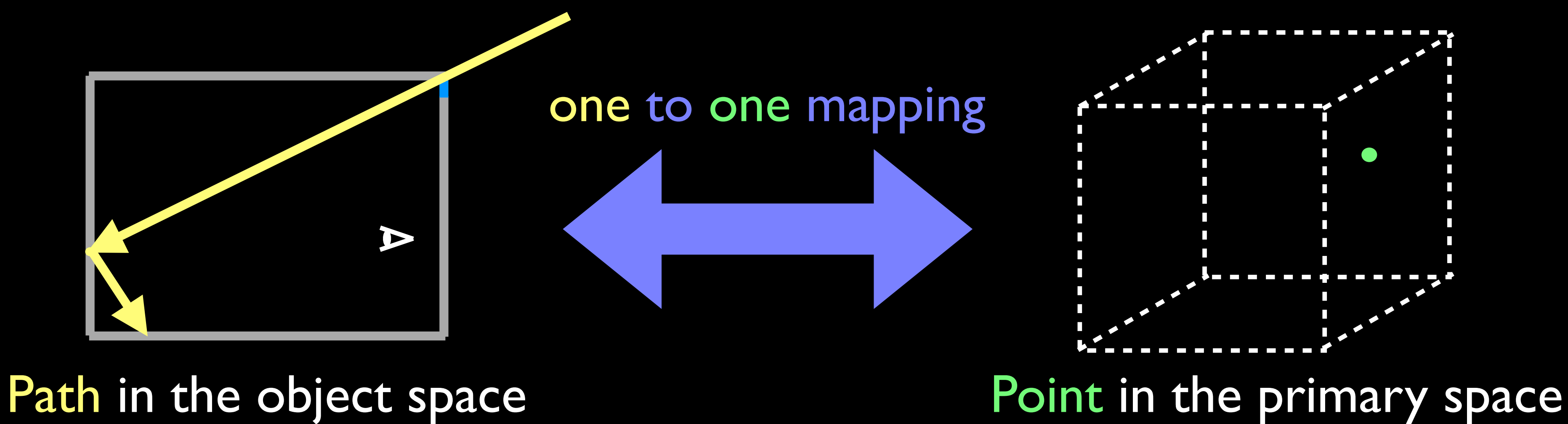






Primary Space

- Mapping a path to a point [Kelemen et al. 2002]
- Path = vector of random numbers $\vec{u} = (\xi_1, \cdots, \xi_N) \in (0,1)^N$



Visibility-based Sampling

- Consider space of random numbers
- Photon path visibility function

If the photon is not visible:

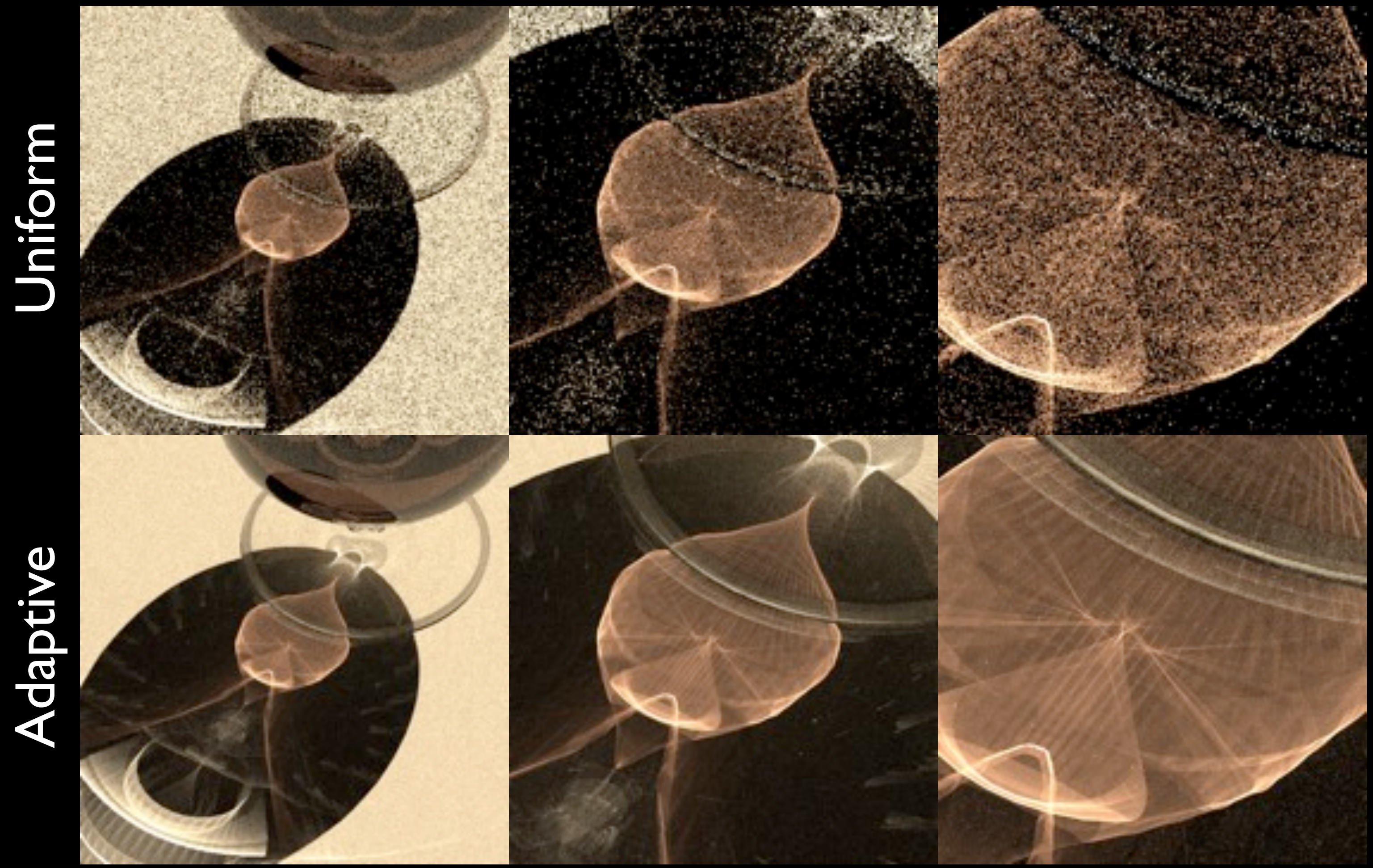
$$V\left(\vec{u}\right) = 0$$

If the photon is visible:

$$V\left(\vec{u}\right) = 1$$

Sample $V\left(\vec{u}\right)$ using Markov chain Monte Carlo Methods

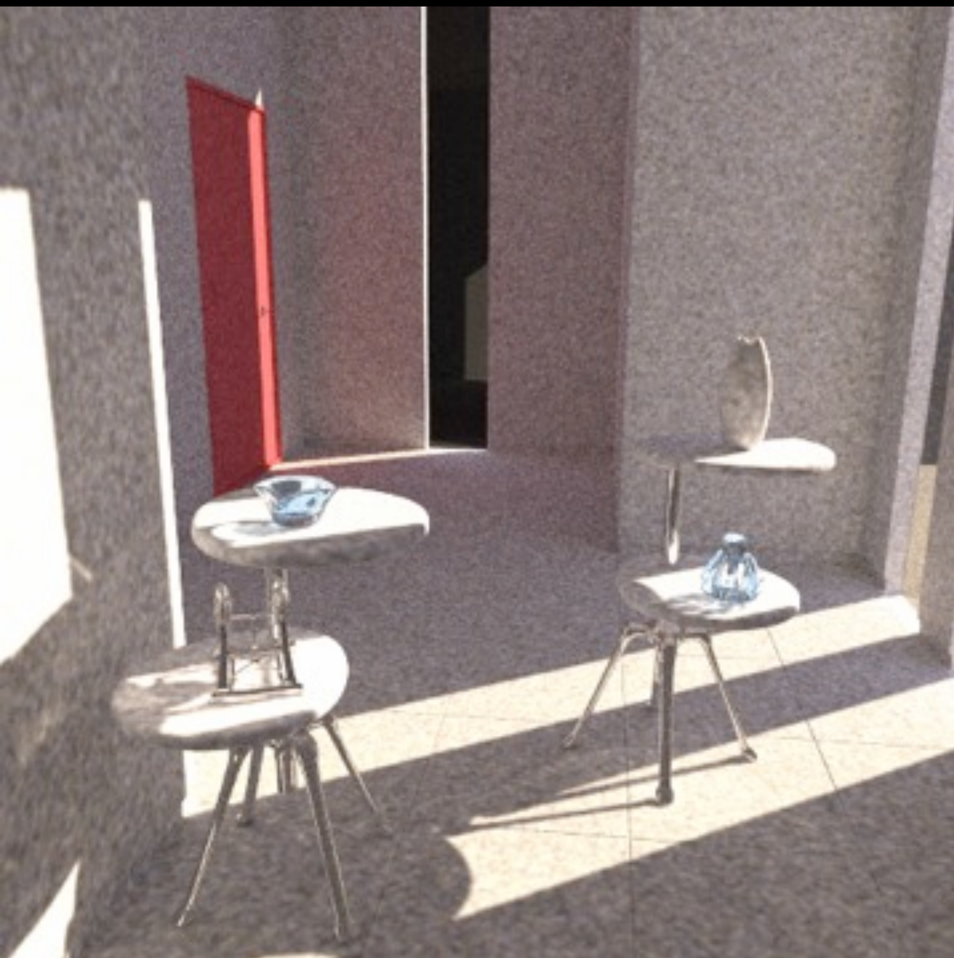
Small-scale Lighting Details



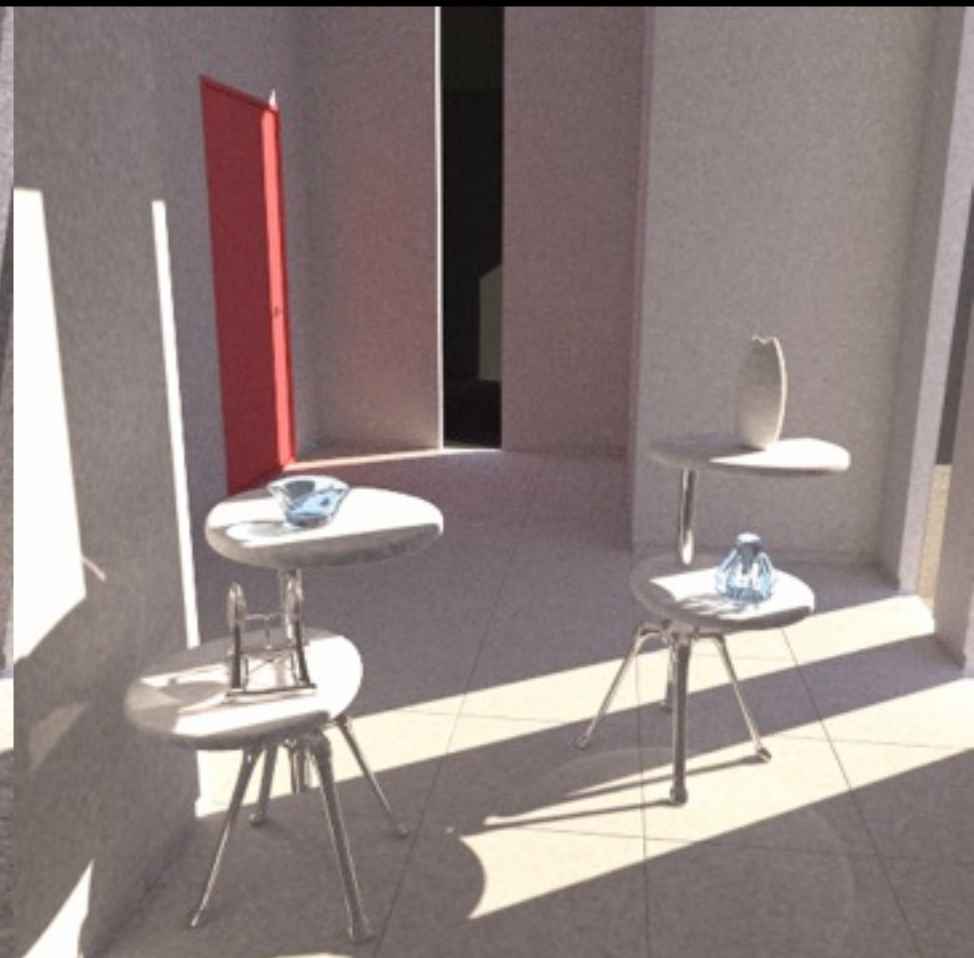
Automatic Parameter Tuning

Value is too small | Automatic | Value is too large

Sunlit Room



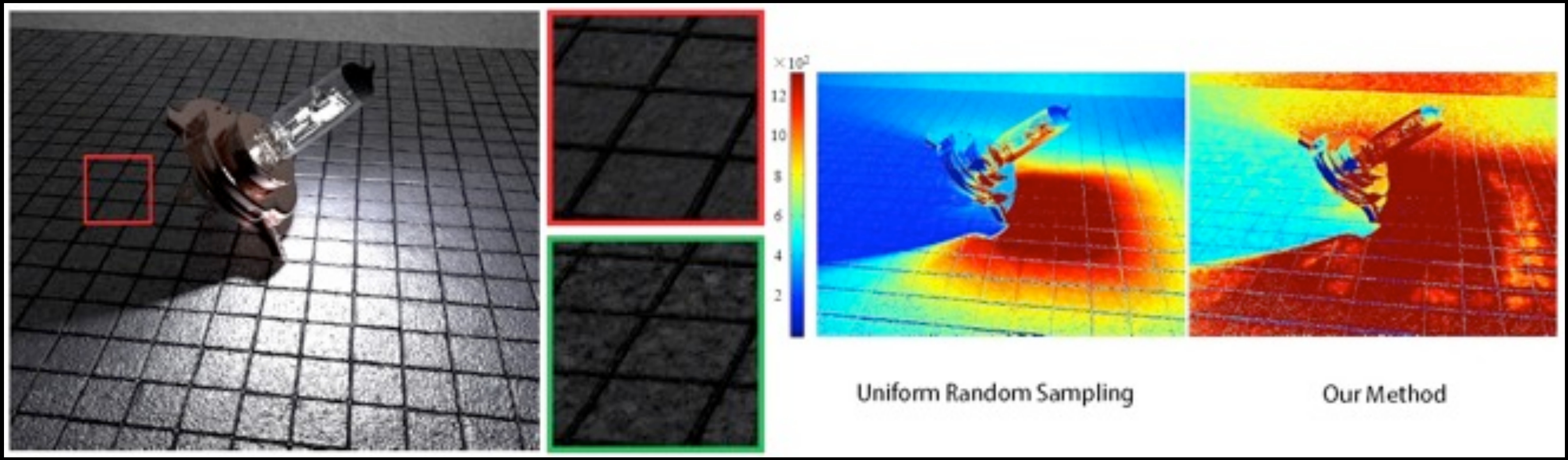
Uniform



Adaptive

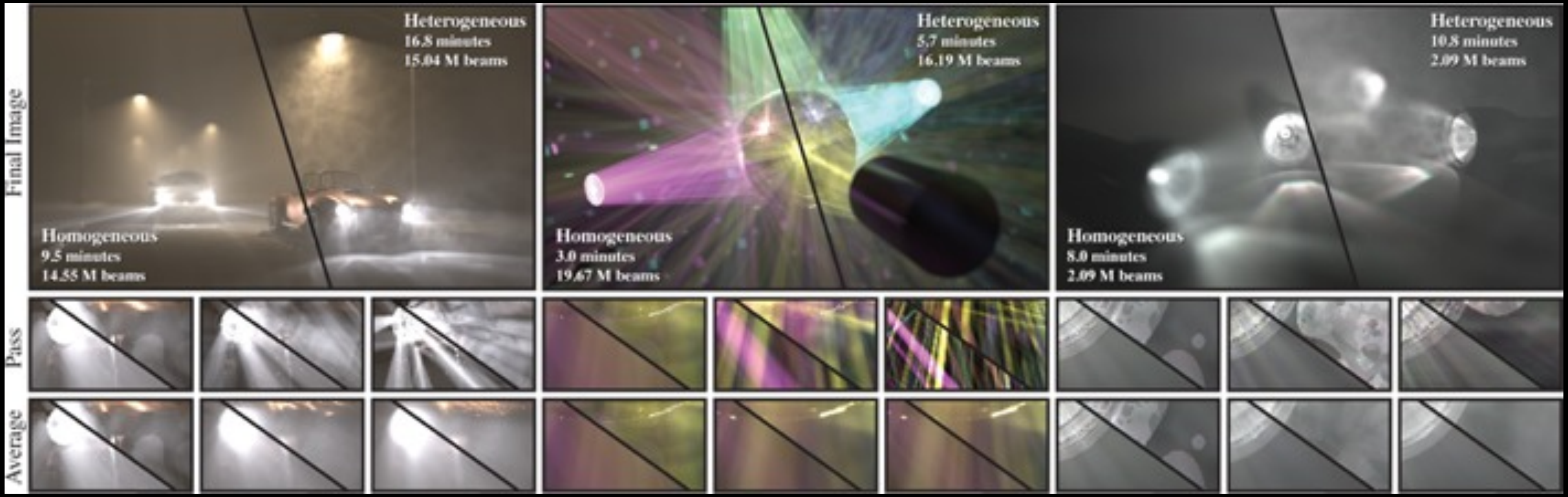
Some Related Work

- Adaptive photon tracing based on photon density on the image [Chen et al. 2011]



Some Related Work

- Progressive photon beams [Jarosz et al. 2011]
  - Wojciech will talk more about it



Some Related Work

- Efficient rendering of dynamic scenes [Weiss and Grosch 2012]

Some Related Work

- Combine density estimation and MC integration [Hachisuka et al. 2012, Georgiev et al. 2012]
  - Iliyan will talk more about it

FAQs

- Q: Is PPM unbiased?

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- A: It is biased and consistent, but does not matter in practice.

$$\mathrm{E}[X] = \lim_{\boxed{N \to \infty}} \sum_{i=1}^{N} x_i$$

BOTH unbiased and consistent methods need inf. samples!

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BOTH unbiased and consistent methods need inf. samples!

"Five Common Misconceptions about Bias in Light Transport Simulation"
cs.au.dk/~toshiya/misc.pdf

FAQs

- Q: Do we still use global + caustics separation?

FAQs

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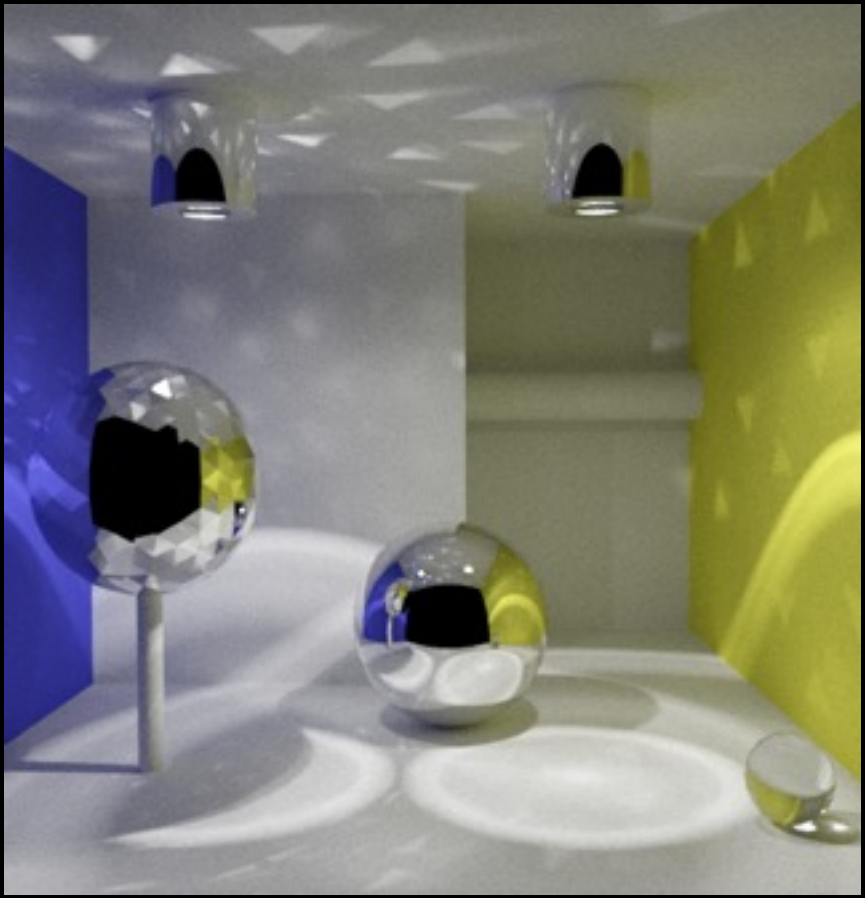
- A: No. Just render everything as one.



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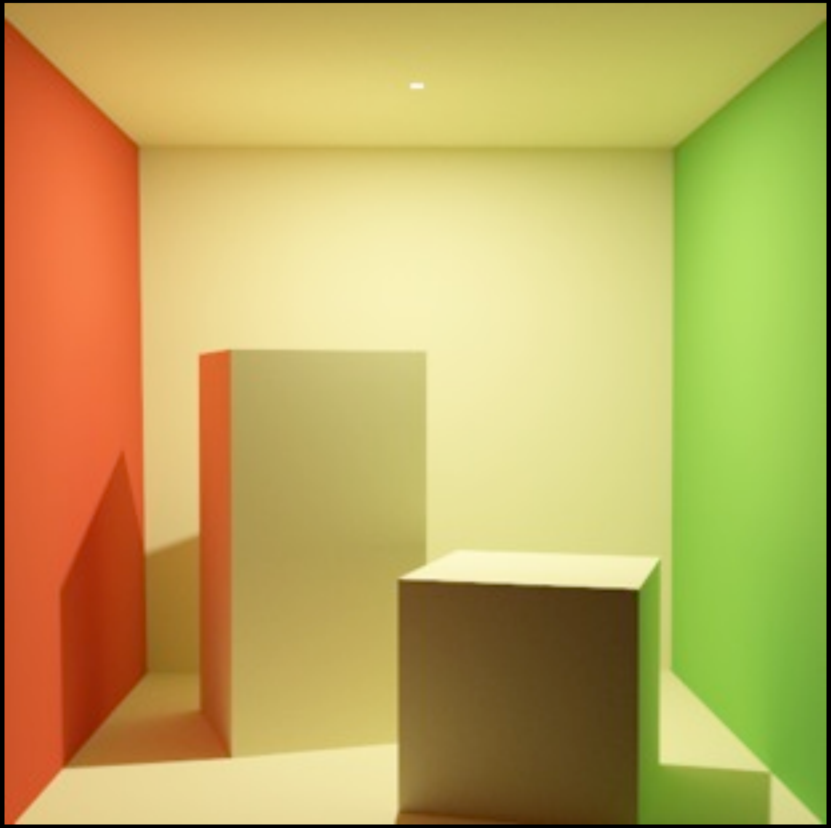
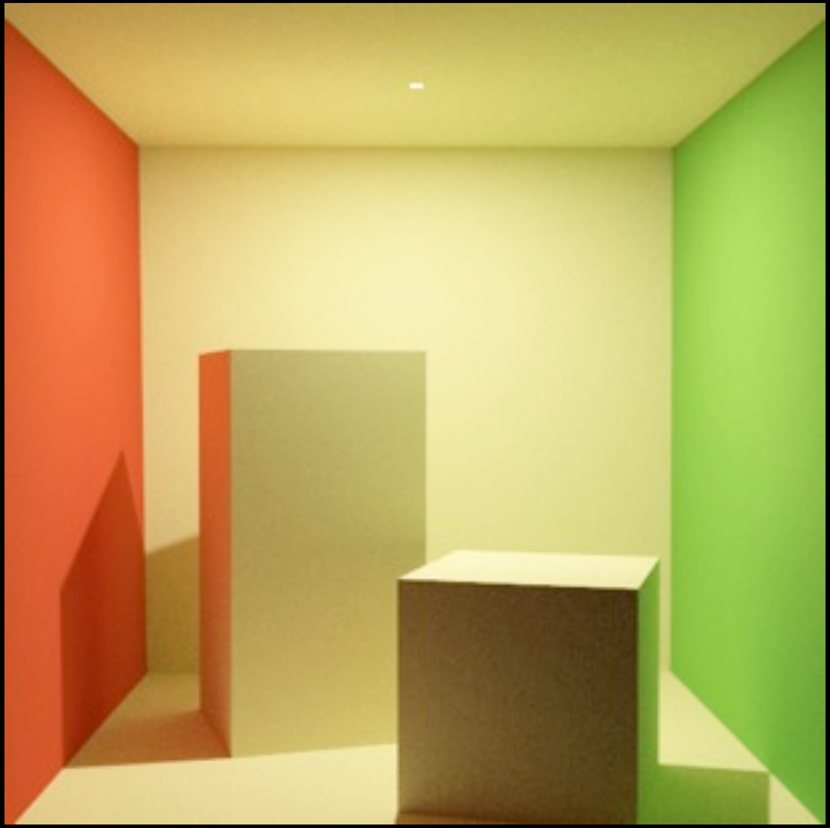


Bidirectional PT



PPM

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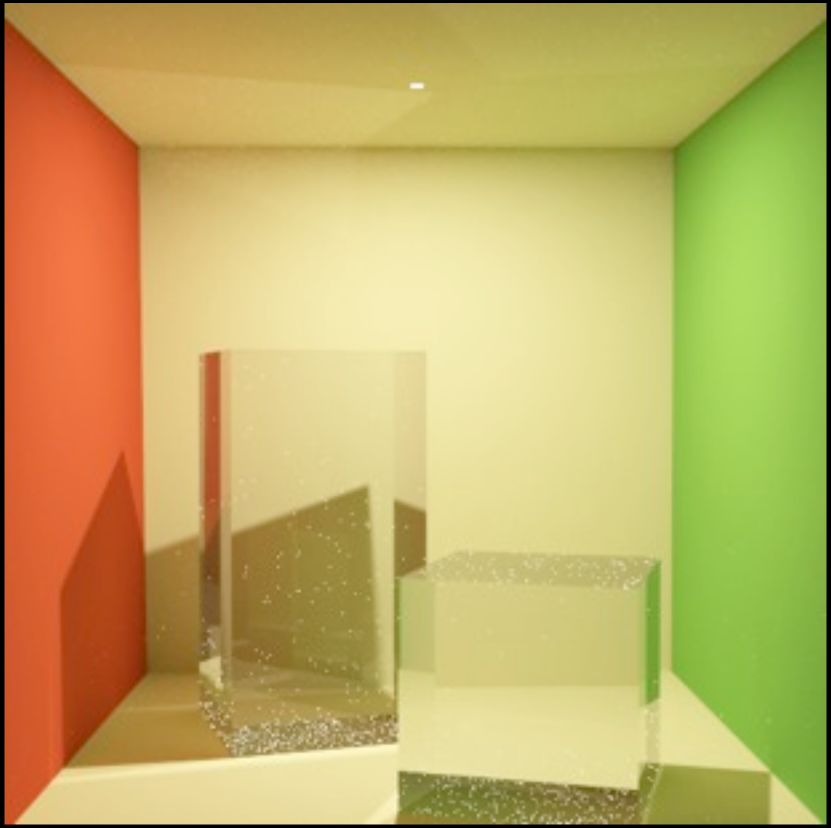

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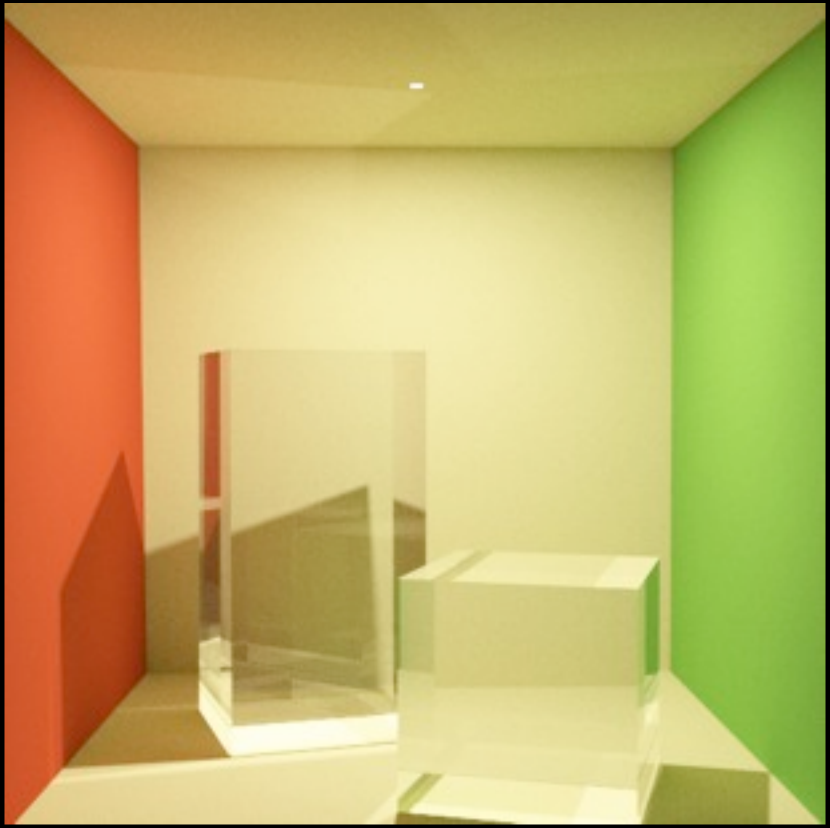

PPM

Summary

- SPPM = PPM + Distributed Ray Tracing
- Error estimation is available
- Adaptive photon tracing based on visibility
- Lots of useful extensions

- My opinion: (S)PPM + extensions is very hard to "break"
  - Just works fine in really many cases

More details

- cs.au.dk/~toshiya

Next Talk

- More advanced and efficient radius reduction