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

\[ L(x, \bar{\omega}) = L_e(x, \bar{\omega}) + \int_S f_r(x, \bar{\omega}, x' \to x) L(x' \to x) V(x, x') G(x, x') dA' \]

\[ G(x, x') = \frac{(\bar{\omega}' \cdot \bar{n})(\bar{\omega}' \cdot \bar{n}')}{||x' - x||^2} \]
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 $\Phi$ 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.
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

\[ L(x, \bar{\omega}) = \int_{\Omega} f_r(x, \bar{\omega}', \bar{\omega}) L'(x, \bar{\omega}') \cos \theta' \, d\omega \]

\[ = \int_{\Omega} f_r(x, \bar{\omega}', \bar{\omega}) \frac{d\Phi^2(x, \bar{\omega}')} {d\omega \cos \theta'} \, dA \cos \theta' \, d\omega \]
Radiance Estimate

\[ \begin{align*}
L(x, \tilde{\omega}) &= \int_{\Omega} f_r(x, \tilde{\omega}', \tilde{\omega})L'(x, \tilde{\omega}') \cos \theta' \, d\omega \\
&= \int_{\Omega} f_r(x, \tilde{\omega}', \tilde{\omega}) \frac{d\Phi^2(x, \tilde{\omega}')}{d\omega \cos \theta' \, dA} \cos \theta' \, d\omega \\
&= \int_{\Omega} f_r(x, \tilde{\omega}', \tilde{\omega}) \frac{d\Phi^2(x, \tilde{\omega}')}{dA}
\end{align*} \]
Radiance Estimate

\[ L(x, \bar{\omega}) = \int_{\Omega} f_r(x, \bar{\omega}', \bar{\omega}) L'(x, \bar{\omega}') \cos \theta' \, d\omega \]

\[ = \int_{\Omega} f_r(x, \bar{\omega}', \bar{\omega}) \frac{d\Phi^2(x, \bar{\omega}')}{d\omega \cos \theta' \, dA} \cos \theta' \, d\omega \]

\[ = \int_{\Omega} f_r(x, \bar{\omega}', \bar{\omega}) \frac{d\Phi^2(x, \bar{\omega}')}{dA} \]

\[ \approx \sum_{p=1}^{n} f_r(x, \bar{\omega}_p', \bar{\omega}) \frac{\Delta \Phi_p(x, \bar{\omega}'_p)}{\Delta A} \]
Radiance Estimate

\[ L(x, \omega) = \int_{\Omega} f_r(x, \omega', \omega)L'(x, \omega') \cos \theta' \, d\omega \]

\[ = \int_{\Omega} f_r(x, \omega', \omega) \frac{d\Phi^2(x, \omega')}{d\omega \cos \theta' \, dA} \cos \theta' \, d\omega \]

\[ = \int_{\Omega} f_r(x, \omega', \omega) \frac{d\Phi^2(x, \omega')}{dA} \]

\[ \approx \sum_{p=1}^{n} f_r(x, \omega'_p, \omega) \frac{\Delta \Phi_p(x, \omega'_p)}{\Delta A} \]

Photon density estimate
Radiance 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

200,000 global photons
Final observations

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