Photon Mapping

CS 319
Advanced Topics in Computer Graphics
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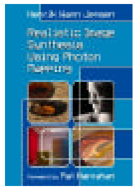
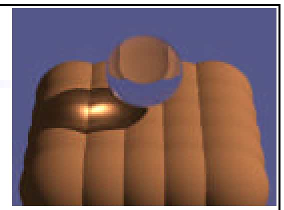


Monte-Carlo Ray Tracing

- Advantages
  - L(D|S)*E – All paths of light
  - Arbitrary geometry
    - Parametrics, subdivs, implicits
    - Procedural models
  - Compact
    - Compute intersections on demand
- Disadvantages
  - Noise
  - Complexity



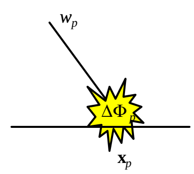
Jensen

Photon Mapping

- Jensen EGRW 95, 96
- Simulates the transport of individual photons
- Photons emitted from source
- Photons deposited on surfaces
- Photons reflected from surfaces to other surfaces
- Photons collected by rendering

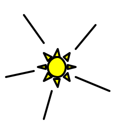
What is a Photon?

- A photon *p* is a particle of light that carries flux $\Delta\Phi_p(\mathbf{x}_p, w_p)$
  - Power: $\Delta\Phi_p$ – magnitude (in Watts) and color of the flux it carries, stored as an RGB triple
  - Position: $\mathbf{x}_p$ – location of the photon
  - Direction: w_p – the incident direction w_i used to compute irradiance
- Photons vs. rays
  - Photons propogate flux
  - Rays gather radiance



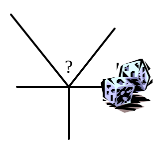
Sources

- Point source
  - Photons emitted uniformly in all directions
- Power of source (W) distributed evenly among photons
- Flux of each photon equal to source power divided by total # of photons
- For example, a 60W light bulb would send out a total of 100K photons, each carrying a flux $\Delta\Phi$ of 0.6 mW
- Photons sent out once per simulation, not continuously as in radiosity



Russian Roulette

- Arvo & Kirk, Particle Transport and Image Synthesis, SIGGRAPH 90, pp. 63-66.
- Reflected flux only a fraction of incident flux
- After several reflections, spending a lot of time keeping track of very little flux
- Instead, absorb some photons and reflect the rest at full power
- Spend time tracing fewer full power photons
- Probability of reflectance is the reflectance *r*, duh. (*aka* albedo)
- Probability of absorption is 1 – *r*.

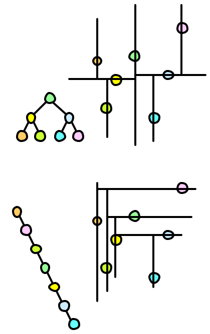


Mixed Surfaces

- Surfaces have specular and diffuse components
  - r_d – diffuse reflectance
  - r_s – specular reflectance
  - $r_d + r_s < 1$ (conservation of energy)
- Let ζ be a uniform random value from 0 to 1
- If $\zeta < r_d$ then reflect diffuse
- Else if $\zeta < r_d + r_s$ then reflect specular
- Otherwise absorb

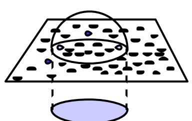
Storing Photons

- Uses a kd-tree – a sequence of axis-aligned partitions
  - 2-D partitions are lines
  - 3-D partitions are planes
- Axis of partitions alternates wrt depth of the tree
- Average access time is $O(\log n)$
- Worst case $O(n)$ when tree is severely lopsided
- Need to maintain a balanced tree, which can be done in $O(n \log n)$
- Can find k nearest neighbors in $O(k + \log n)$ time using a heap



Reflected Radiance

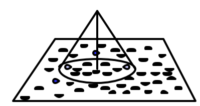
- Recall the reflected radiance equation
  $$L_r(\mathbf{x},w_r) = \int_\Omega f_r(w_i,w_r) L_i(\mathbf{x},w_i)(N \cdot w_i) dw_i$$
- Convert incident radiance into incident flux
  $$L_i(\mathbf{x},w_i) = \frac{d^2\Phi_i(\mathbf{x},w_i)}{(N \cdot w_i) dw_i dA_i}$$
- Reflected radiance in terms of incident flux
  $$L_r(\mathbf{x},w_r) = \int_\Omega f_r(w_i,w_r) \frac{d^2\Phi_i(\mathbf{x},w_i)}{dA_i}$$
- Numerically
  $$L_r(\mathbf{x},w_r) \approx \frac{1}{\Delta A}\sum_{p=1}^{n} f_r(w_p,w_r)\Delta\Phi_p(\mathbf{x},w_p)$$



$\Delta A = pr^2$

Filtering

- Too few photons cause blurry results
- Simple averaging produces a box filtering of photons
- Photons nearer to the sample should be weighted more heavily
- Results in a cone filtering of photons



$$L_r(\mathbf{x},w_r) \approx \frac{1}{(1-\frac{2}{3k})pr^2}\sum_{p=1}^{n}\left(1-\frac{\|\mathbf{x}-\mathbf{x}_p\|}{kr}\right) f_r(w_p,w_r)\Delta\Phi_p(\mathbf{x}_p,w_p)$$

Rendering

- Photons in photon map are collected by eye rays cast by a distributed ray tracer
- Multiple photon maps
  - Indirect irradiance map
  - Caustic map
- Rays use the radiance constructed from reflected flux density from nearest neighbor photons