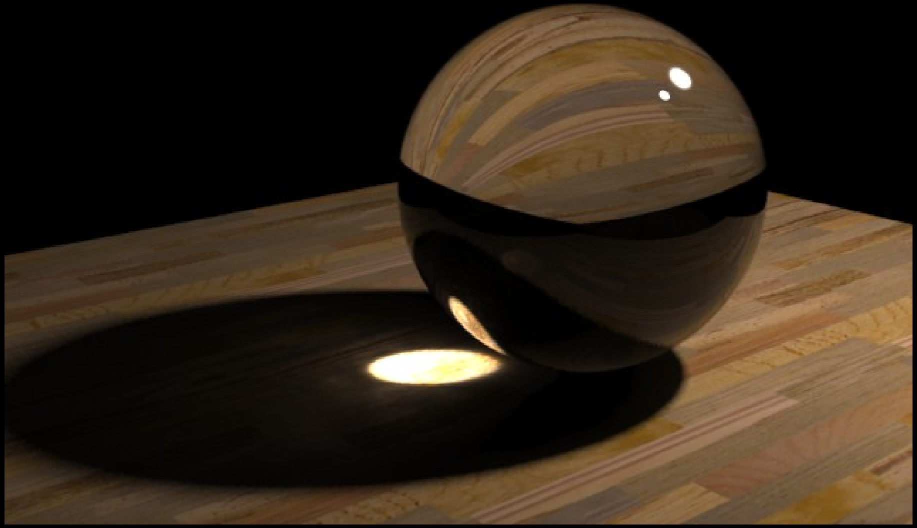
Photon Mapping



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Motivation

Global Illumination

Motivation

Direct Illumination

Motivation

Before photon mapping

- Radiosity
  - Mostly diffuse
  - Mesh based lighting representation
- Monte Carlo path tracing
  - Noisy
  - Slow convergence

Motivation

$$\begin{aligned} L(x,\vec{\omega}) &= L_e(x,\vec{\omega}) + \\ & \int_S f_r(x,\vec{\omega},x' \to x) L(x' \to x) V(x,x') G(x,x') dA' \end{aligned}$$

$$G(x,x') = \frac{(\vec{\omega}' \cdot \vec{n})(\vec{\omega}' \cdot \vec{n}')}{||x' - x||^2}$$

Motivation

Specular-Diffuse-Specular light transport is difficult

Basic Observation

- The lights are important
- The camera / eye is important

Photon Mapping

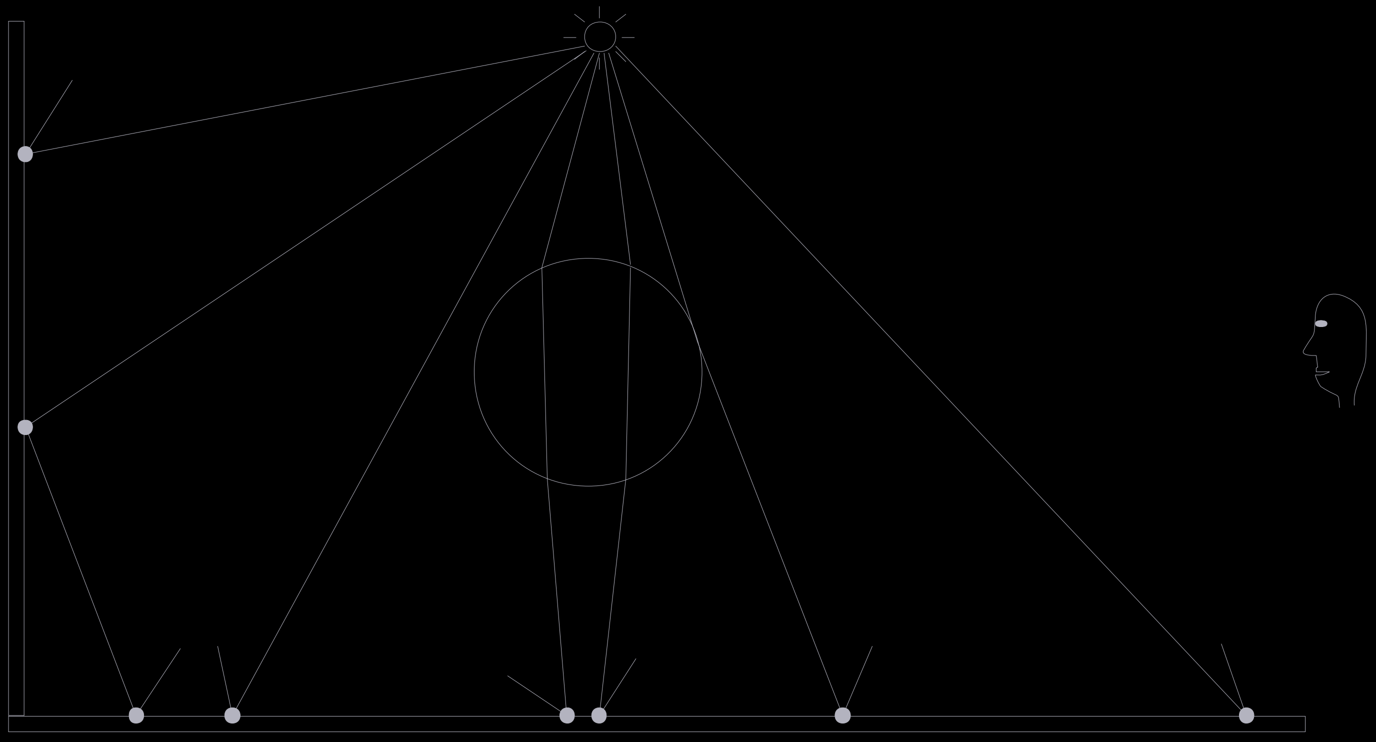
Photon Mapping

A two-pass method

Pass 1: Build the photon map (photon tracing)

Pass 2: Render the image using the photon map

Pass 1: Building the Photon Map



Photon Tracing

Photon Tracing

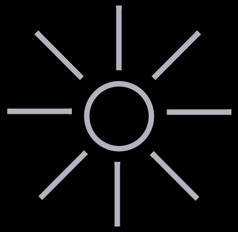
- Photon emission
- Photon scattering
- Photon storing

What is a photon?

- Flux (power) - not radiance!
- Collection of physical photons
  - A fraction of the light source power
  - Several wavelengths combined into one entity

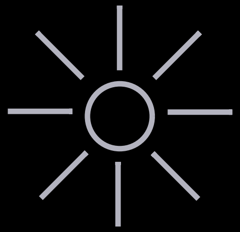
Photon emission

Given Φ Watt lightbulb.
Emit N photons.
Each photon has the power $\frac{\Phi}{N}$ Watt.



- Photon power depends on the number of emitted photons.

Diffuse point light

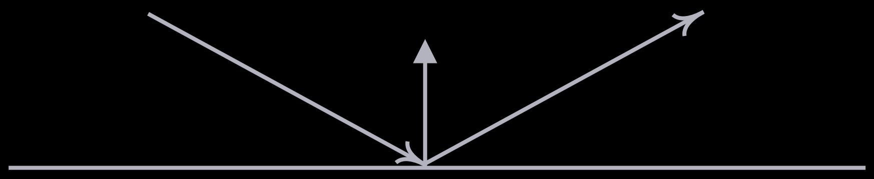


Generate random direction
Emit photon in that direction

```
// Find random direction
do {
  x = 2.0*random()-1.0;
  y = 2.0*random()-1.0;
  z = 2.0*random()-1.0;
} while ( (x*x + y*y + z*z) > 1.0 );
```

Photon scattering

Same as path tracing (with small exceptions).



$$\vec{d}_r = \vec{d}_i - 2\vec{n}(\vec{n} \cdot \vec{d}_i)$$

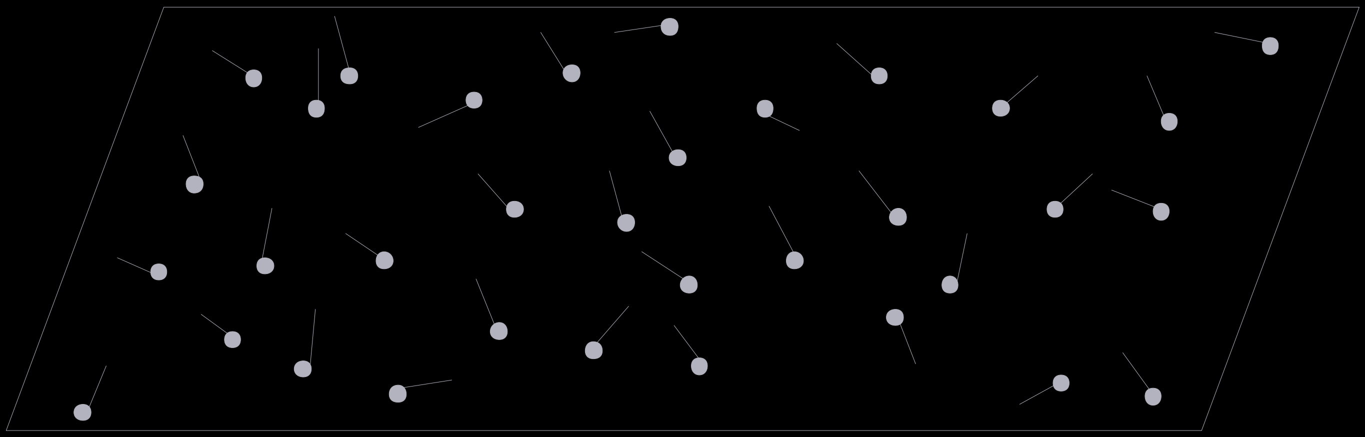
Photon scattering

Important optimizations:

- Use Russian roulette to avoid bias
- Create only one photon per scattering event

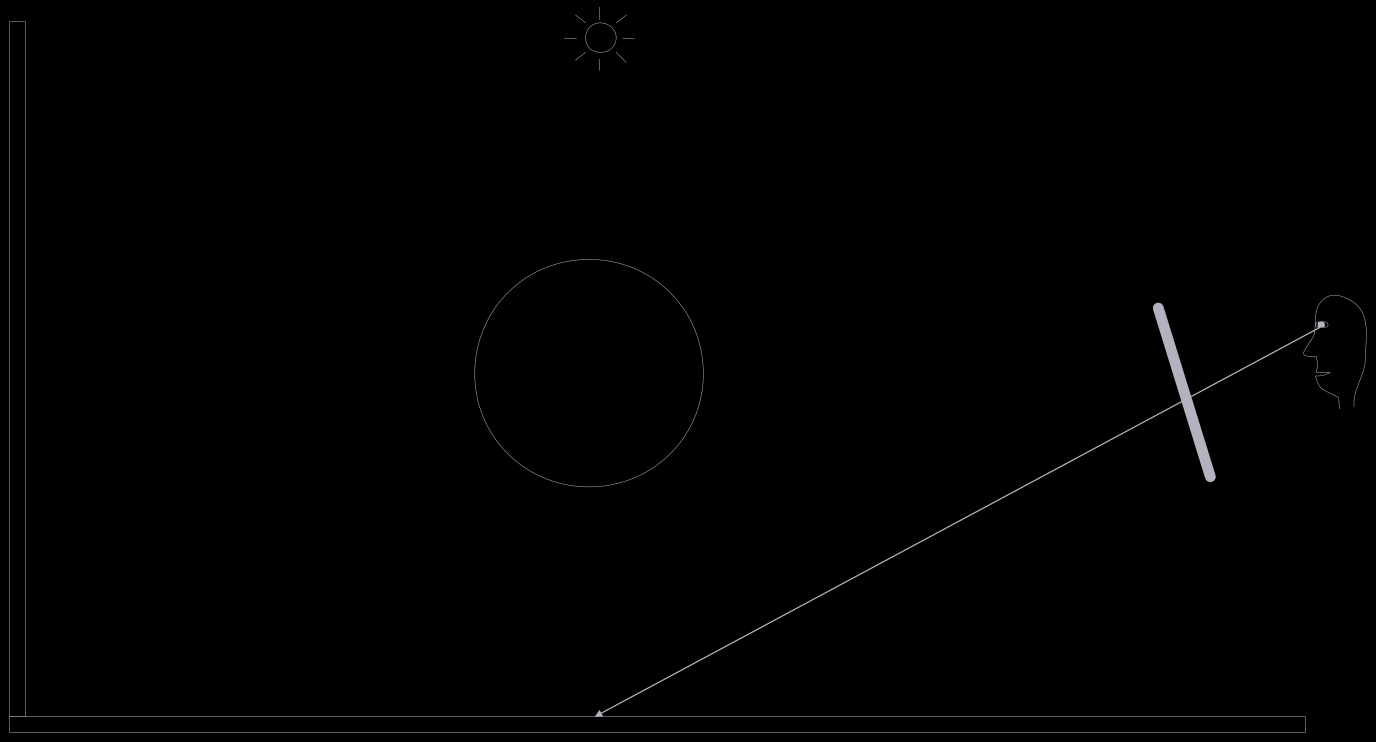
Photon storing

When a photon hits a non-specular surface information about it is stored in a global data structure called the photon map. The information includes the photon power, incoming direction and the hit location.



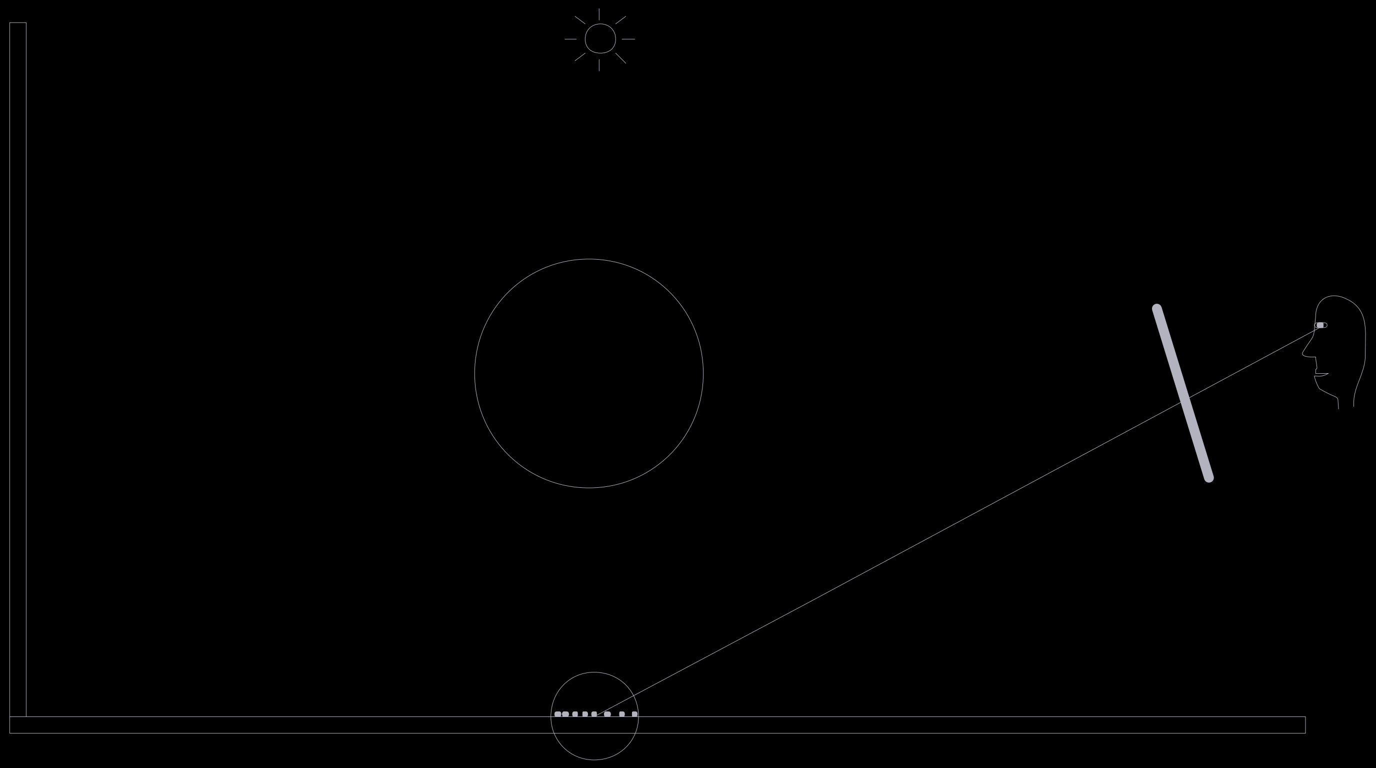
Photon map

Pass 2: Rendering

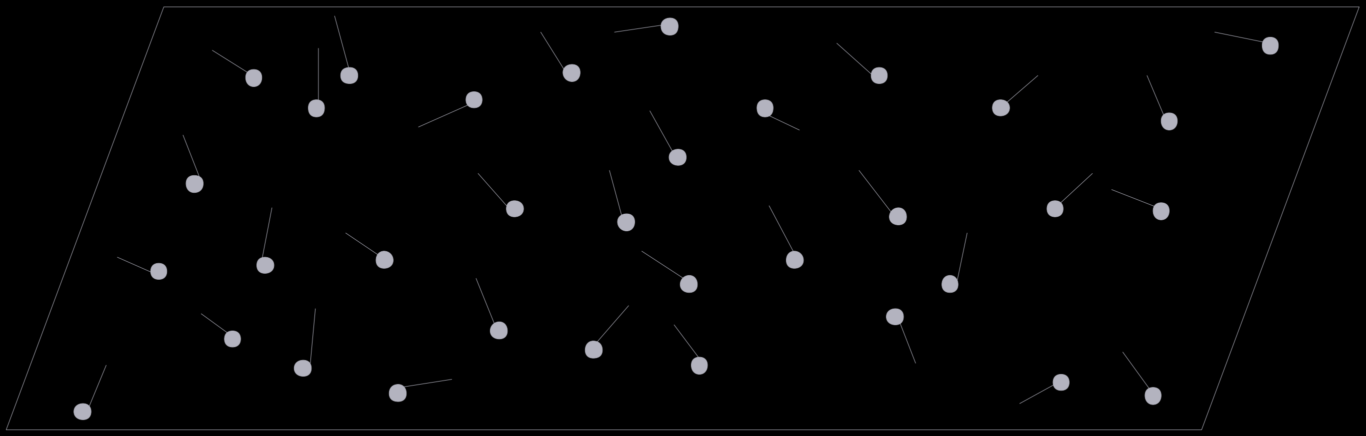


Ray Tracing

Rendering with the photon map



Rendering with the photon map



We need radiance, but the photons carry flux

Radiance Estimate

$$L(x, \vec{\omega}) \; = \; \int_{\Omega} f_r(x, \vec{\omega}', \vec{\omega}) L'(x, \vec{\omega}') \cos\theta' \, d\omega$$

Radiance Estimate

$$\begin{aligned} L(x,\vec{\omega}) &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) L'(x,\vec{\omega}') \cos\theta' \, d\omega \\ &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{d\omega \cos\theta' dA} \cos\theta' d\omega \end{aligned}$$

Radiance Estimate

$$
\begin{aligned}
L(x,\vec{\omega}) &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) L'(x,\vec{\omega}') \cos\theta' \, d\omega \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{d\omega \cos\theta' dA} \cos\theta' d\omega \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{dA}
\end{aligned}
$$

Radiance Estimate

$$\begin{aligned}
L(x,\vec{\omega}) &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) L'(x,\vec{\omega}') \cos\theta'\, d\omega \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{d\omega \cos\theta' dA} \cos\theta' d\omega \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{dA} \\
&\approx \sum_{p=1}^{n} f_r(x,\vec{\omega}'_p,\vec{\omega}) \frac{\Delta\Phi_p(x,\vec{\omega}'_p)}{\Delta A}
\end{aligned}$$

Radiance Estimate

$$
\begin{aligned}
L(x,\vec{\omega}) &= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) L'(x,\vec{\omega}') \cos\theta' \, d\omega \\
&= \int_{\Omega} f_r(x,\vec{\omega}',\vec{\omega}) \frac{d\Phi^2(x,\vec{\omega}')}{d\omega \cos\theta' dA} \cos\theta' d\omega \\
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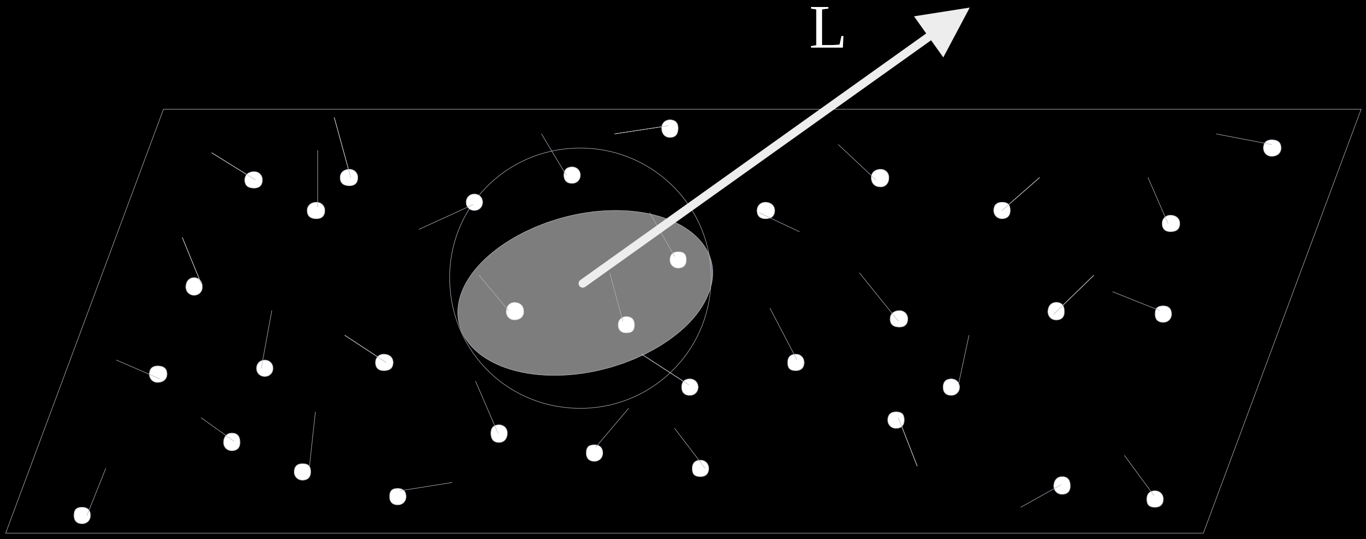
\end{aligned}
$$

Photon density estimate

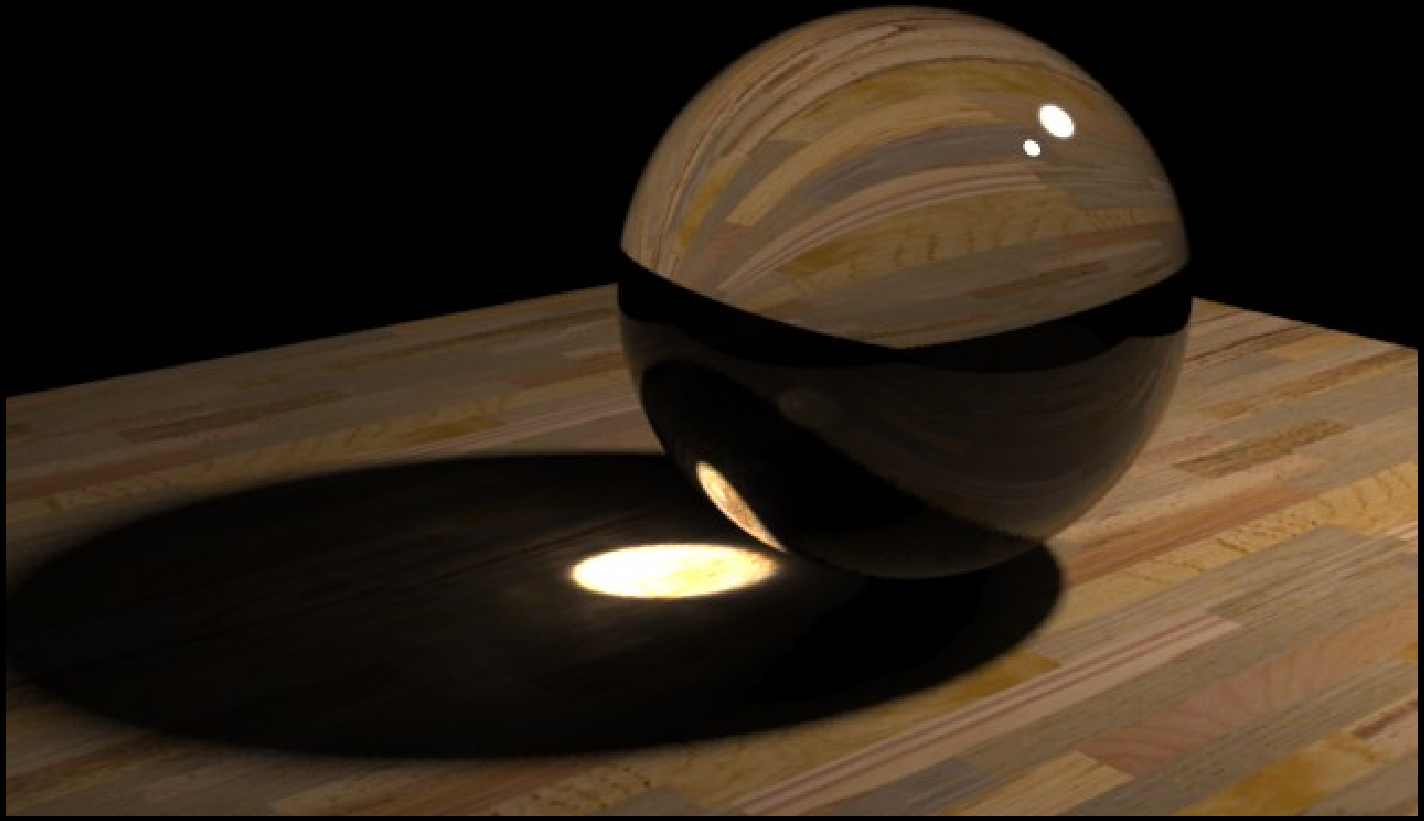
Radiance Estimate



knn estimate

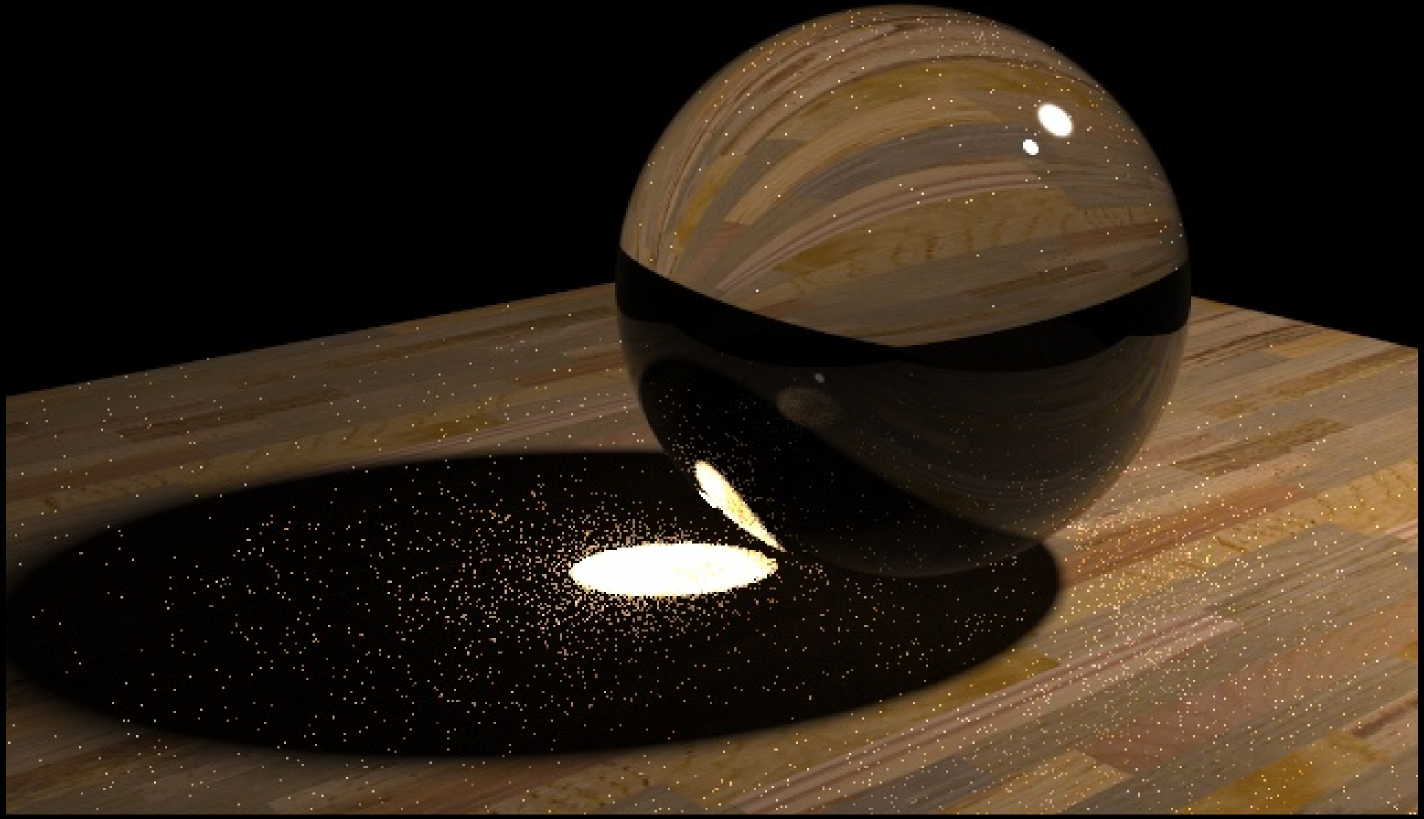
$$L(x,\vec{\omega}) \approx \sum_{p=1}^{n} f_r(x,\vec{\omega}'_p,\vec{\omega})\frac{\Delta\Phi_p(x,\vec{\omega}'_p)}{\pi r^2}$$

Caustic from a Glass Sphere



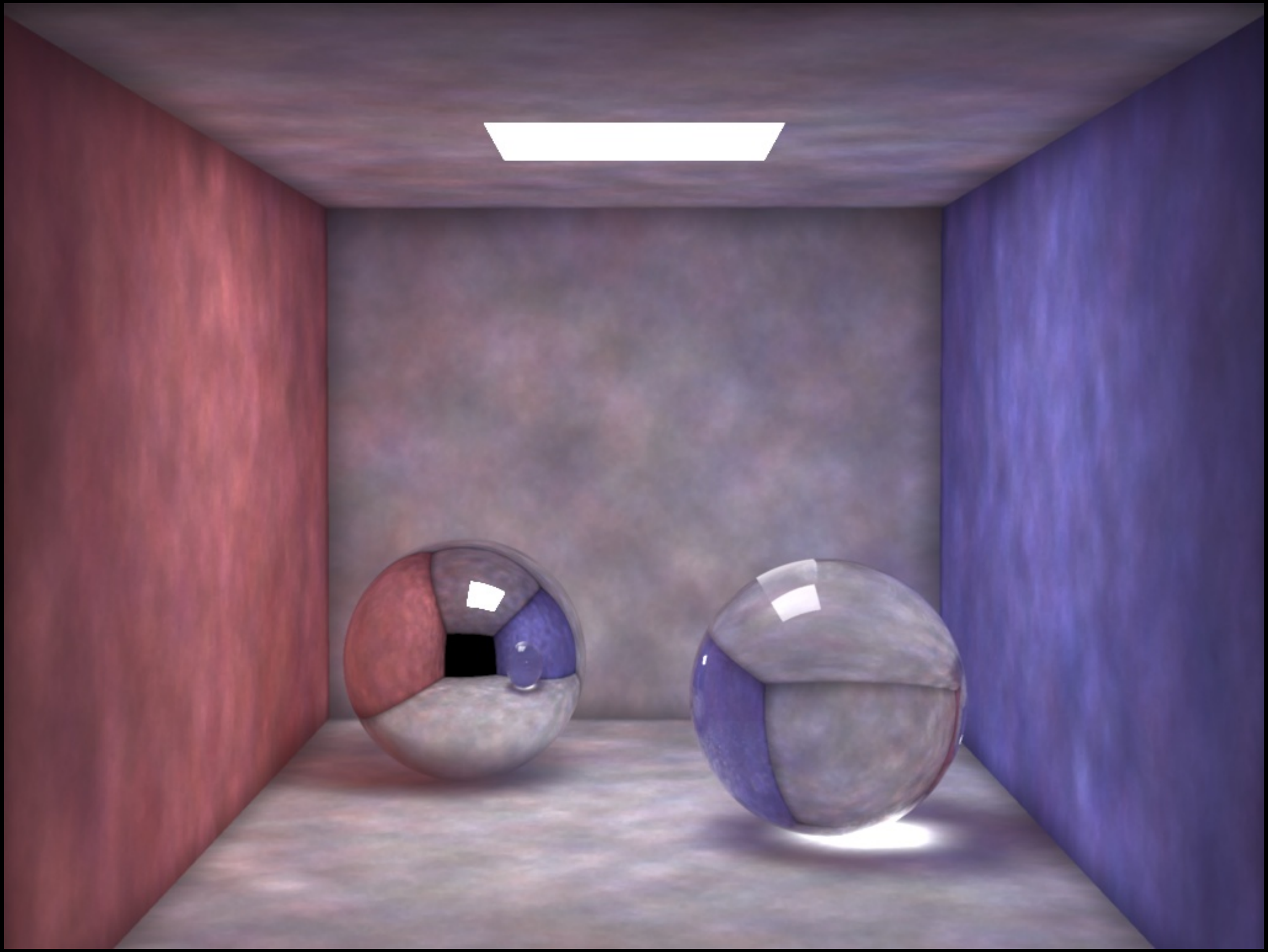
Photon Mapping: 10000 photons / 50 photons in radiance estimate

Caustic from a Glass Sphere



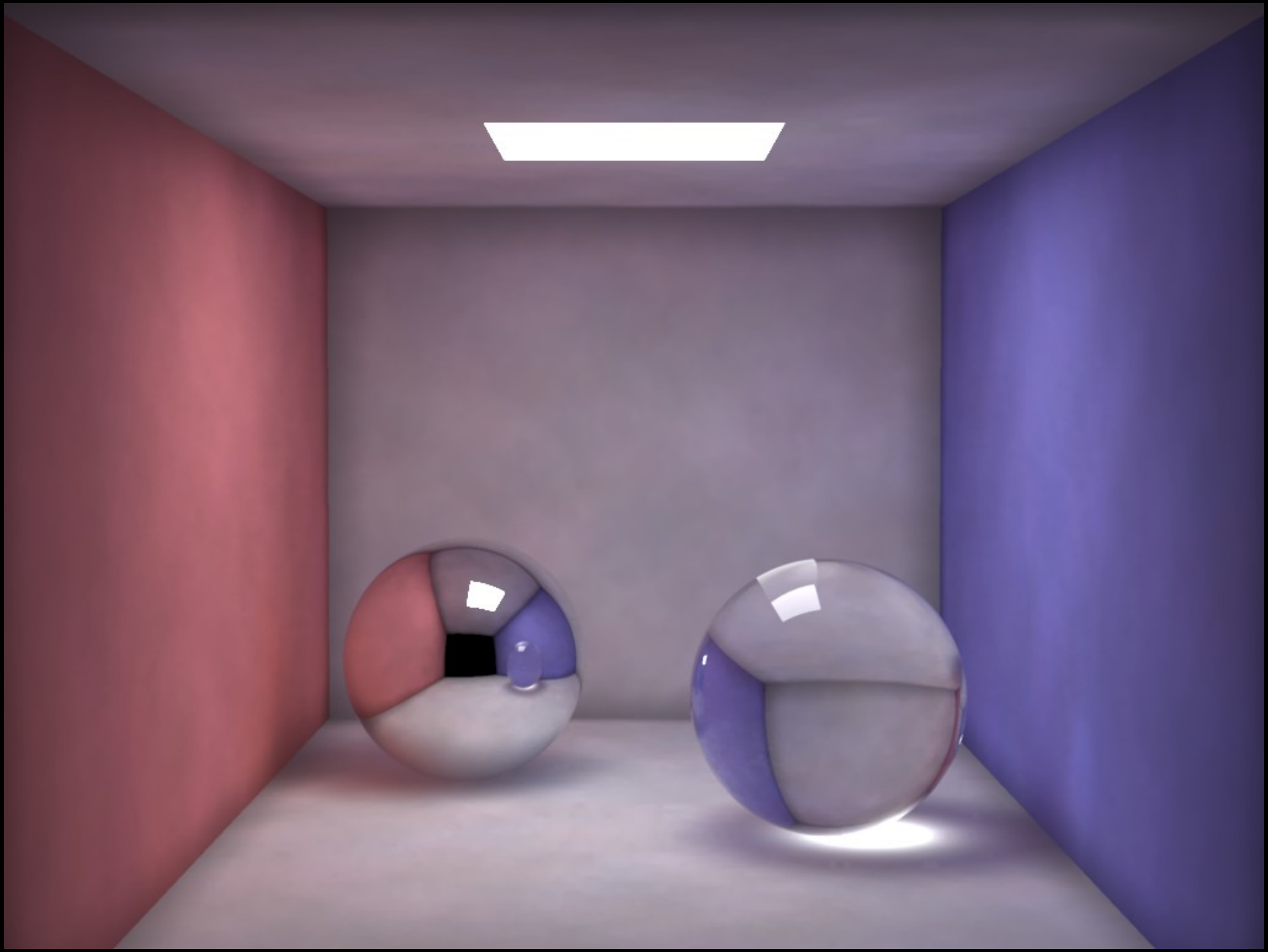
Path Tracing: 1000 paths/pixel

Global Illumination



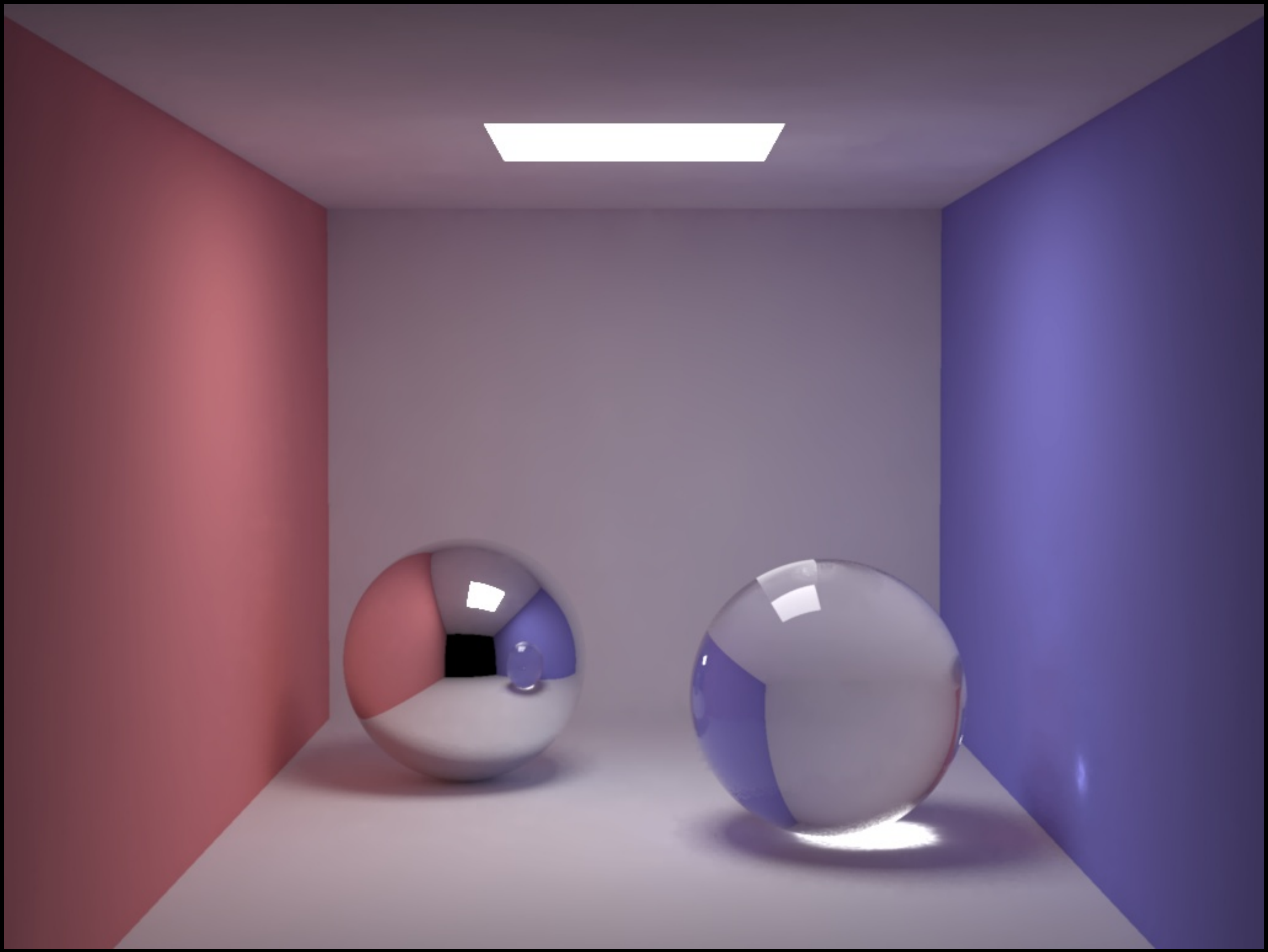
100000 photons / 50 photons in radiance estimate

Global Illumination



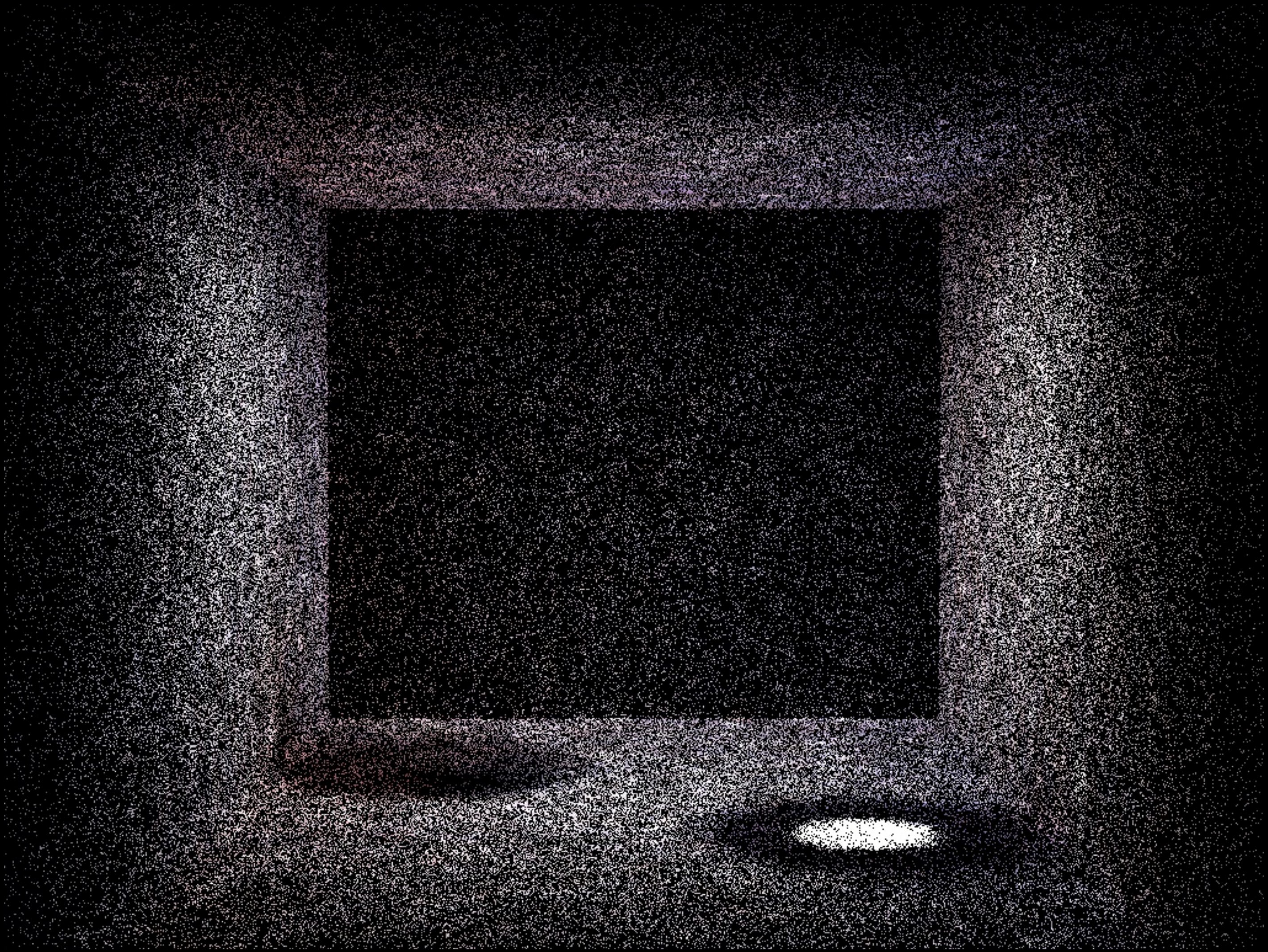
500000 photons / 500 photons in radiance estimate

Adding final gathering



200000 global photons, 50000 caustic photons

Global Photons



200000 global photons

Final observations

- Photon mapping is consistent
- Density estimate is the source of bias (blur)