Lecture 13: Photon Mapping and Environment Maps

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Kavita Bala
Computer Science
Cornell University

Regexps to classify paths

- "Looking" directly at a light source
  - **L E**
- Seeing a diffuse surface
  - **L D E**
- Seeing a diffuse surface reflected in a mirror
  - **L D S E**

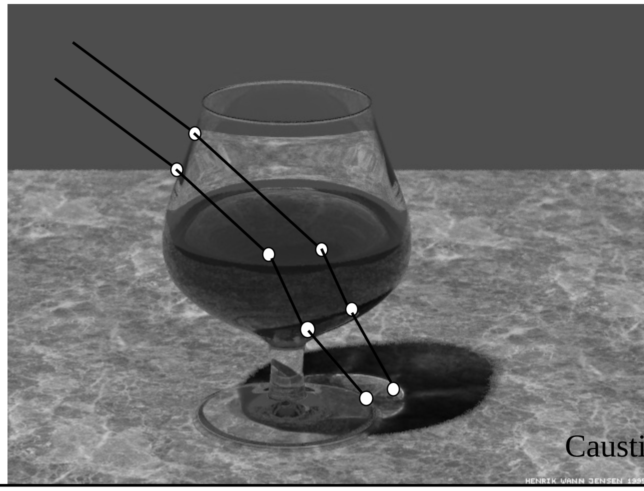
- Bidirectional path tracing is…?
  - **L (G|D|S)* (G|D|S)* E**
  - = **L (G|D|S)* E**

Light Tracing

- Some sub-paths are best sampled from the light
  - Where light is focused – *caustics*
  - Where most of the light's energy goes to a small region of the world
- Several variants

Photon Map

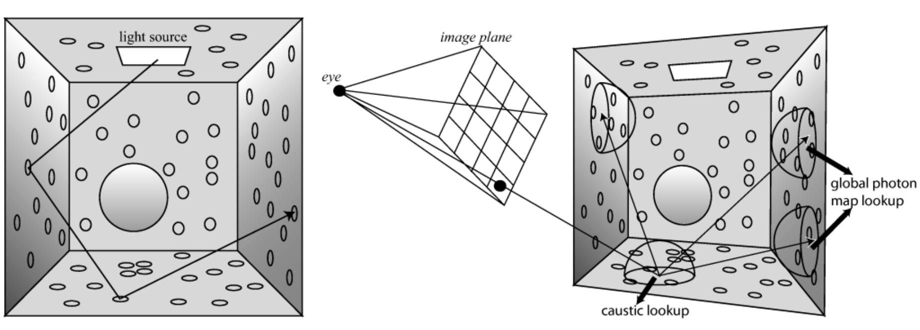
- Build on irradiance caching
- Use bidirectional ray tracing



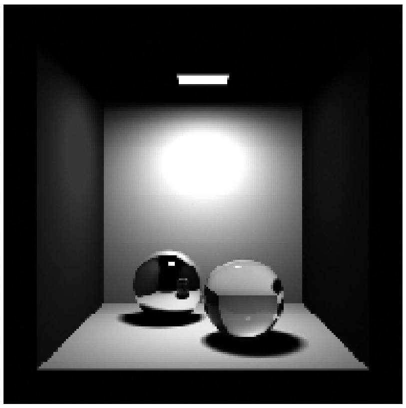
Caustic: LS+ D E

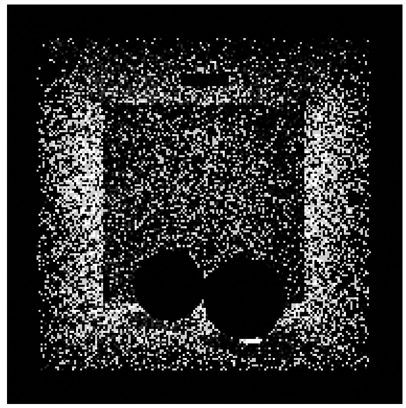
Photon Map

- 2 passes:
  - shoot "photons" (light-rays) and record any hit-points
  - shoot viewing rays, collect information from stored photons

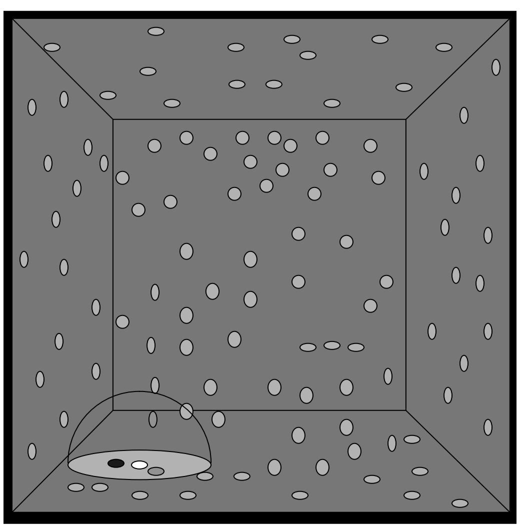


Pass 1: shoot photons





Pass 2: viewing ray (naive)



- Search for N closest photons
- Assume these photons hit the point we're interested in
- Compute estimate

Indirect Visualization

Figure 3: The Museum scene

Figure 4: Direct visualization of the global photon map in the Museum scene

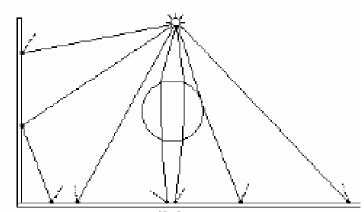
Photon Map

- Break lighting into several components
  - – LDS*E and LS*E paths (direct + specular)
  - – LS+DS*E paths (caustic)
  - – L(S|D)*DDS*E paths (indirect)

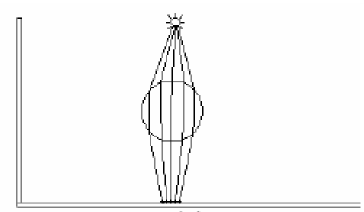
- Use a different technique for each component
  - – Note that S*E part is common – always start by tracing rays from the eye through specular bounces to a diffuse surface (or a light)

2 Photon Maps

- Global Photon Map
  - Low resolution
    - Captures low frequency variation in shading
  - Will not be viewed directly
  - Not good enough for caustics and specular



Global photon map



Caustic photon map

Reflection Equation Decomposition

$$f_r(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) = f_{r,spec}(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) + f_{r,diffuse}(\underline{\omega}_i, \underline{x}, \underline{\omega}_o)$$

$$L(\underline{x}, \underline{\omega}_i) = L_{direct}(\underline{x}, \underline{\omega}_i) + L_{caustic}(\underline{x}, \underline{\omega}_i) + L_{indirect}(\underline{x}, \underline{\omega}_i)$$

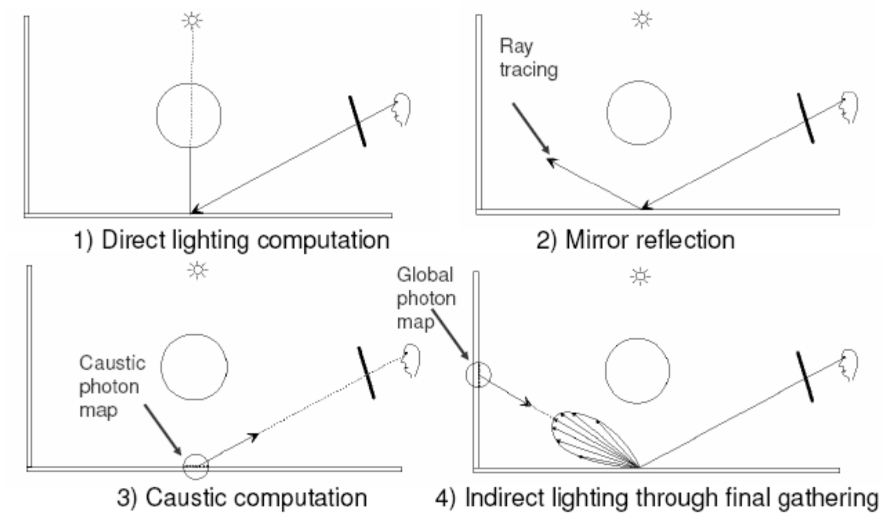
$$L\ (\underline{x}, \underline{\omega}_o) = \int_{\Omega_+} f_r(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) L(\underline{x}, \underline{\omega}_i) \cos\theta_i \, d\omega_i =$$

1) $$\int_{\Omega_+} f_r(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) L_{direct}(\underline{x}, \underline{\omega}_i) \cos\theta_i \, d\omega_i +$$

2) $$\int_{\Omega_+} f_{r,spec}(\underline{\omega}_i, \underline{x}, \underline{\omega}_o)(L_{caustic}(\underline{x}, \underline{\omega}_i) + L_{indirect}(\underline{x}, \underline{\omega}_i)) \cos\theta_i \, d\omega_i +$$

3) $$\int_{\Omega_+} f_{r,diffuse}(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) L_{caustic}(\underline{x}, \underline{\omega}_i) \cos\theta_i \, d\omega_i +$$

4) $$\int_{\Omega_+} f_{r,diffuse}(\underline{\omega}_i, \underline{x}, \underline{\omega}_o) L_{indirect}(\underline{x}, \underline{\omega}_i) \cos\theta_i \, d\omega_i$$



Questions

- What is in the map?
- How to compute it?
- Store in what data structure?
- How to use it?

Pass 1

- Shoot some number of photons
  - Magic parameter
  - Photons carry flux
- Sample from the light based on light source

- Photon hits surface
  - Pure specular: reflect
  - Diffuse, glossy: Deposit and continue
- How to continue?

Diffuse photon interaction

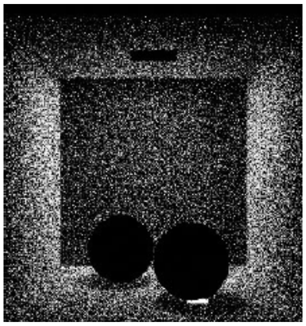
- Material with reflectivity d; p = d
- u = random ()
- If (u < p)
  - Reflect photon with power phi
- Else
  - Absorb photon

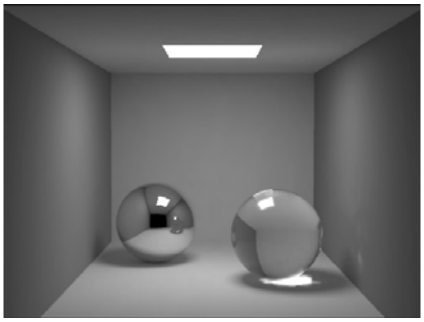
Glossy Interaction

- Discrete pdf q_1, q_2, q_3

$$p_1 + p_2 + p_3 = 1$$
$$p_1 = \rho_d$$
$$p_2 = \rho_s$$

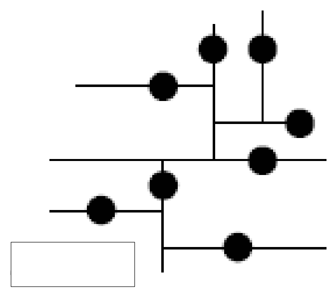
$$PhotonPath = \begin{cases} diffuse \mid u < p_1 \\ specular \mid p_1 < u < p1 + p_2 \\ absorb \mid p_1 + p_2 < u < 1 \end{cases}$$





Efficiency

- Want k nearest photons
  - Use *Left-balanced kd-tree*
  - Heap representation to avoid pointing to sub-trees



Kd-tree

- Compactness
  - Location of photon
  - Flux
  - Incoming direction

Search algorithm

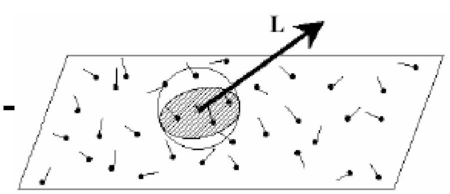
- Want k nearest photons
- Or want photons within some distance d

- Start at root of kd-tree: check left first or right first based on location of x
  - Check other side if not enough on this side

- Keep heap of photons (based on distance from query point)
  - Can check root to see which is farthest photon
  - If find a new photon, remove the farthest one

Estimate

-

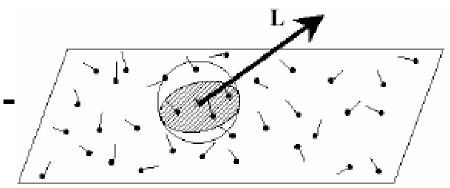


$$L_r(x \to \Theta) = \int f_r(x, \Theta \leftrightarrow \Psi) L_i(x \leftarrow \Psi) \cdot (n.\Psi) \cdot d\omega_\Psi$$

$$L_i(x \leftarrow \Psi) = \frac{d^2 P_i(x, \Psi)}{dA_i (n.\Psi) d\omega_\Psi}$$

Estimate

-



$$L_r(x \to \Theta) = \int f_r(x, \Theta \leftrightarrow \Psi) \frac{d^2 P_i(x, \Psi)}{dA_i (n.\Psi) d\omega_\Psi} \cdot (n.\Psi) \cdot d\omega_\Psi$$

$$L_r(x \to \Theta) = \int f_r(x, \Theta \leftrightarrow \Psi) \frac{d^2 P_i(x, \Psi)}{dA_i}$$

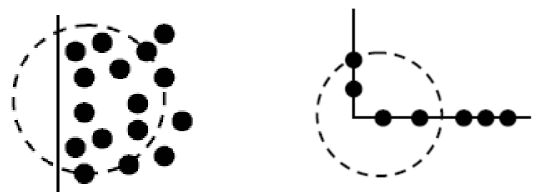
Estimate

- Estimation from map:
  - Find nearest neighbors (ignore those with very dissimilar normal)
  - Compute estimate of outgoing radiance

$$L_r(x \to \Theta) \approx \sum_{p=1}^{n} f_r(x, \Theta \leftrightarrow \Psi_p) \frac{\Delta P_p(x, \Psi_p)}{\Delta A}$$

$$L_r(x \to \Theta) \approx \frac{1}{\pi r^2} \sum_{p=1}^{n} f_r(x, \Theta \leftrightarrow \Psi_p) \Delta P_p(x, \Psi_p)$$

Is the area right?

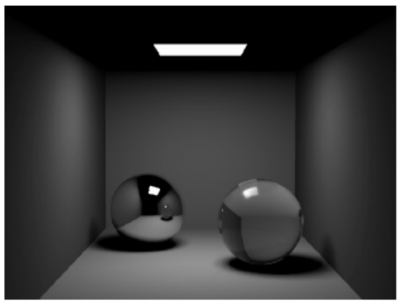


Filtering

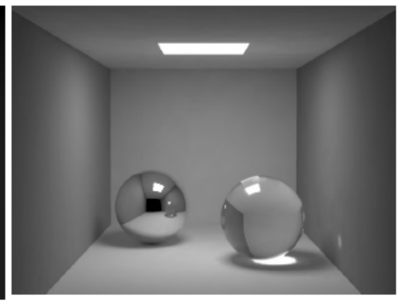
- Visualizing maps as is create noisy images
  - – Need EXTREMELY large amount of photons
- Filtering techniques can be used with different type of kernels
  - – Apply a Gaussian (or other kernels) on the photon map results
    - Particularly used for caustics

Results

200,000 and 50,000 photons in the global and caustic maps



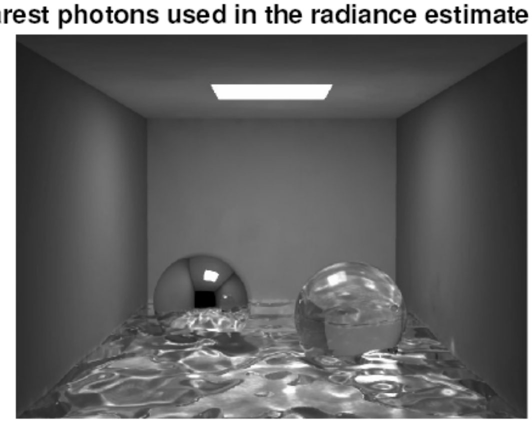
Ray traced image
(direct lighting only)



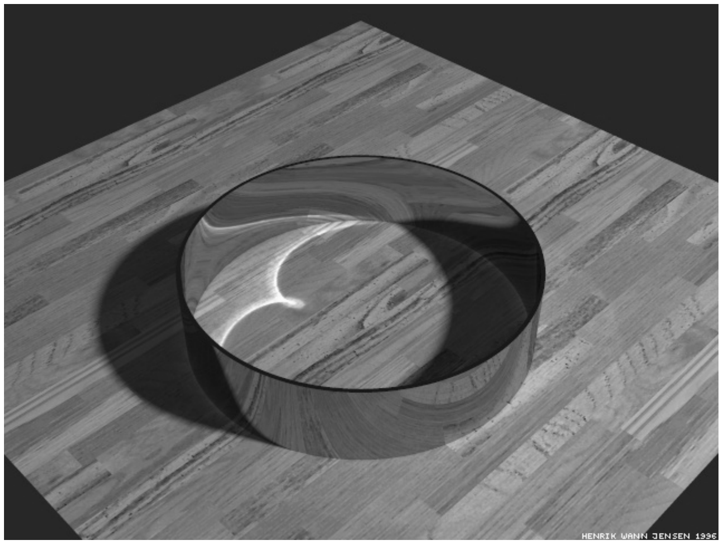
Full global illumination

Results

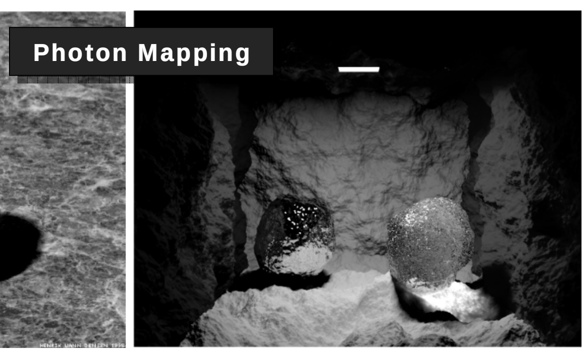
500,000 photons in both the global and caustic maps,
100 nearest photons used in the radiance estimate



Photon Map Results



Showcase pictures



- Geometry-independent

Examples

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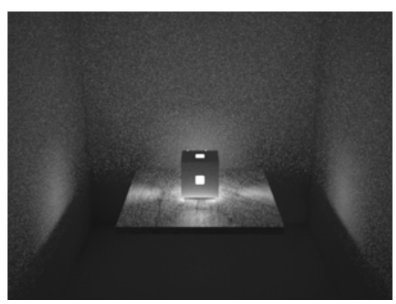
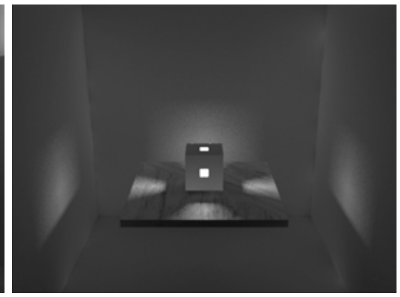
Photon Map Failure



With Better Sampling



Photon Map Summary

- Combines various techniques depending on the situation
- Produces very good results reasonably efficiently
- Geometric problems can still cause bleeding
- Sampling from the light can cause problems if most of the light's power fails to reach the image