Global Illumination using Photon Maps

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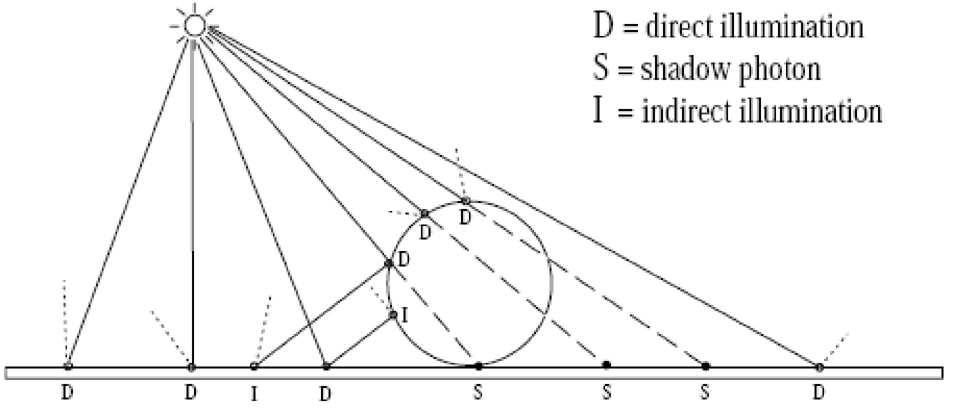
Photon Mapping

- Ray casting from light sources
- Hits may be Reflected or Absorbed
  - Reflections according to BRDF
- Resulting energy stored as a Photon Map
- Rays extended through rest of scene to create Shadow Photons at each successive hit



Global Illumination

- 2-pass
  - First pass: Photon map production
    - One high-res directed toward specular objects (Caustics)
    - One low-res directed toward all objects (Global)
  - Caustic map directly used in visualization
  - Global map used only to guide second pass

Rendering Equation Revisited

$$\begin{aligned} L_r &= \int_\Omega f_r L_{i,l} \cos\theta_i \, d\omega_i + \\ &\int_\Omega f_{r,s}(L_{i,c} + L_{i,d}) \cos\theta_i \, d\omega_i + \\ &\int_\Omega f_{r,d} L_{i,c} \cos\theta_i \, d\omega_i + \\ &\int_\Omega f_{r,d} L_{i,d} \cos\theta_i \, d\omega_i \end{aligned}$$

$$f_r = f_{r,s} + f_{r,d} \quad \text{and} \quad L_i = L_{i,l} + L_{i,c} + L_{i,d}$$

L_r: Radiance returned by ray

L_i: Incoming radiance: direct light contribution, caustic (specular), & diffuse

f_r: BRDF: diffuse and specular

What do we do with that?

- Each term evaluated to compute a part of the radiance at a point
- Can be evaluated approximately or accurately
  - Accurate: Surface seen directly or specularly
  - Approximate: Reflected diffusely or low contribution

First Term: Direct Illumination

$$\int_{\Omega} f_r L_{i,l} \cos\theta_i \, d\omega_i$$

- Normally computed using shadow rays
- Approximate: Estimate using global photon map
- Accurate: Search nearest photons in map
  - If all in shadow or not in shadow, assume the same
  - If mixed, send shadow rays

Second Term: Specular Reflection

$$\int_{\Omega} f_{r,s}(L_{i,c} + L_{i,d}) \cos\theta_i \, d\omega_i$$

- Evaluated with Monte Carlo ray tracing
- Importance sampling based on BRDF minimizes computation

Third Term: Caustics

$$\int_{\Omega} f_{r,d} L_{i,c} \cos\theta_i \, d\omega_i$$

- Visualized directly from caustic photon map
- Caustics almost impossible to calculate via Monte Carlo ray tracing
- Higher resolution of caustic map necessary for correct visualization

Fourth Term: Indirect Illumination

$$\int_{\Omega} f_{r,d} L_{i,d} \cos\theta_i \, d\omega_i$$

- Light that has been diffusely reflected
- Approximate: Estimate using global photon map
- Accurate: Use importance sampling
  - BRDF and global photon map used to generate optimal directions
  - Lambertian surfaces: If nearby values have already been computed, just interpolate

Radiance Estimation

$$L_r(\mathbf{x}, \Psi_r) = \int_\Omega f_r(\mathbf{x}, \Psi_r, \Psi_i) \frac{d^2\Phi_i(\mathbf{x}, \Psi_i)}{dA\, d\omega_i} d\omega_i \approx \sum_{p=1}^{N} f_r(\mathbf{x}, \Psi_r, \Psi_{i,p}) \frac{\Delta\Phi_p(\mathbf{x}, \Psi_{i,p})}{\pi r^2}$$

- Direct or indirect diffuse/glossy reflections
- Essentially, add up BRDF contributions from N nearest photons within a sphere over area πr^2 in the global photon map
- Computing an adaptive variable area is too intensive
- Using a fixed area gives bad estimates with too few photons or blurry estimates with too many
  - Apply a cone filter when photon density too low