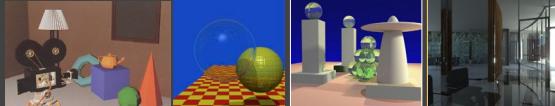


Computer Graphics II: Rendering

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

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



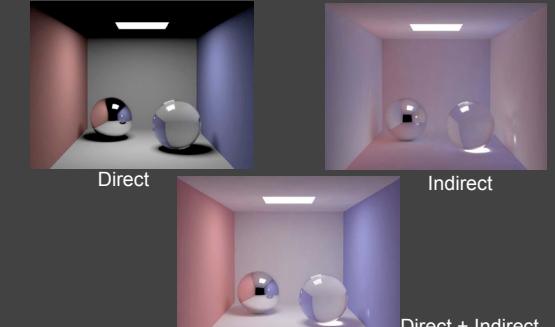
To Do

- 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?
- Can it be made more efficient (90s until today)?
 - Multiple Importance Sampling (Homework 4)
 - Irradiance Caching takes advantage of coherence*
 - Correct sampling: Stratified, Multiple Importance, Bidirectional Path Tracing, Metropolis, VCM/UPS, ...
 - Photon Mapping
 - Modern adaptive sampling, cut-based integration
- Advanced topics (next time)
- Denoising (next time)

Smoothness of Indirect Lighting



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

$L_i(x, \omega)$

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

$E(x) = \int L_i(x, \omega) \cos \theta \, d\omega$

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

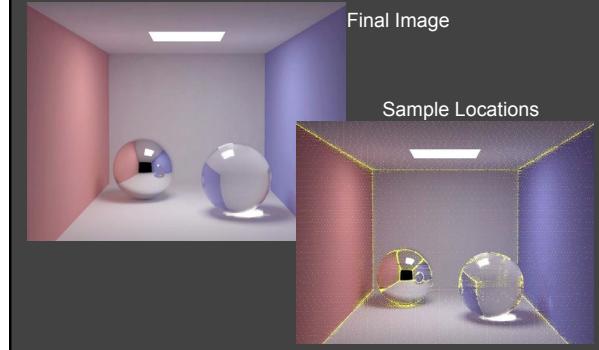
$$\leq E_0 \left(\frac{4}{\pi} \frac{\|x - x_0\|}{x_{avg}} + \sqrt{2 - 2 \vec{N}(x) \cdot \vec{N}(x_0)} \right)$$

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

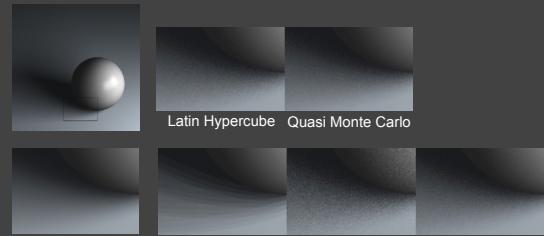
$$V[F_N] = \frac{1}{N^2} \sum_{i=1}^{\sqrt{N}} V[F_i] = \frac{V[F_E]}{N^{1.5}}$$

Pat Hanrahan, Spring 2002

CS348B Lecture 9

D. Mitchell 95, Consequences of stratified sampling in graphics

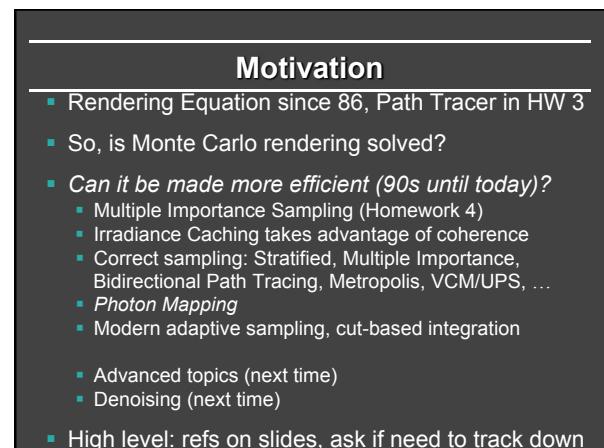
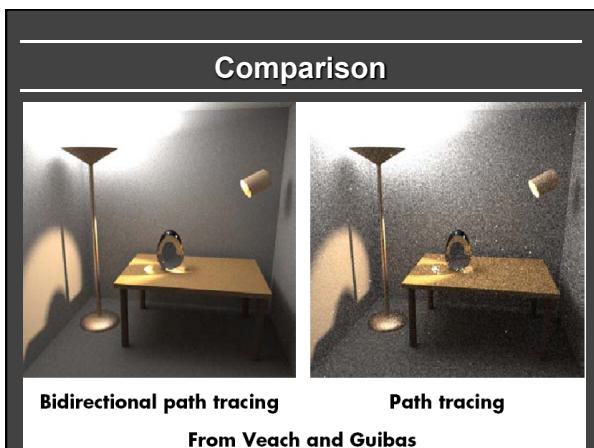
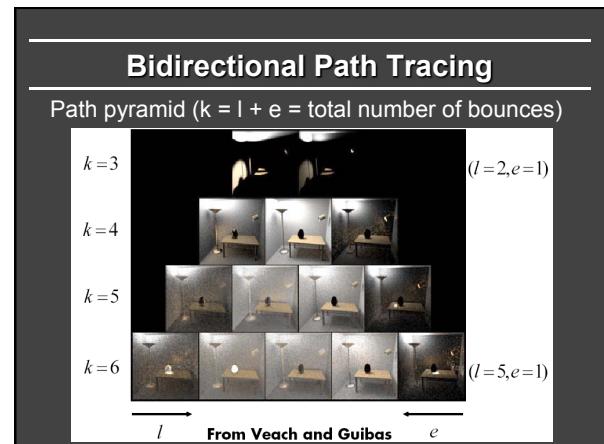
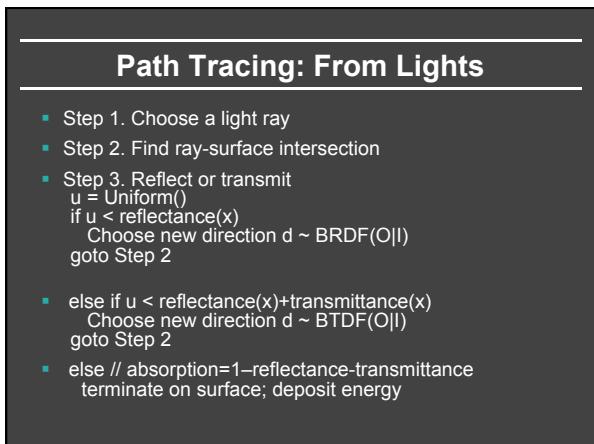
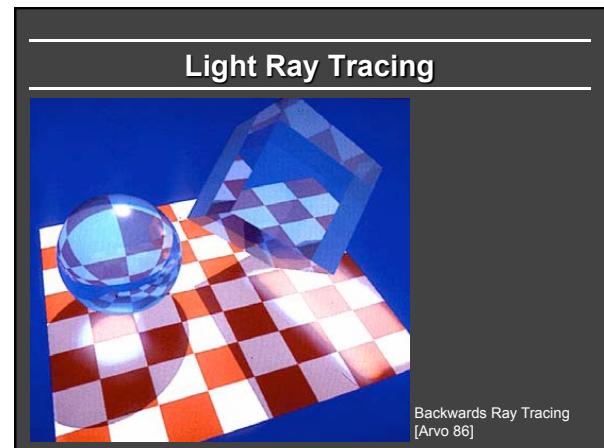
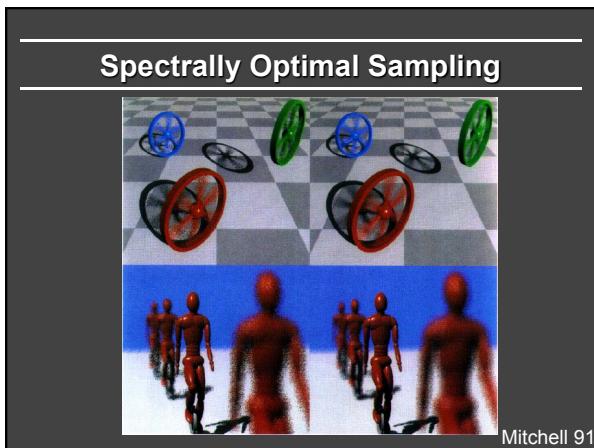
Comparison of simple patterns



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



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

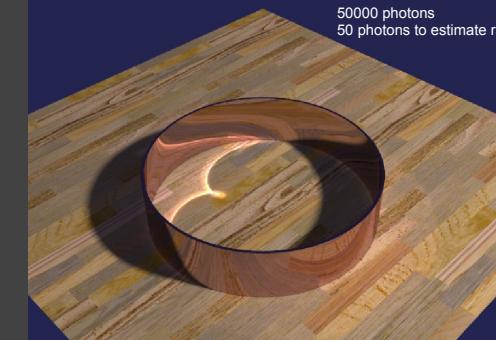
Caustics

Photon Mapping: 10000 photons
50 photons in radiance estimate



Reflections Inside a Metal Ring

50000 photons
50 photons to estimate radiance



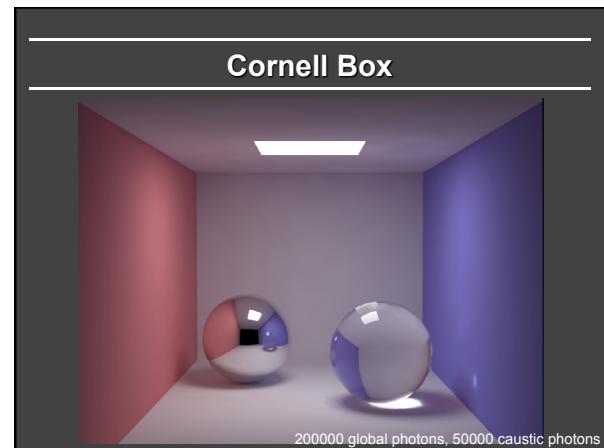
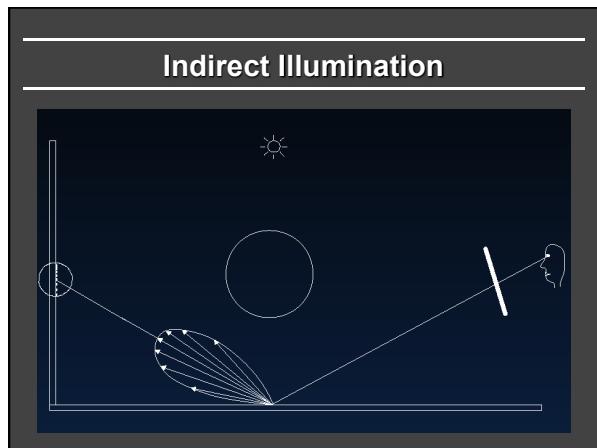
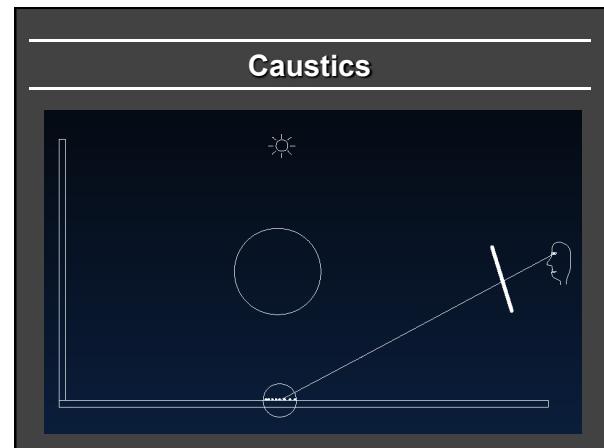
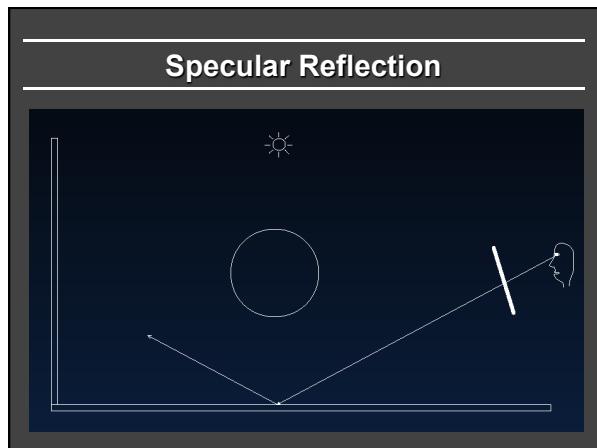
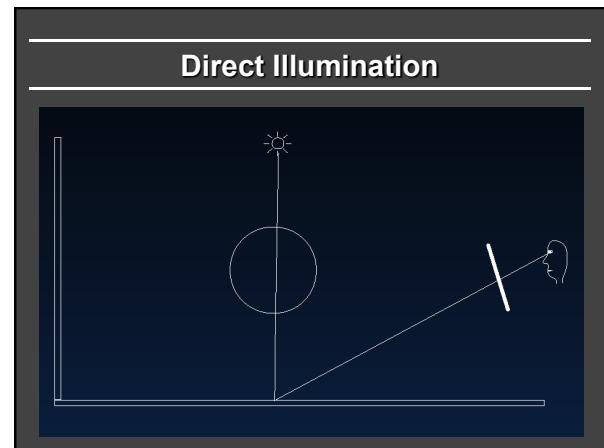
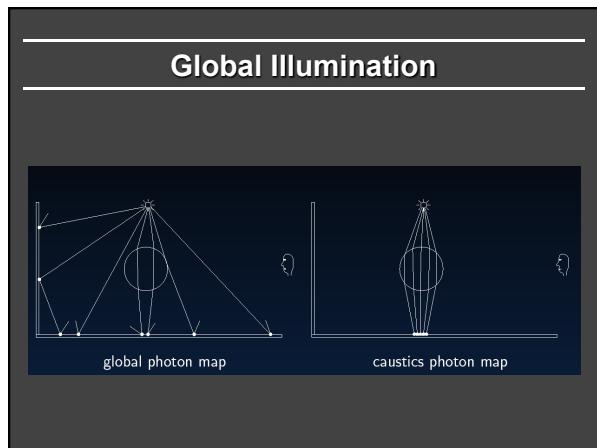
Caustics on Glossy Surfaces

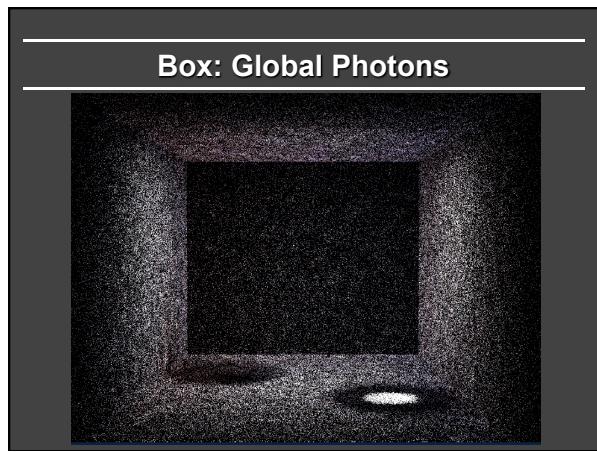


340000 photons, 100 photons in radiance estimate

HDR Environment Illumination







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Lightcuts

- Efficient, accurate complex illumination

Environment map lighting & indirect
Time 111s

Textured area lights & indirect
(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

Clusters

Individual Lights

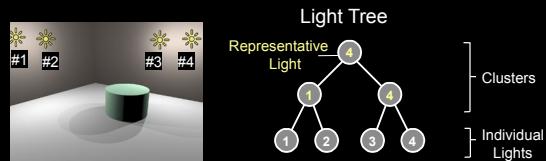
Key Concepts

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



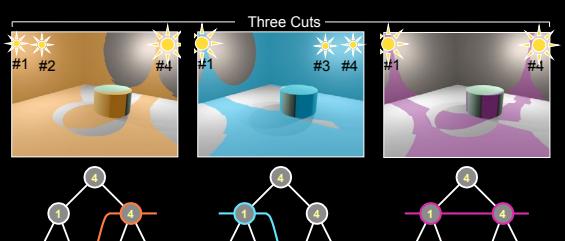
37

Simple Example



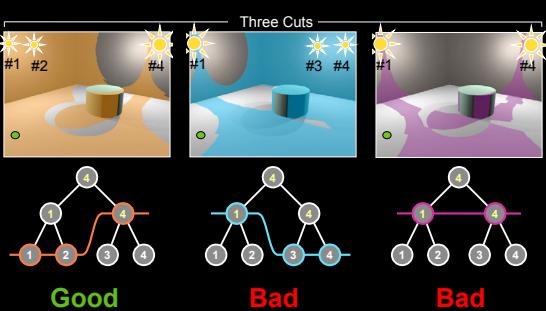
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Three Example Cuts



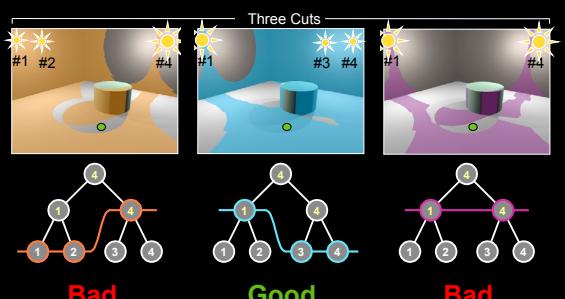
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Three Example Cuts



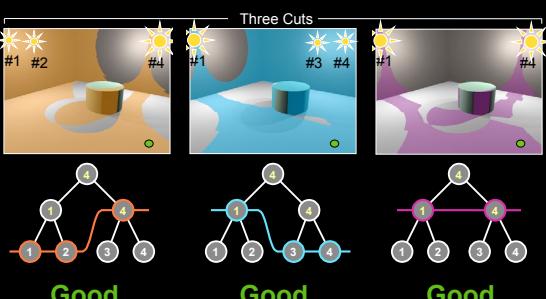
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Three Example Cuts

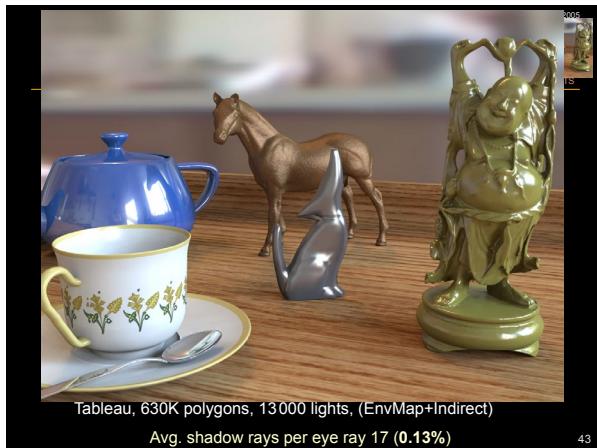


41

Three Example Cuts



42



43