Photorealistic Rendering

Photorealistic Rendering

Ray tracing v. photorealistic rendering

What illumination effects are captured by ray tracing?

What illumination effects are not captured by ray tracing?

Ray tracing v. Photorealistic rendering

Ambient Light

Ray tracing v. photorealistic rendering

Caustics

Ray tracing v. photorealistic rendering

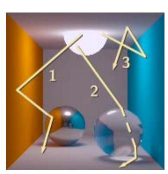
Color bleeding

Ray tracing v. photorealistic rendering

LDSE notation

L - Light
D - Diffuse
S - Specular
E - eye

LDE
LSE
L[D|S]E
LD^+E
LS^*DE
$L[D|S]^+E$



Describe path 1/2/3 with path notation

Which is handled by ray tracing?

Rendering samples the environment

To understand how different graphics sampling strategies affect accuracy (or don't)

How can the shading / illumination be modeled mathematically?

Shading as integration

Rendering Equation (also called the Transport Equation)

$$L_o(x,\vec{w}) = L_e(x,\vec{w}) + \int_\Omega f_r(x,\vec{w}',\vec{w}) L_i(x,\vec{w}')(\vec{w}'\cdot\vec{n})d\vec{w}'$$

Bidirectional Reflectance Function (BDRF)

$$f_r(x,\vec{w}',\vec{w}) = \frac{dL_r(x,\vec{w})}{L_i(x,\vec{w}')(\vec{w}'\cdot\vec{n})d\vec{w}'}$$

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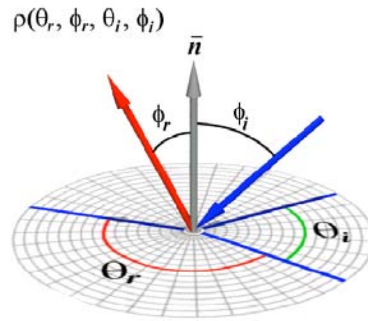
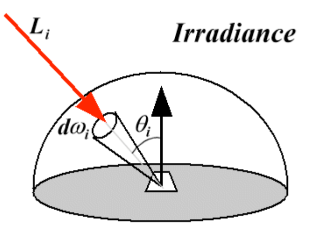




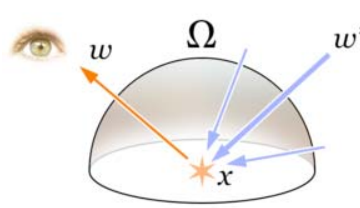
$$E_i = \int_{\Omega_i} L_i \cos\theta_i d\omega_i$$

Light at a point incoming from all directions

Radiance - light at a point in a given direction

incoming - Field Radiance

outgoing - Radiance exitance or surface radiance



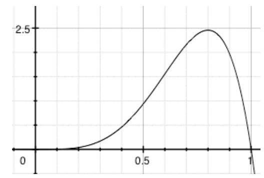
Integration estimation by sampling

Shading 'equation' not analytic

Need to estimate shading integral by sampling

Need to understand how best to control error

Basic statistics



Continuous random variable

Probability density function (pdf)

Relative likelihood for the value of a continuous variable to occur at a point

Probability of a continuous random variable falling within a set is the integral of the pdf over the set

$$p(x) \geq 0$$

$$\int_S p(x)d\mu = 1$$

Basic statistics

Expected value $E(X) = \int_{x\in S} xp(x)dx$

Standard deviation

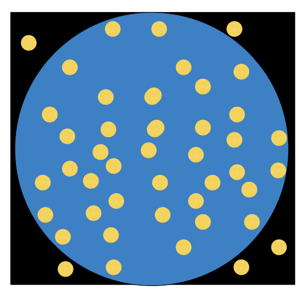
$$\sigma(X) = \sqrt{E([X - E(X)]^2)} = \sqrt{E(X^2) - [E(X)]^2}$$

Variation

$$var(X) = E([X - E(X)]^2) = E(X^2) - [E(X)]^2$$

Integration estimation by sampling

Monte Carlo Integration



$$I = \int_{x\in S} f(x)dx$$

$$I \approx V\frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

$$var(f) \equiv \sigma = \frac{1}{N-1}\sum_{i=1}^{N}(f(x_i) - \langle f\rangle)^2$$

Average score by integration

(dart throwing example)

f(x) - score at a point on target

p(x) - pdf of score at a point on target

$$average\_score = \int_S f(x)p(x)d\mu$$

$$E(x) \approx \frac{1}{N}\sum_{i=1}^{N} x_i$$ if x_i generated with p(x)

Integration estimation by sampling

How accurate is it?

How to estimate and reduce the error?

How to minimize the number of samples?

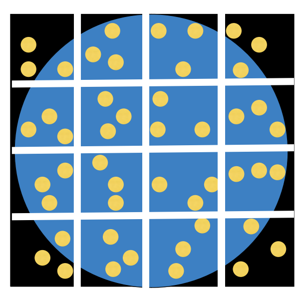
Law of large numbers

In the limit, sampling is correct

$$Prob[E(x) = \lim_{N\to\infty} \frac{1}{N}\sum_{i=1}^{N} x_i] = 1$$

Stratified sampling

$$var(\sum_{i=1}^{N} \frac{g(x_i)}{p(x_i)}) = \sum_{i=1}^{N} var(\frac{g(x_i)}{p(x_i)})$$



Sum of variances – break down into subproblems and get better estimate

$$\int_{S_i} p(x)d\mu = \frac{1}{N}\int_S p(x)\mu$$

Law of diminishing returns

error related to standard deviation

standard deviation proportional to $\frac{1}{\sqrt{N}}$

need 4x samples to get 2x better estimate

Non-uniform sampling distribution

Areas of high variability

Take more samples in those areas to reduce error

Give more weight to samples in sparse areas (value reflects more area)

Importance sampling

sample non-uniform distribution

uniform sample & weigh by distribution

non-uniform sample & weigh evenly

$$E(f(x)) = \int_{x \in S} f(x)p(x)d\mu \approx \frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

Alternatives to Ray Tracing

Trace more rays from eye?

Trace rays from light source?

Do both?

Radiosity - Jim Kajiya

Propogate diffuse light around environment: LD^*E

Precompute diffuse (viewer independent) illumination

From Heat Transfer Theory develped in the '50s

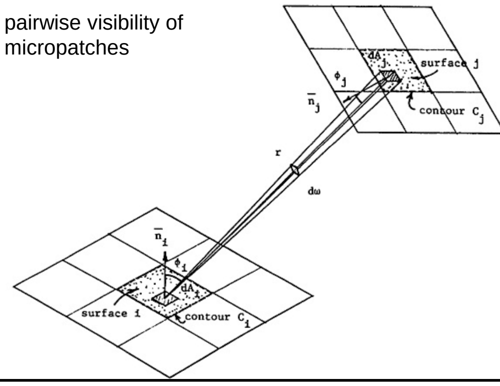
Not a ray tracing approach - usually combined with it

Break environment up into micro-patches

Determine pairwise visibility between each pair of micro-patches

Radiosity - Form Factor

pairwise visibility of micropatches

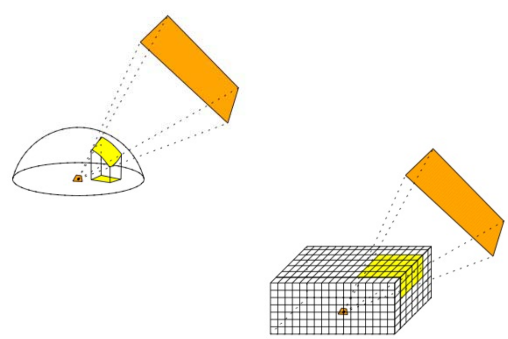


Radiosity - form factor

$$F_{12} = \frac{1}{A} \int_{x_1 \in S_1} \int_{x_2 \in S_2} \frac{g(x_1, x_2) cos\theta_1 cos\theta_2 dA_1 dA_2}{\pi \|x_1 - x_2\|^2}$$

$$F_{12} \approx A_2 \frac{g(x_1, x_2) cos\theta_1 cos\theta_2}{\pi \|x_1 - x_2\|^2}$$

Radiosity - form factor



Radiosity

$$\begin{bmatrix} 1-\rho_1F_{1,1} & -\rho_1F_{1,2} & \cdots & -\rho_1F_{1,N} \\ -\rho_2F_{2,1} & 1-\rho_2F_{2,2} & \cdots & -\rho_2F_{2,N} \\ \vdots & & & \vdots \\ -\rho_NF_{N,1} & -\rho_NF_{N,2} & \cdots & 1-\rho_NF_{N,N} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_N \end{bmatrix} = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_N \end{bmatrix}$$

Solve large matrix equation

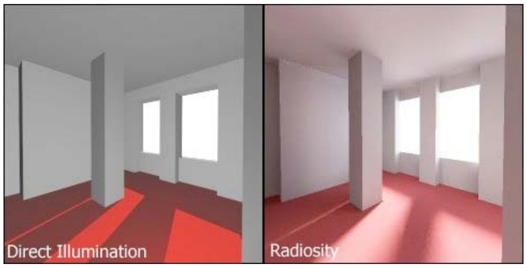
Radiosity - progressive refinement

$$B_i = E_i + \rho_i \sum_{i=1} B_j F_{ji}$$

Initially $B_i = E_i$

Itertively add emissions propogated around enviroment

Radiosity



Radiosity

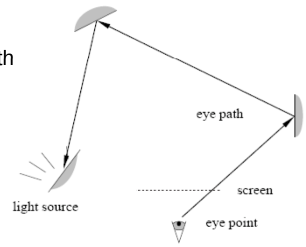
Path Tracing - Jim Kajiya

Extension of ray tracing

At every intersection, select random direction to generate secondary (and beyond) ray - Do this a lot

Until it hits a light source
Until a certain maximum depth

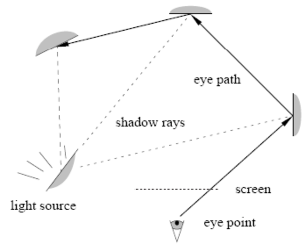
Probabilistically terminate
"Russian Roulette"



Diagrams from:
http://graphics.ucsd.edu/~iman/BDPT/

Path Tracing

Improve by illuminating each intermediate point



Path Tracing

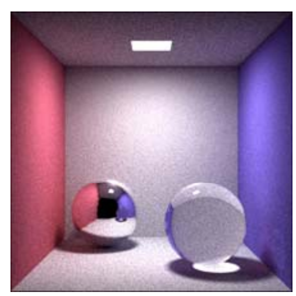
Accurate - if enough rays are generated

Inefficient

Unbiased
Accurate in the limit

http://feeblemind.tuxfamily.org/dotclear/images/cimetiere-des-pixels/sunflow/sponza/sponza_SF-path_tracing-logo.png

Path Tracing



From:
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Path Tracing

http://sunflow.sourceforge.net/gallery/v0060/livingroom.png

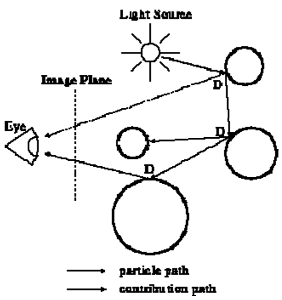
Light Tracing - Philip Dutre

Generate a bunch of 'particles' at light source

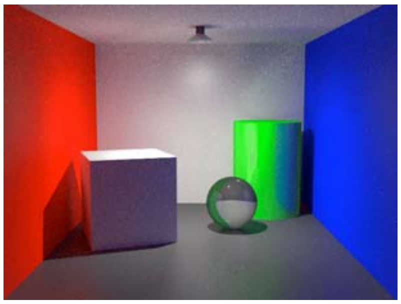
Trace each particle through environment

- Every time a hit
  - calculate contribution to eye
  - randomly bounce particle into scene
- Probabilistically terminate
- unbiased

Light Tracing



Light Tracing



: www.graphics.cornell.edu/~eric/thesis/images.html

Light Tracing

Photon Mapping - Henrik Wann Jensen

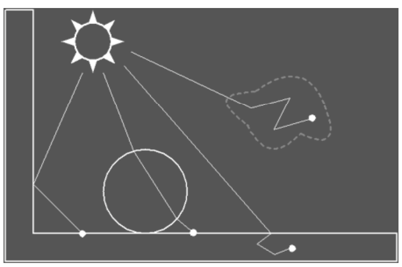
2 pass algorithm

1st pass - photons shot from light source and 'deposited' on surfaces as they bounce around the environment - probabalistically

2nd pass - ray tracing with indirect illumination coming from querying the photon map by shooting secondary rays

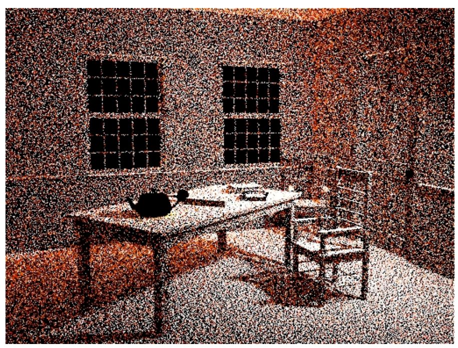
Biased - photon map is sparse, so at query point photon map is interpolated from close-by photon deposits

Photon Mapping



http://web.cs.wpi.edu/~emmanuel/courses/cs563/write_ups/zackw/photon_mapping/PhotonMapping.html

Photon Map



http://jgt.akpeters.com/papers/Christensen99/Fig2a.jpg

Photon Mapping

From

http://www.ypoart.com/tutorials/photon/index.php

Photon Mapping

Photon Mapping

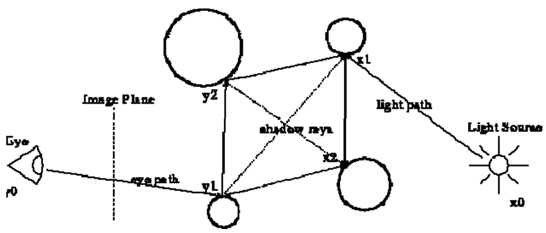
Bi-Directional Path Tracing

Generate paths from light

Generate paths from eye

Hook up vertices from one path to vertices of other path, to get multiple paths from eye to light

Bi-Directional Path Tracing



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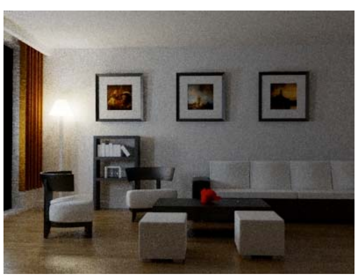
Bi-Directional Path Tracing

Bi-Directional Path Tracing



Bi-Directional Path Tracing

Consider