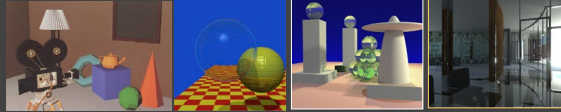


Computer Graphics II: Rendering

CSE 168 [Spr 20], Lecture 12: High Quality Rendering
Ravi Ramamoorthi

<http://viscomp.ucsd.edu/classes/cse168/sp20>



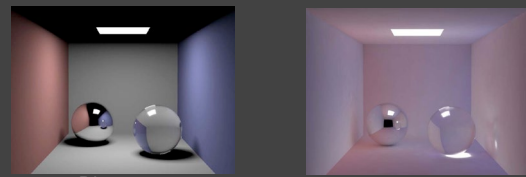
To Do

- Homework 4 (importance sampling) due May 18
- These lectures cover more advanced topics
 - May be relevant for your final project
 - Or curiosity in terms of frontiers of modern rendering

Motivation

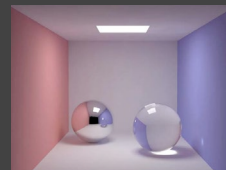
- Rendering Equation since 86, Path Tracer in HW 3
- So, is Monte Carlo rendering solved?
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 - Irradiance Caching takes advantage of coherence*
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- Denoising (next time)

Smoothness of Indirect Lighting



Direct

Indirect

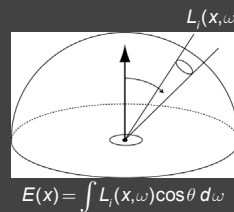


Direct + Indirect

Irradiance Caching

- Empirically, (diffuse) interreflections low frequency
- Therefore, should be able to sample sparsely
- Irradiance caching samples irradiance at few points on surfaces, and then interpolates
- Ward, Rubinstein, Clear. SIGGRAPH 88, *A ray tracing solution for diffuse interreflection*

Irradiance Calculation



$$E(x) = \frac{\sum_i w(x_i) E_i(x_i)}{\sum_i w(x_i)} \quad w(x) = \frac{1}{\epsilon(x)}$$

$$\epsilon(x) \leq \left| \frac{\partial E}{\partial x}(x - x_0) + \frac{\partial E}{\partial \theta}(\theta - \theta_0) \right|$$

position rotation

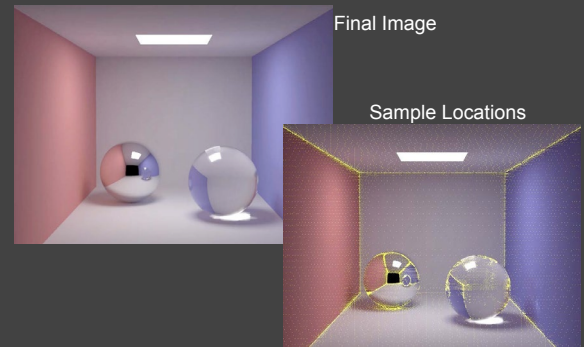
$$\leq E_0 \left(\frac{4}{\pi} \frac{\|x - x_0\|}{x_{avg}} + \sqrt{2 - 2\bar{N}(x) \cdot \bar{N}(x_0)} \right)$$

Derivation in Ward paper

Algorithm Outline

- Find all samples with $w(x) > q$
- if (samples found)
 - interpolate
- else
 - compute new irradiance
- N.B. Subsample the image first and then fill in

Irradiance Caching Example



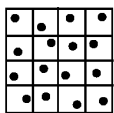
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Better Sampling

- Smarter ways to Monte Carlo sample
- Long history: Stratified, Importance, Bi-Directional, Multiple Importance, Metropolis
- Good reference is Veach thesis
- We only briefly discuss a couple of strategies

Stratified Sampling



Stratified sampling like jittered sampling

Allocate samples per region

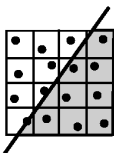
$$N = \sum_{i=1}^m N_i \quad F_N = \frac{1}{N} \sum_{i=1}^m N_i F_i$$

New variance

$$V[F_N] = \frac{1}{N^2} \sum_{i=1}^m N_i V[F_i]$$

Thus, if the variance in regions is less than the overall variance, there will be a reduction in resulting variance

For example: An edge through a pixel



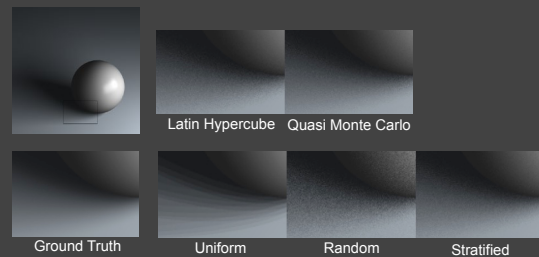
$$V[F_N] = \frac{1}{N^2} \sum_{i=1}^N V[F_i] = \frac{V[F_i]}{N^{1/3}}$$

CS348B Lecture 9

Pat Hanrahan, Spring 2002

D. Mitchell 95, Consequences of stratified sampling in graphics

Comparison of simple patterns

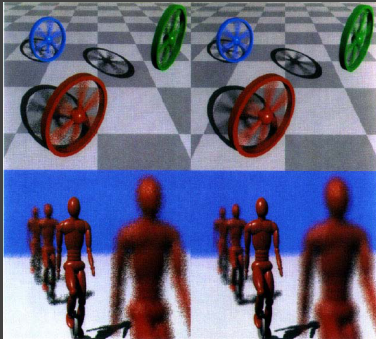


16 samples for area light, 4 samples per pixel, total 64 samples

If interested, see my paper "A Theory of Monte Carlo Visibility Sampling"

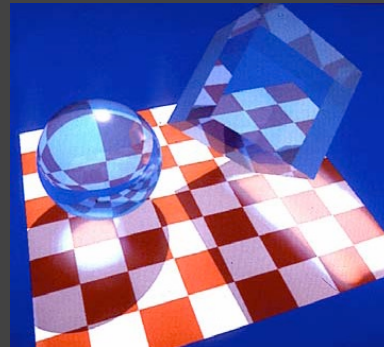
Figures courtesy Tianyu Liu

Spectrally Optimal Sampling



Mitchell 91

Light Ray Tracing



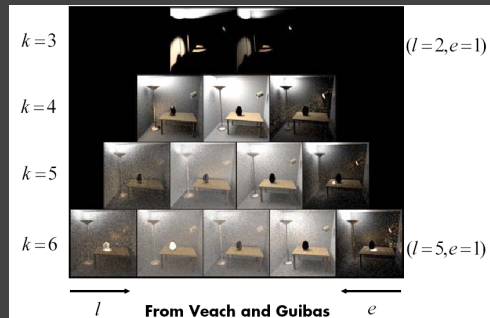
Backwards Ray Tracing
[Arvo 86]

Path Tracing: From Lights

- Step 1. Choose a light ray
- Step 2. Find ray-surface intersection
- Step 3. Reflect or transmit
 - $u = \text{Uniform}()$
 - if $u < \text{reflectance}(x)$
 - Choose new direction $d \sim \text{BRDF}(O|I)$
 - goto Step 2
 - else if $u < \text{reflectance}(x) + \text{transmittance}(x)$
 - Choose new direction $d \sim \text{BTDF}(O|I)$
 - goto Step 2
 - else // $\text{absorption} = 1 - \text{reflectance} - \text{transmittance}$
 - terminate on surface; deposit energy

Bidirectional Path Tracing

Path pyramid ($k = l + e = \text{total number of bounces}$)



Comparison



Bidirectional path tracing

Path tracing

From Veach and Guibas

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Why Photon Map?

- Some visual effects like caustics hard with standard path tracing from eye
- May usually miss light source altogether
- Instead, store “photons” from light in kd-tree
- Look-up into this as needed
- Combines tracing from light source, and eye
- Similar to bidirectional path tracing, but compute photon map only once for all eye rays
- *Global Illumination using Photon Maps* H. Jensen. *Rendering Techniques (EGSR 1996)*, pp 21-30. (Also book: *Realistic Image Synthesis using Photon Mapping*)

Caustics

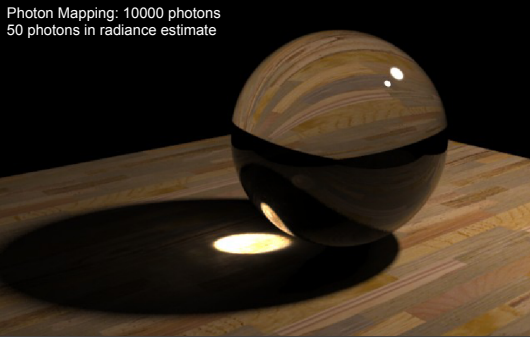
Path Tracing: 1000 paths/pixel
Note noise in caustics



Slides courtesy Henrik Wann Jensen

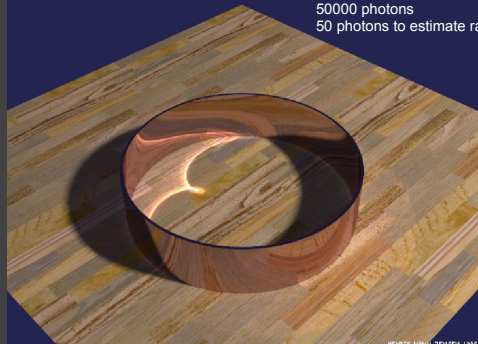
Caustics

Photon Mapping: 10000 photons
50 photons in radiance estimate



Reflections Inside a Metal Ring

50000 photons
50 photons to estimate radiance

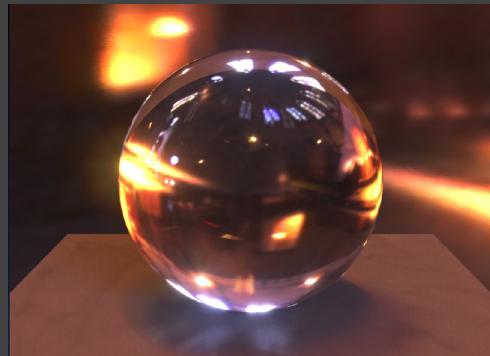


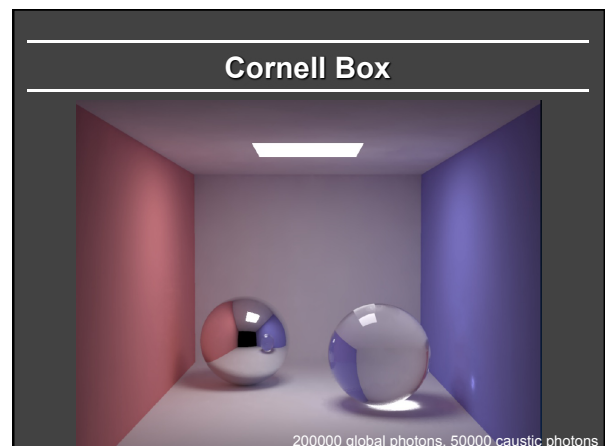
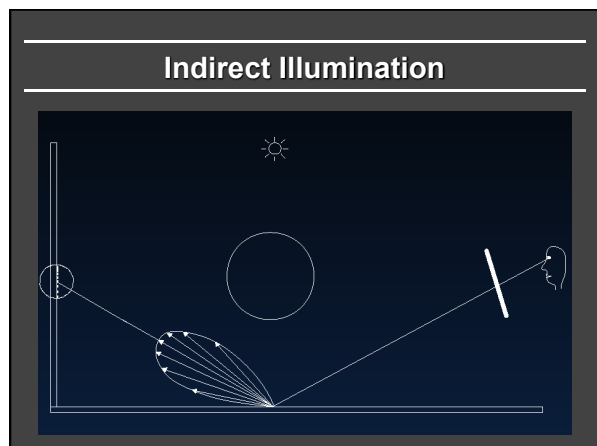
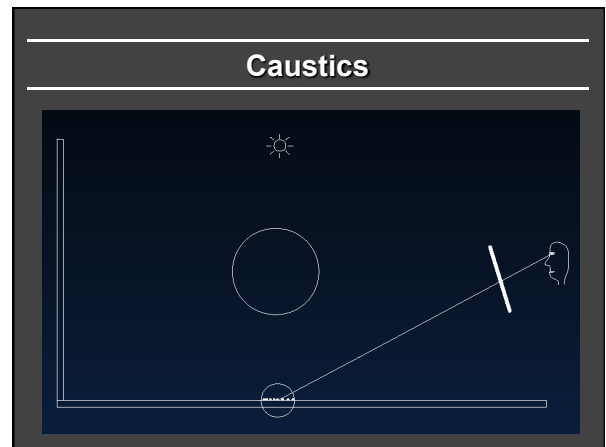
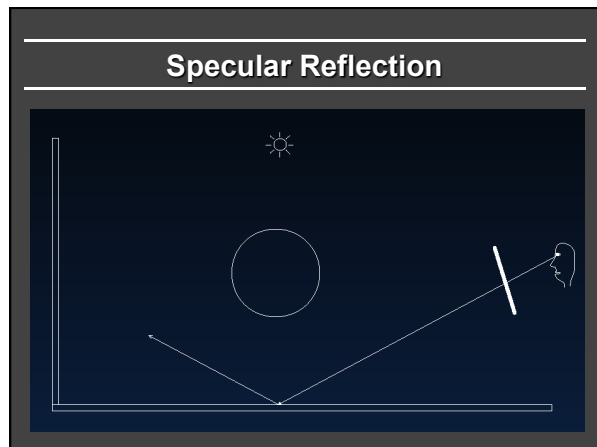
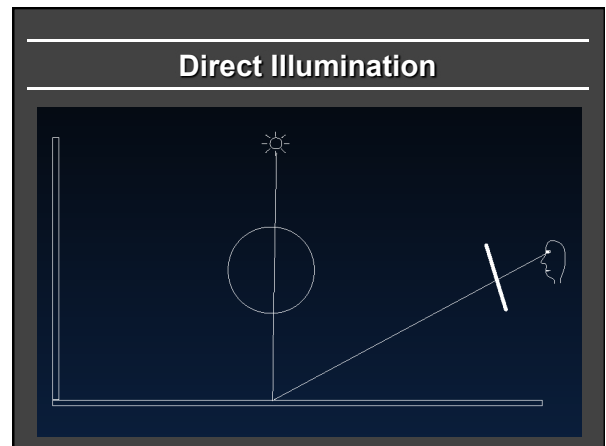
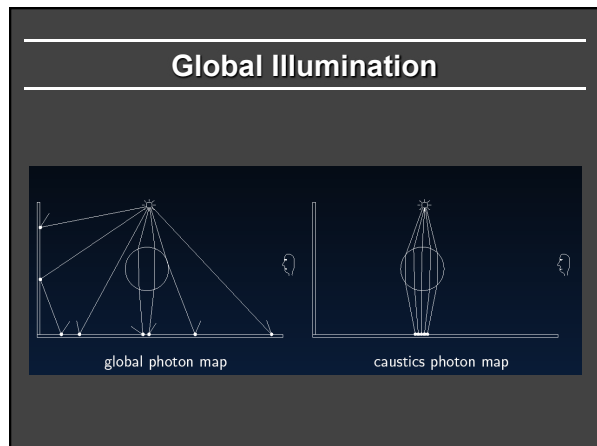
Caustics on Glossy Surfaces



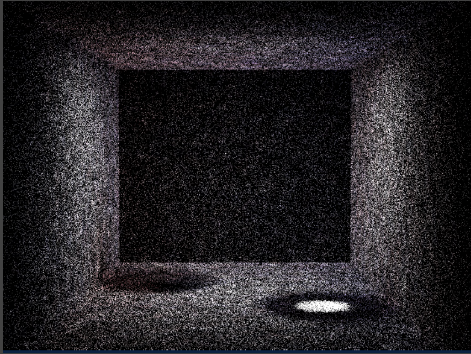
340000 photons, 100 photons in radiance estimate

HDR Environment Illumination





Box: Global Photons



Mies House: Swimming Pool



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Lightcuts

- Efficient, accurate complex illumination



Environment map lighting & indirect
Time 111s

Textured area lights & indirect
Time 98s

(640x480, Anti-aliased, Glossy materials)

From Walter et al. SIGGRAPH 05

Complex Lighting

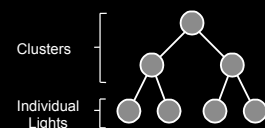
- Simulate complex illumination using point lights
 - Area lights
 - HDR environment maps
 - Sun & sky light
 - Indirect illumination
- Unifies illumination
 - Enables tradeoffs between components



Area lights + Sun/sky + Indirect

Key Concepts

- Light Cluster
- Light Tree
 - Binary tree of lights and clusters



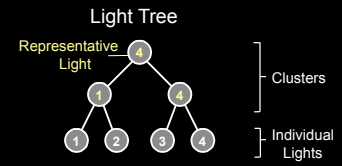
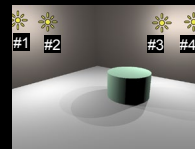
Key Concepts

- Light Cluster
- Light Tree
- A Cut
 - A set of nodes that partitions the lights into clusters



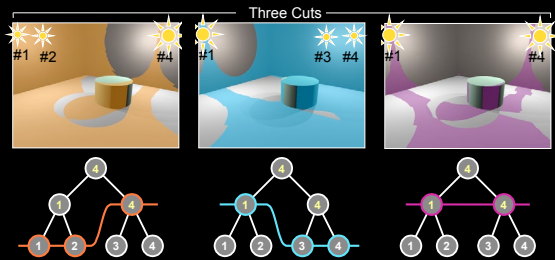
37

Simple Example



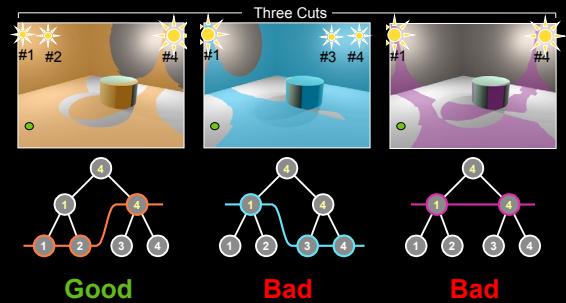
38

Three Example Cuts



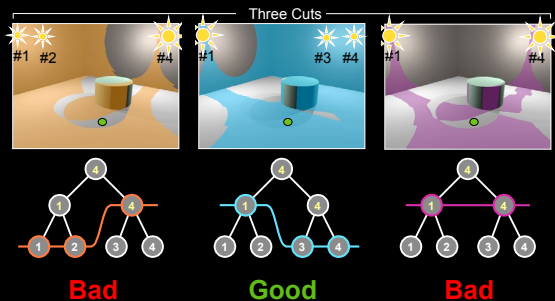
39

Three Example Cuts



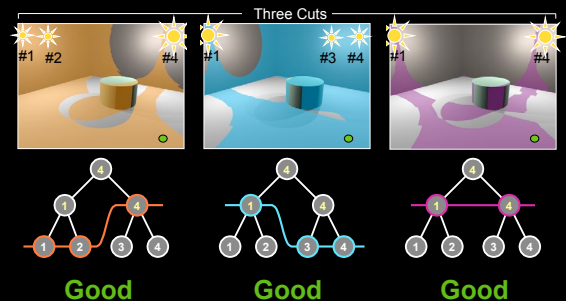
40

Three Example Cuts



41

Three Example Cuts



42



Tableau, 630K polygons, 13000 lights, (EnvMap+Indirect)

Avg. shadow rays per eye ray 17 (0.13%)

43