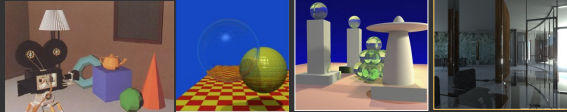


Computer Graphics II: Rendering

CSE 168 [Spr 24], Lecture 12: High Quality Rendering
Ravi Ramamoorthi

<http://viscomp.ucsd.edu/classes/cse168/sp24>



1

To Do

- Homework 4 (importance sampling) due May 20
- These lectures cover more advanced topics
 - May be relevant for your final project
 - Or curiosity in terms of frontiers of modern rendering

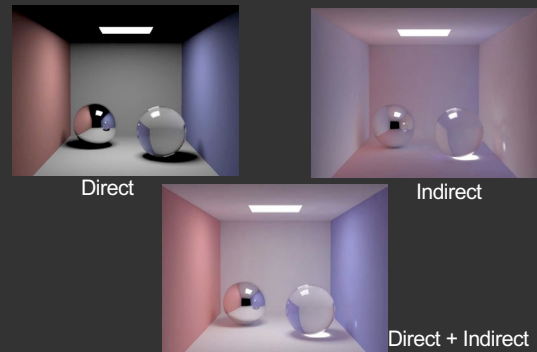
2

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, ...
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- Denoising (next time)

3

Smoothness of Indirect Lighting



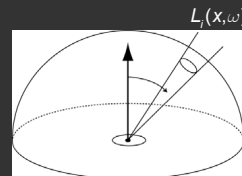
4

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*

5

Irradiance Calculation



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

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

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

position rotation

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

Derivation in Ward paper

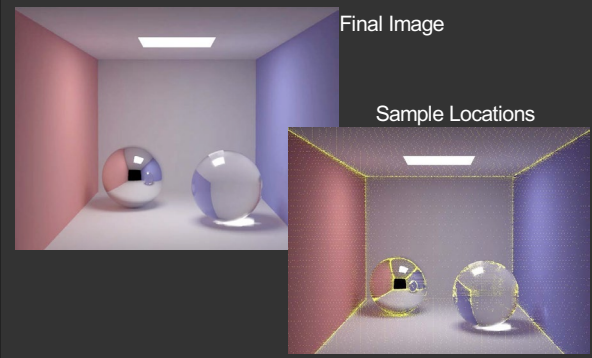
6

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

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Irradiance Caching Example



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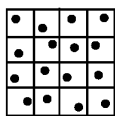
9

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

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Stratified Sampling



Stratified sampling like jittered sampling

Allocate samples per region

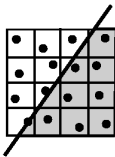
$$N = \sum_{i=1}^m N_i \quad F_N = \frac{1}{N} \sum_{i=1}^m N_i F_i$$

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



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

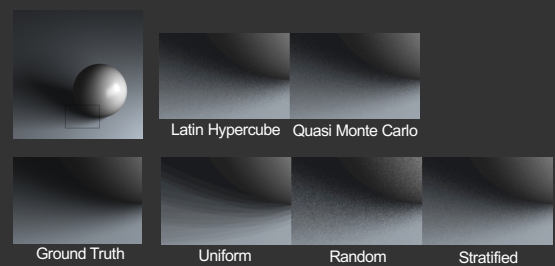
CS348B Lecture 9

Pat Hanrahan, Spring 2002

D. Mitchell 95, Consequences of stratified sampling in graphics

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Comparison of simple patterns



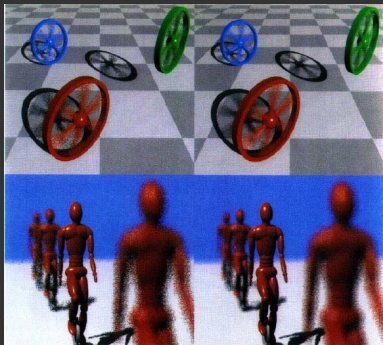
16 samples for area light, 4 samples per pixel, total 64 samples

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

Figures courtesy Tianyu Liu

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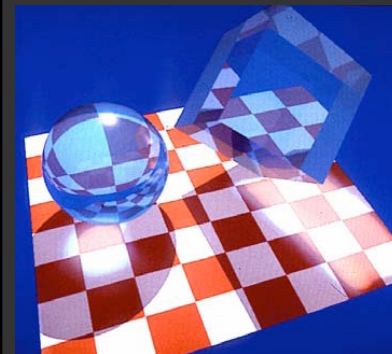
Spectrally Optimal Sampling



Mitchell 91

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Light Ray Tracing



Backwards Ray Tracing
[Arvo 86]

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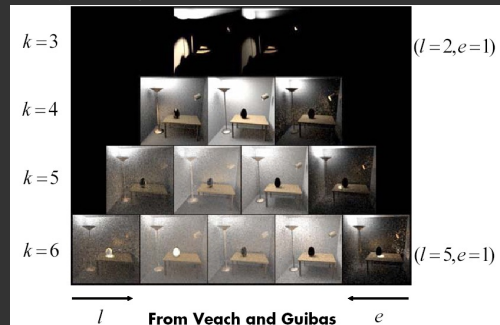
Path Tracing: From Lights

- 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 $d \sim \text{BRDF}(O||)$
 - goto Step 2
 - else if $u < \text{reflectance}(x) + \text{transmittance}(x)$
 - Choose new direction $d \sim \text{BTDF}(O||)$
 - goto Step 2
 - else // absorption = 1 - reflectance - transmittance
 - terminate on surface; deposit energy

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Bidirectional Path Tracing

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



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Comparison



Bidirectional path tracing

Path tracing

From Veach and Guibas

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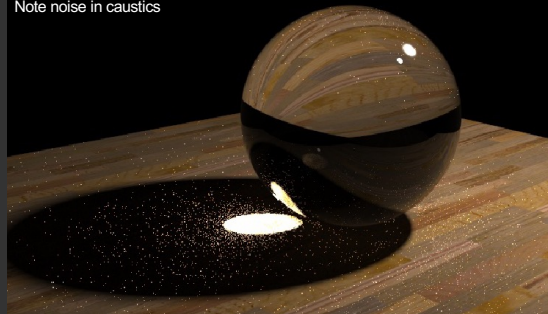
Why Photon Map?

- 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*)

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Caustics

Path Tracing: 1000 paths/pixel
Note noise in caustics



Slides courtesy Henrik Wann Jensen

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Caustics

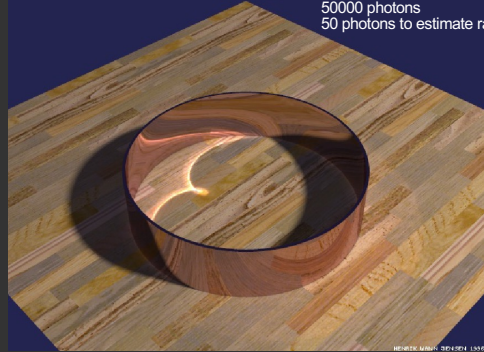
Photon Mapping: 10000 photons
50 photons in radiance estimate



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Reflections Inside a Metal Ring

50000 photons
50 photons to estimate radiance



22

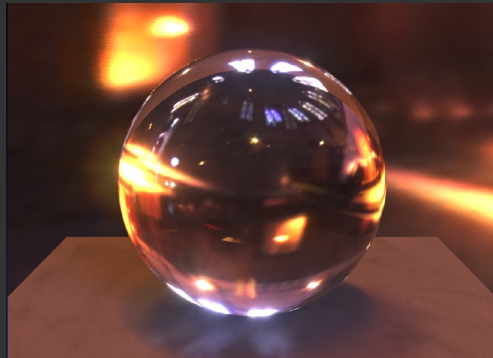
Caustics on Glossy Surfaces



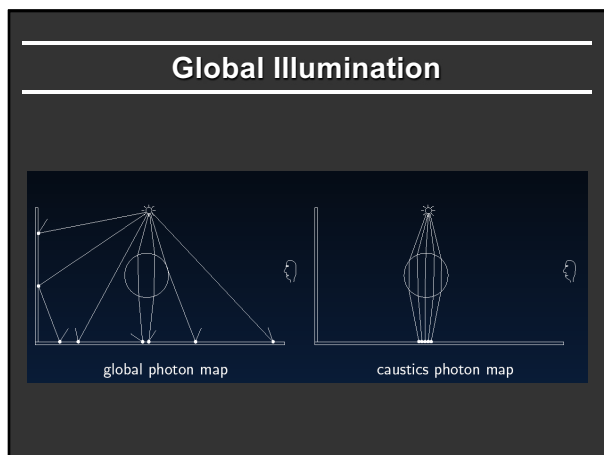
340000 photons, 100 photons in radiance estimate

23

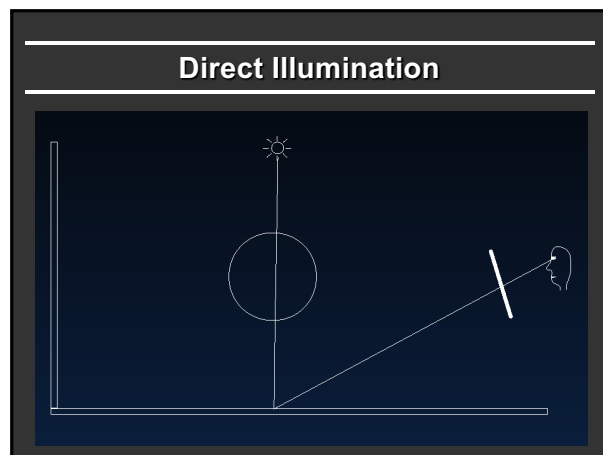
HDR Environment Illumination



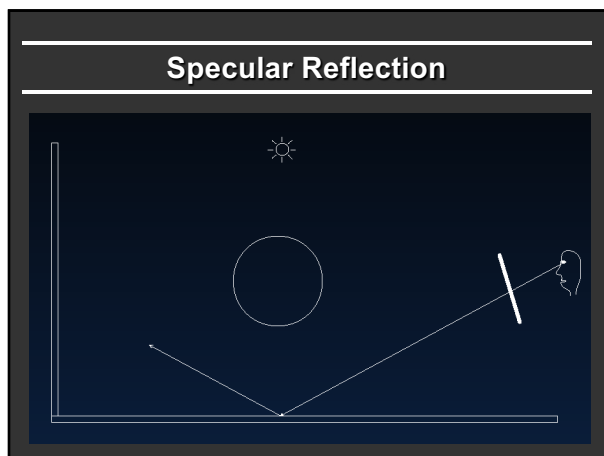
24



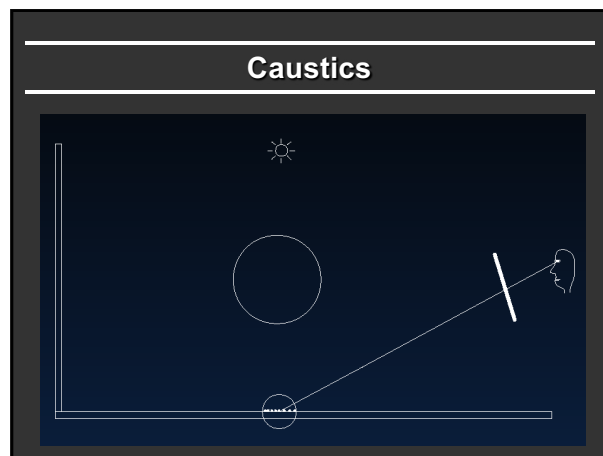
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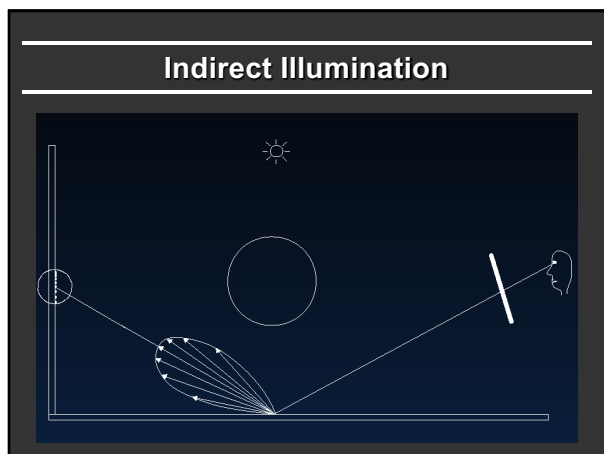
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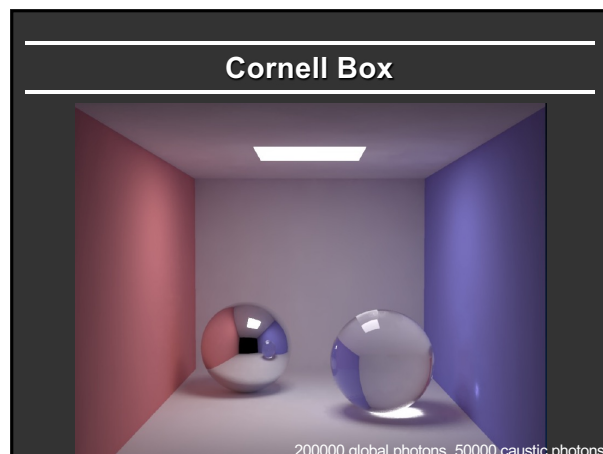
27



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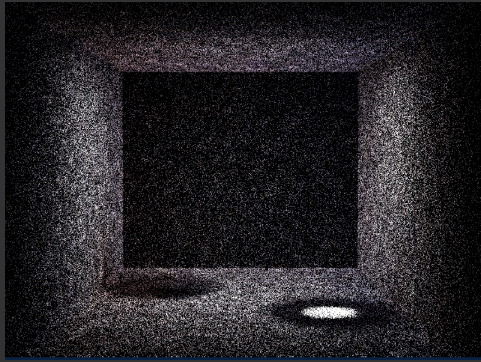


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Box: Global Photons



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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

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Complex Lighting

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

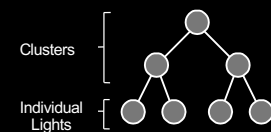


Area lights + Sun/sky + Indirect

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Key Concepts

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



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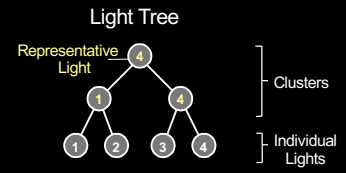
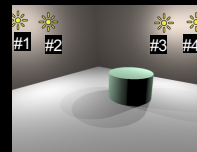
Key Concepts

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



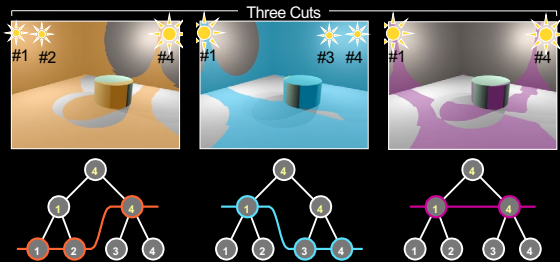
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Simple Example



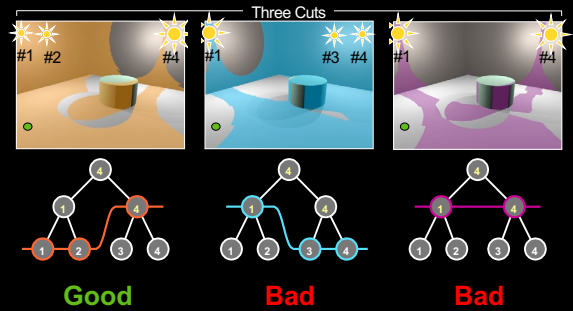
38

Three Example Cuts



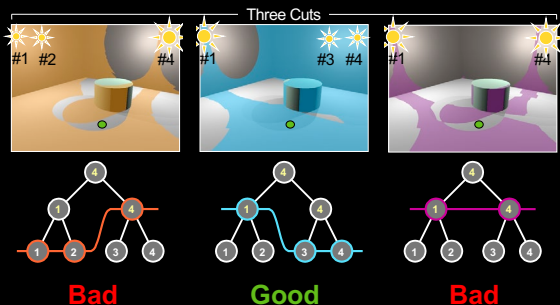
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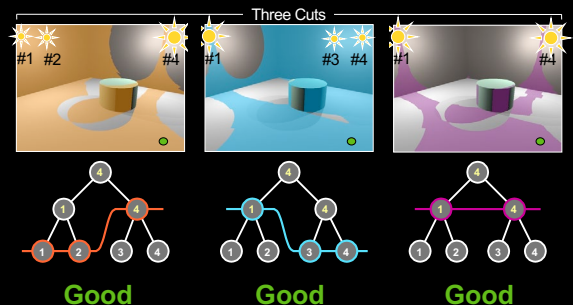
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Three Example Cuts



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Three Example Cuts



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