Monte Carlo Path Tracing and Caching Illumination

An Introduction

Beyond Ray Tracing and Radiosity

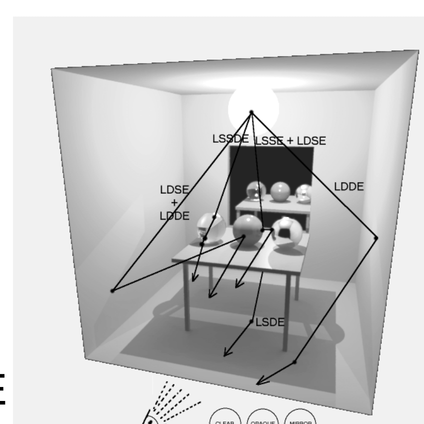
- What effects are missing from them?
  - Ray tracing: missing indirection illumination from diffuse surfaces.
  - Radiosity: no specular surfaces
- Let's classify the missing effects more formally using the notation in Watt's 10.1.3 (next slide)

Path Notation

- Each path is terminated by the eye and a light:
  - E: the eye
  - L: the light
- Types of Reflection (and transmission):
  - D: Diffuse
  - S: Specular
  - Note that the “specular” here means mirror-like reflection (single outgoing direction). Hanrahan’s SG01 course note has an additional “glossy” type.

Path Notation

- A path is written as a regular expression.
- Examples:
  - Ray tracing: LD[S*]E
  - Radiosity: LD*E
- Complete global illumination: L(D|S)*E



Bi-direction Ray Tracing

- Also called two-pass ray tracing.
- Note that the Monte Carlo technique is not involved.
- The concept of "caching illumination" (as a mean of communication between two passes.) -- After the first pass, illumination maps are stored (cached) on diffuse surfaces.

Multi-pass Methods

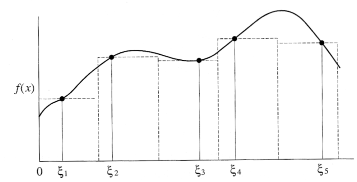
Note: don't confuse "multi-pass" with "bi-directional" or the multiple random samples in Monte Carlo methods.

- LS*DS*E is included in bi-directional ray tracing.
- How about the interaction between two diffuse surfaces? (radiosity déjà vu?)

Monte Carlo Integration

- Estimate the integral of $f(x)$ by taking random samples ξ and evaluate $f(\xi)$.
- Variance of the estimate decreases with the number of samples taken (N):

$$\sigma^2 = \frac{1}{N}\left(\int f^2(x)dx - f^2(\xi)\right)$$



Biased Distribution

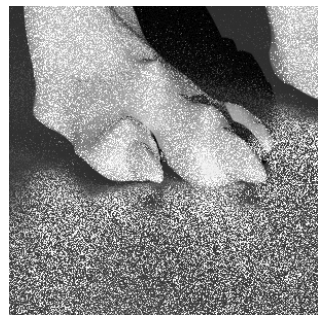
- What if the probability distribution ($p(x)$) of the samples is not uniform?
- Example:
  - What is the expected value of a flawless dice?
  - What if the dice is flawed and the number 6 appears twice as often as the other numbers?
  - How to fix it to get the same expected value?

$$\text{Assume } X_i \in [0,1], E[f(X_i)] = \frac{1}{N}\sum_{i=1}^{N} f(X_i) \text{ if not biased}$$

$$E[f(X_i)] = \sum_{i=1}^{N} \frac{f(X_i)}{p(X_i)} \text{ if biased}$$

Noise in Rendered Images

- The variance (in estimation of the integral) shows up as noise in the rendered images.



Importance Sampling

- One way to reduce the variance (with a fixed number of samples) is to use more samples in more “important” parts.
- Brighter illumination tends to be more important.
- More detail in Veach’s thesis and his “Metropolis Light Transport” paper.

Monte Carlo Path Tracing

- Apply the Monte Carlo techniques to solve the integral in the rendering equation.
- Questions are:
  - What is the cost?
  - How to reduce the variance (noise)?

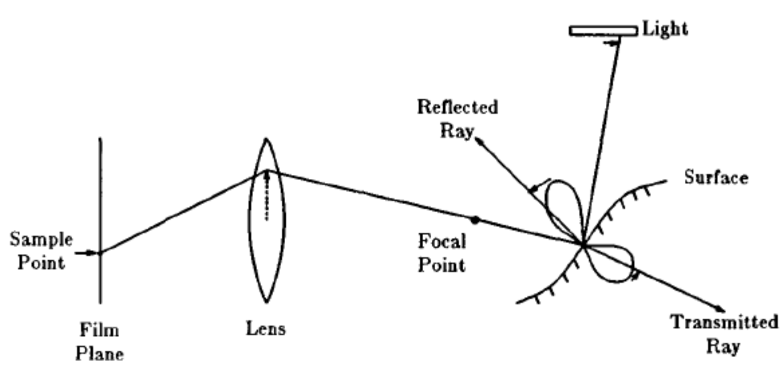
Integrals

- In rendering equation:
  - Reflection and transmission.
  - Visibility
  - Light source
- In image formation (camera)
  - Pixel
  - Aperture
  - Time
  - Wavelength

Effects

- By distributing samples in each integral, we get different effects:
  - Reflection and transmission → blurred
  - Visibility → fog or smoke
  - Light source → penumbras and soft shadow
- In image formation (camera)
  - Pixel → anialiasing
  - Aperture → depth of field
  - Time → motion blue
  - Wavelength → dispersion

Typical Distributed Ray Path



Summary

- Monte Carlo path (ray) tracing is an elegant solution for including diffuse and glossy surfaces.
- To improve efficiency, we have (at least) two weapons:
  - Importance sampling
  - Caching illumination

Exercises (Food for Thought)

- Can the multi-pass method (i.e., light-ray tracing, radiosity, then eye-ray tracing) replace the Monte Carlo path tracing approach? (*Hint: glossy?*)
- What are the differences between Cook's distributed ray tracing and a complete Monte Carlo path tracing?

References

- Pharr's chapters 14-16.
- Watt's Ch.10 (especially 10.1.3, and 10.4 to 10.9)
- Or, see SIGGRAPH 2001 Course 29 by Pat Hanrahan for a different view.
- After that, you shall be ready for more advanced topics, such as:
  - Global Illumination Using the Photon Maps by H. W. Jensen