CSE168: Rendering Algorithms
Photon Mapping 2

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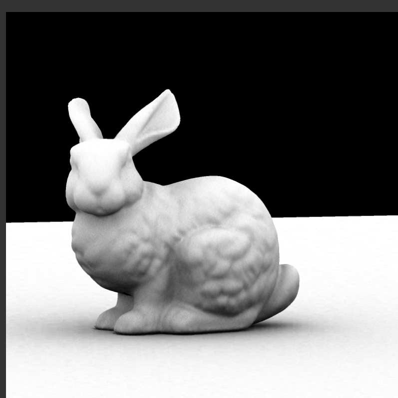
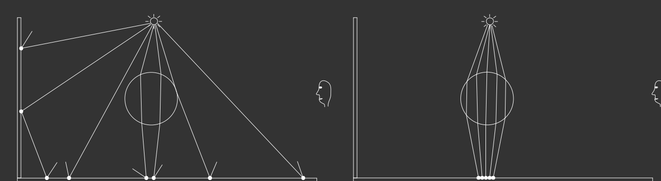
Todays Menu

- Rendering tricks
- Two-pass photon mapping
- Photon tracing
- Photon scattering
- Russian roulette
- Irradiance caching

Ambient Occlusion



Practical two-pass photon mapping

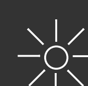


global photon map caustics photon map

Photon tracing

- Photon emission
- Photon scattering
- Photon storing

Photon emission



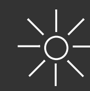
Given Φ Watt lightbulb.
Emit N photons.
Each photon has the power $\frac{\Phi}{N}$ Watt.

- Photon power depends on the number of emitted photons. Not on the number of photons in the photon map.

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

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 );
```


Example: Diffuse square light

- Generate random position p on square
- Generate diffuse direction d
- Emit photon from p in direction d

```
// Generate diffuse direction
u = random();
v = 2*π*random();
d = vector( cos(v)√u, sin(v)√u, √(1-u) );
```


Surface interactions

The photon is

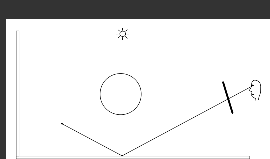
- Stored (at diffuse surfaces) and
- Absorbed (A) or
- Reflected (R) or
- Transmitted (T)

$$A + R + T = 1.0$$

Photon scattering

Photons are reflected like normal rays.

E.g. specular reflection:



$$\vec{\omega}_r = -2(\vec{\omega} \cdot \vec{n})\vec{n} + \vec{\omega}$$

Photon scattering

But photons carry flux (power):

E.g. specular reflection:

$$\Phi_r(x, \omega_r) = R_s * \Phi_i(x, \omega)$$

Can still use Fresnel, Snell's law etc.

Photon scattering

The simple way:

Given incoming photon with power Φ_p

Reflect photon with the power $R * \Phi_p$

Transmit photon with the power $T * \Phi_p$

- Risk: Too many low-powered photons - wasteful!
- When do we stop (systematic bias)?
- Photons with similar power is a good thing.

Russian Roulette

- Statistical technique
- Known from Monte Carlo particle physics
- Introduced to graphics by Arvo and Kirk in 1990

Russian Roulette

Probability of termination: p

$$E\{X\} = p \cdot 0 + (1-p) \cdot \frac{E\{X\}}{1-p} = E\{X\}$$

Terminate un-important photons and still get the correct result.

Russian Roulette Example

Surface reflectance: R = 0.5
Incoming photon: Φ_p = 2 W

```
r = random();
if ( r < 0.5 )
  reflect photon with power 2 W
else
  photon is absorbed
```


Russian Roulette Intuition

Surface reflectance: R = 0.5
200 incoming photons with power: Φ_p = 2 Watt

Reflect 100 photons with power 2 Watt instead of 200 photons with power 1 Watt.

Russian Roulette

- Very important!
- Use to eliminate un-important photons
- Gives photons with similar power :)

Sampling a BRDF

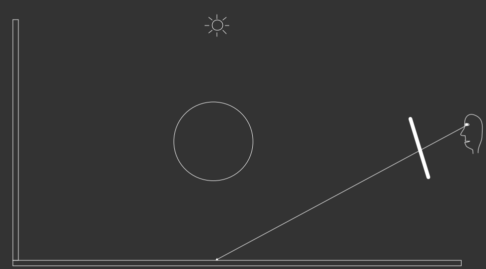
$$f_r(x,\vec{\omega}_i,\vec{\omega}_o) = w_1 f_{r,1}(x,\vec{\omega}_i,\vec{\omega}_o) + w_2 f_{r,2}(x,\vec{\omega}_i,\vec{\omega}_o)$$

Sampling a BRDF

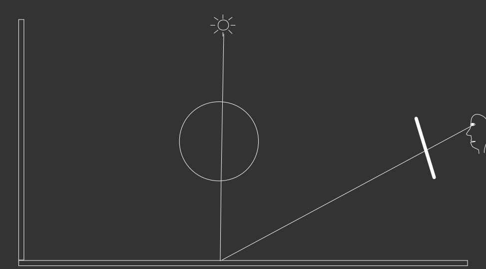
$$f_r(x,\vec{\omega}_i,\vec{\omega}_o) = w_1 \cdot f_{r,d} + w_2 \cdot f_{r,s}$$

```
r = random()·(w1 + w2);
if ( r < w1 )
  reflect diffuse photon
else
  reflect specular
```

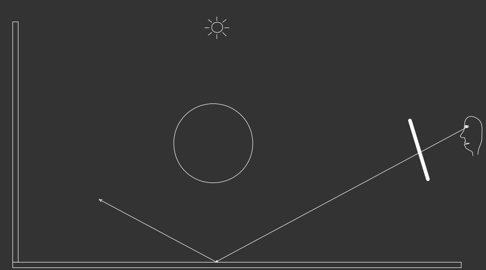

Rendering



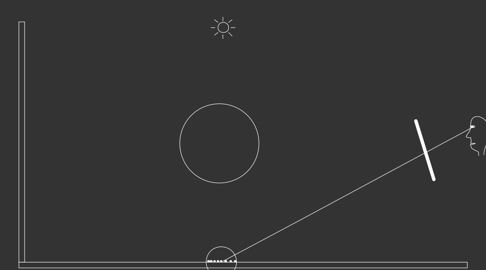
Direct Illumination



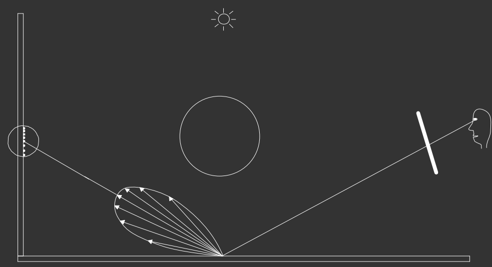
Specular Reflection



Caustics



Indirect Illumination



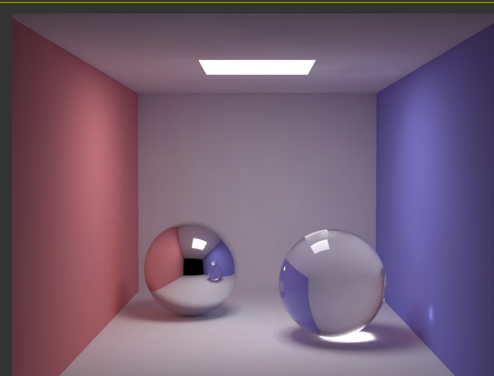
Rendering Equation Solution

$$
\begin{aligned}
L_r(x,\vec{\omega}) &= \int_{\Omega_x} f_r(x,\vec{\omega}',\vec{\omega}) L_i(x,\vec{\omega}') \cos\theta_i \, d\omega_i' \\
&= \int_{\Omega_x} f_r(x,\vec{\omega}',\vec{\omega}) L_{i,l}(x,\vec{\omega}') \cos\theta_i \, d\omega_i' + \\
&\quad \int_{\Omega_x} f_{r,s}(x,\vec{\omega}',\vec{\omega}) (L_{i,c}(x,\vec{\omega}') + L_{i,d}(x,\vec{\omega}')) \cos\theta_i \, d\omega_i' + \\
&\quad \int_{\Omega_x} f_{r,d}(x,\vec{\omega}',\vec{\omega}) L_{i,c}(x,\vec{\omega}') \cos\theta_i \, d\omega_i' + \\
&\quad \int_{\Omega_x} f_{r,d}(x,\vec{\omega}',\vec{\omega}) L_{i,d}(x,\vec{\omega}') \cos\theta_i \, d\omega_i' .
\end{aligned}
$$

Features

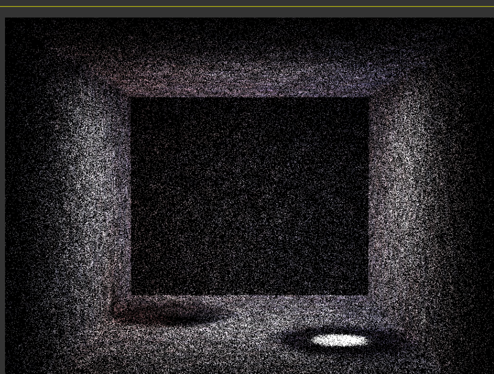
- Photon tracing is unbiased
  - Radiance estimate is biased but consistent
  - The reconstruction error is local
- Illumination representation is decoupled from the geometry

Box



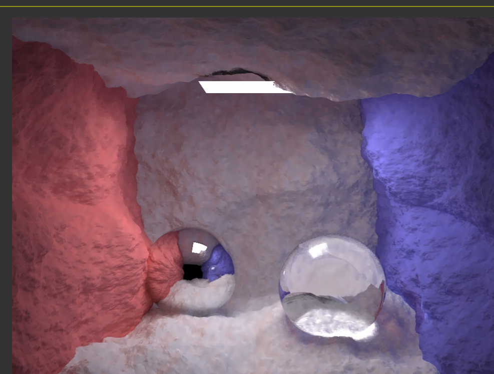
200000 global photons, 50000 caustic photons

Box: Global Photons



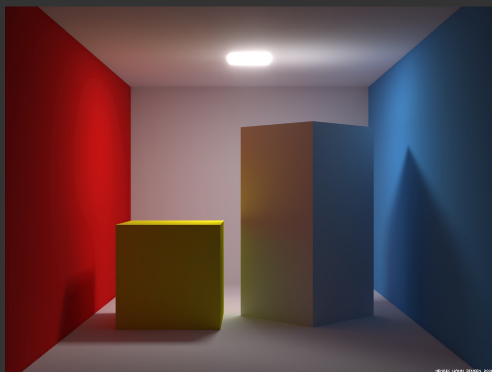
200000 global photons

Fractal Box



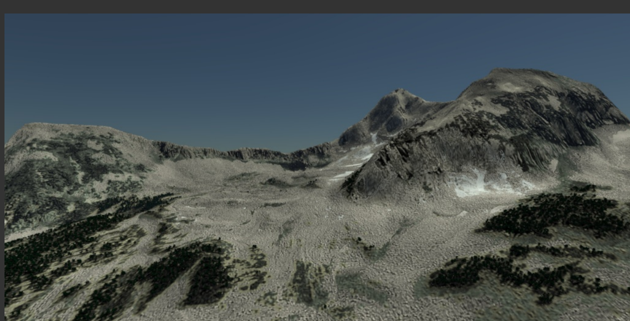
200000 global photons, 50000 caustic photons

Cornell Box



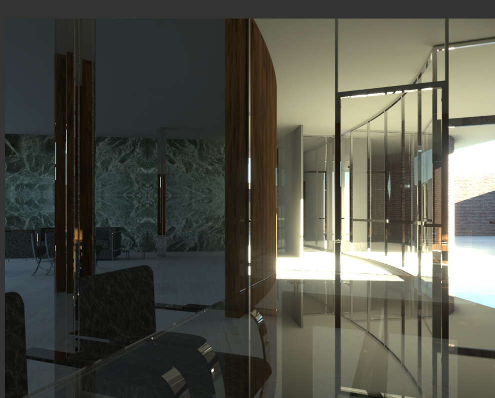
Indirect Illumination

Little Matterhorn



Mies house (3pm)

Mies house (6pm)



Box: Indirect Irradiance