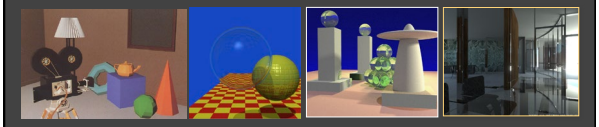
Computer Graphics II: Rendering

CSE 168 [Spr 21], Lecture 12: High Quality Rendering
Ravi Ramamoorthi

http://viscomp.ucsd.edu/classes/cse168/sp21



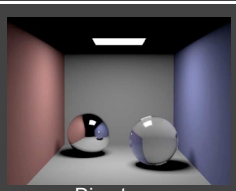
To Do

- Homework 4 (importance sampling) due May 17
- These lectures cover more advanced topics
  - May be relevant for your final project
  - Or curiosity in terms of frontiers of modern rendering

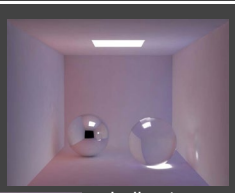
Motivation

- 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)

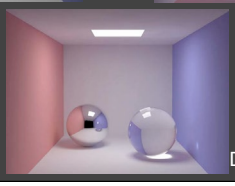
Smoothness of Indirect Lighting



Direct



Indirect

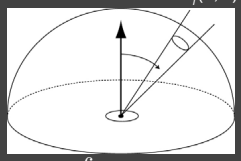


Direct + Indirect

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



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

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

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

position rotation

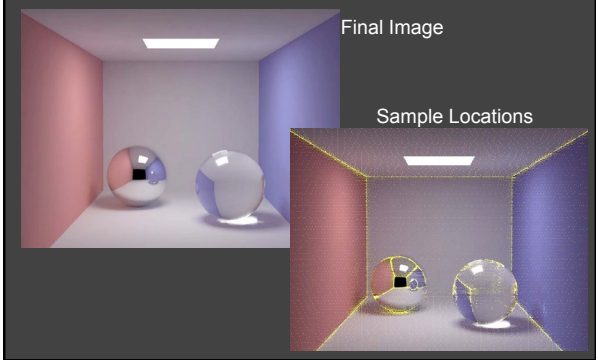
$$\leq E_0 \left(\frac{4}{\pi} \frac{||x - x_0||}{x_{avg}} + \sqrt{2 - 2\vec{N}(x) \cdot \vec{N}(x_0)} \right)$$

Derivation in Ward paper

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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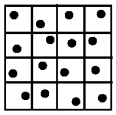
Better Sampling

- 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



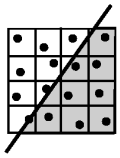
Stratified sampling like jittered sampling

Allocate samples per region

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

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

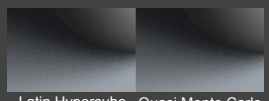
For example: An edge through a pixel

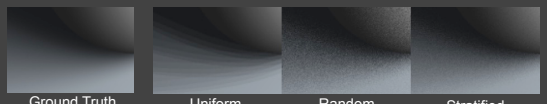
$$V[F_N] = \frac{1}{N^2}\sum_{i=1}^{\sqrt{N}} V[F_j] = \frac{V[F_E]}{N^{1.5}}$$

CS348B Lecture 9 — Pat Hanrahan, Spring 2002

D. Mitchell 95, Consequences of stratified sampling in graphics

Comparison of simple patterns



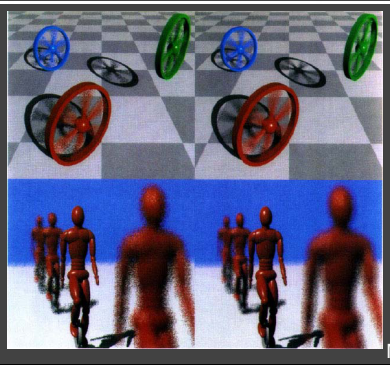


16 samples for area light, 4 samples per pixel, total 64 samples

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

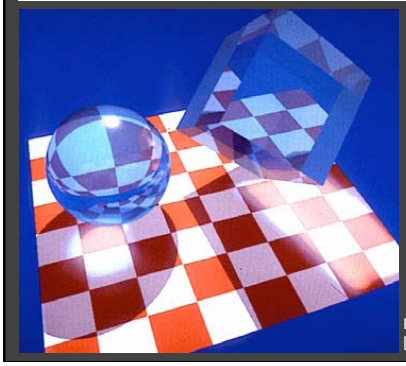
Figures courtesy Tianyu Liu

Spectrally Optimal Sampling



Mitchell 91

Light Ray Tracing



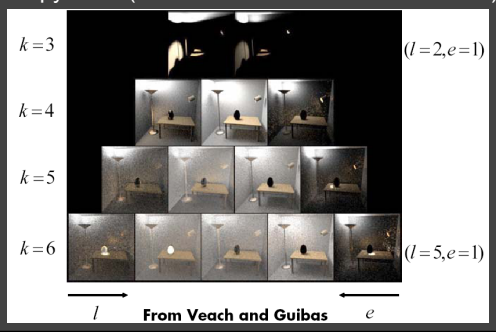
Backwards Ray Tracing
[Arvo 86]

Path Tracing: From Lights

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

Bidirectional Path Tracing

Path pyramid (k = l + e = total number of bounces)



Comparison

Bidirectional path tracing Path tracing

From Veach and Guibas

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  - *Photon Mapping*
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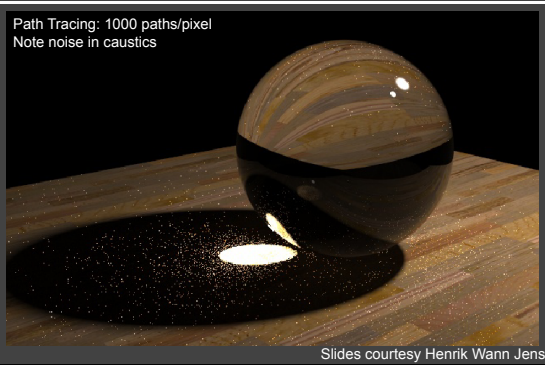
Why Photon Map?

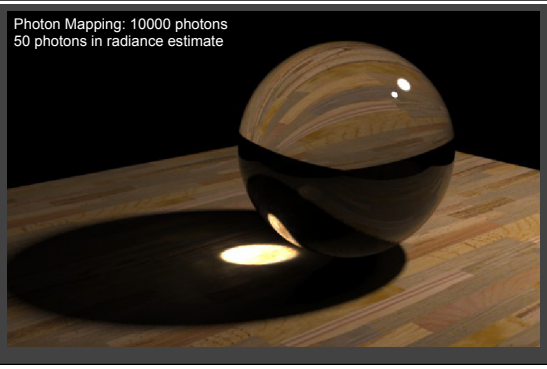
- Some visual effects like caustics hard with standard path tracing from eye
- May usually miss light source altogether
- Instead, store "photons" from light in kd-tree
- Look-up into this as needed
- Combines tracing from light source, and eye
- Similar to bidirectional path tracing, but compute photon 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

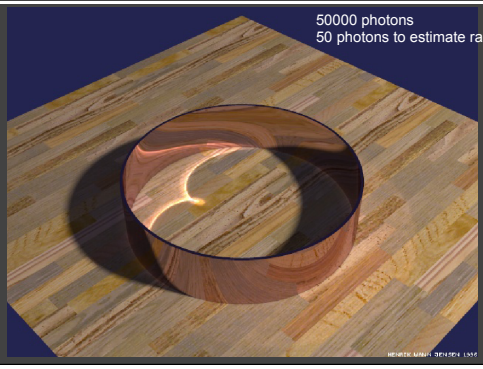


Slides courtesy Henrik Wann Jensen

Caustics



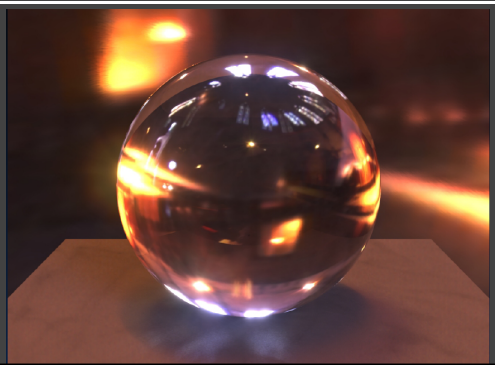
Reflections Inside a Metal Ring



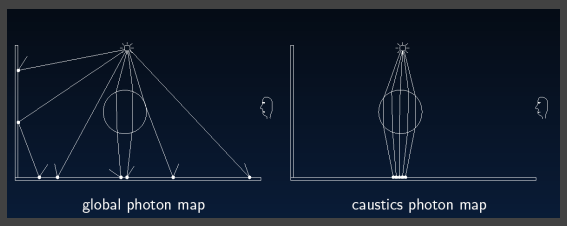
Caustics on Glossy Surfaces

340000 photons, 100 photons in radiance estimate

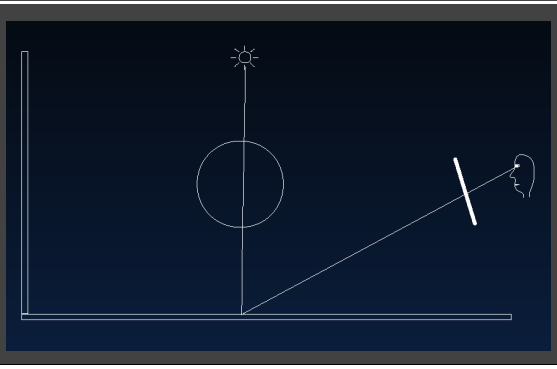
HDR Environment Illumination



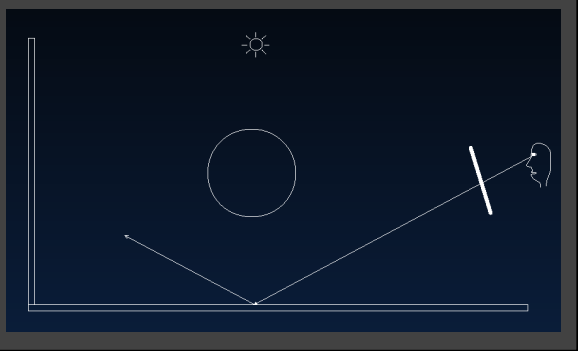
Global Illumination



Direct Illumination



Specular Reflection



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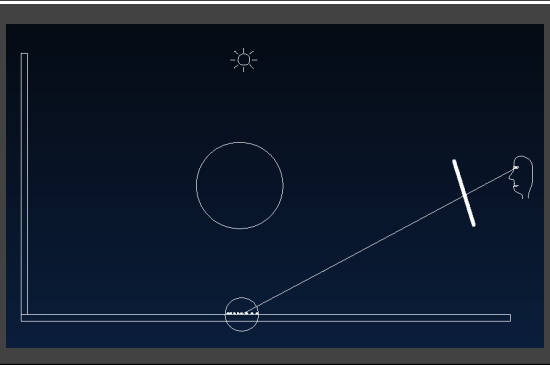
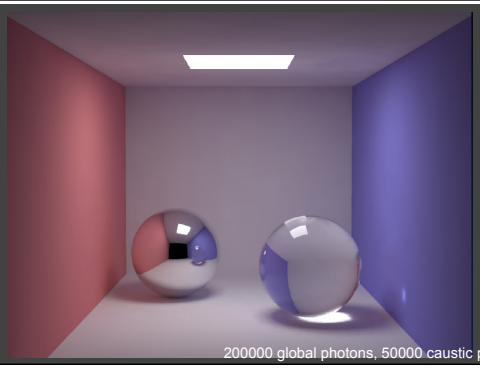
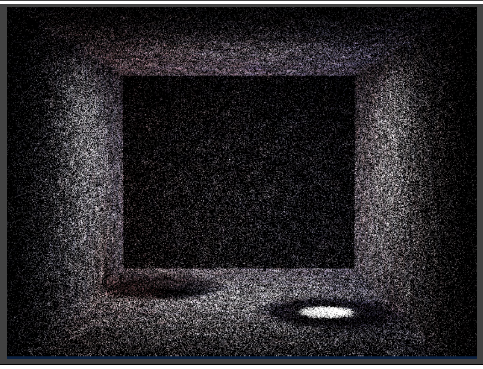


Indirect Illumination

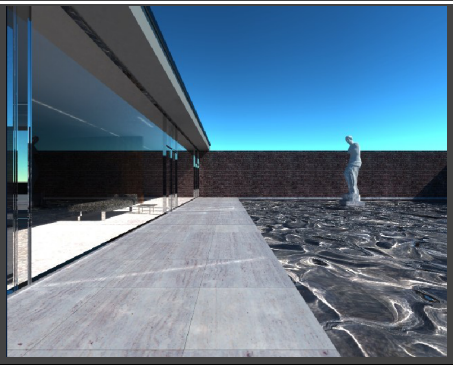
Cornell Box



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

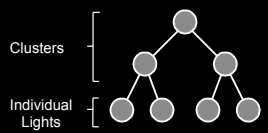
Complex Lighting

- 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



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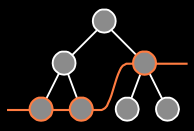
Key Concepts

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



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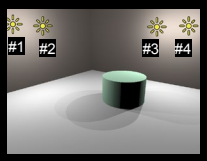
Simple Example



Light Tree

Representative Light

Clusters

Individual Lights

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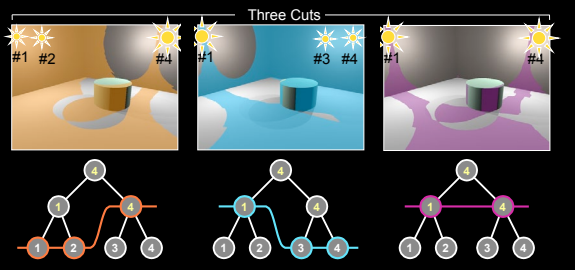
Three Example Cuts



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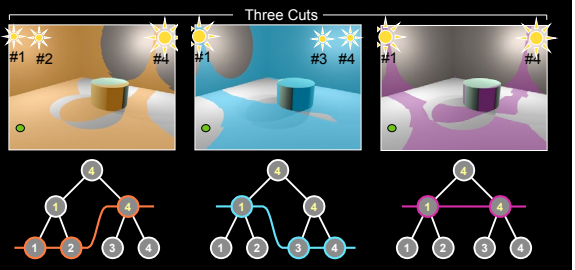

Good Bad Bad

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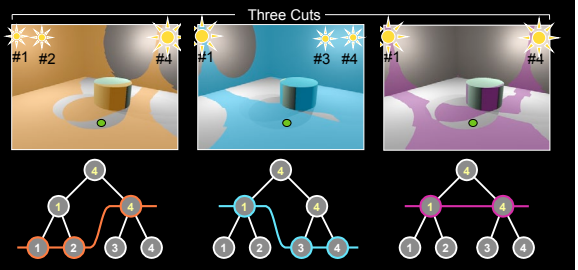
Three Example Cuts



Bad Good Bad

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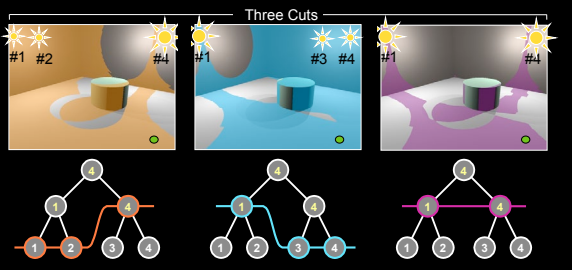

Good Good Good

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NVIDIA ReSTIR RTX DI

- Bitterli et al. 20 Spatiotemporal reservoir resampling
- Real-Time Direct Lighting from millions of lights