Comprehensive Overview

CIS782

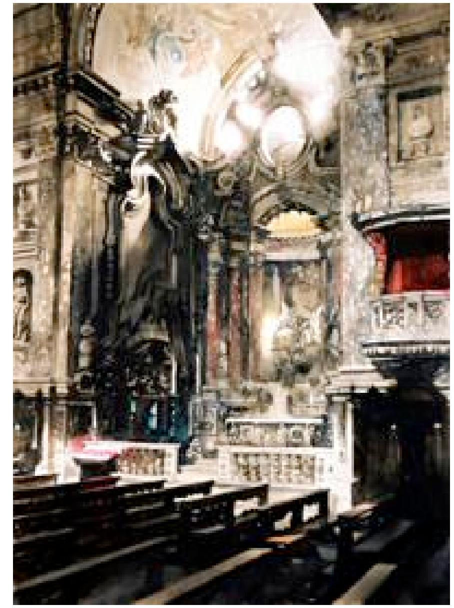
Advanced Computer Graphics

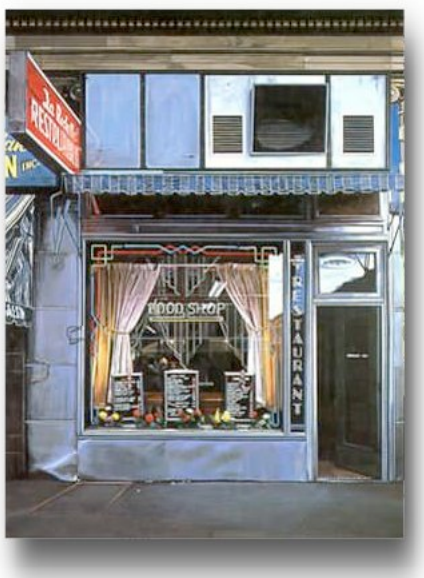
Based on notes of Raghu Machiraju and Torsten Moeller

Realism Through Synthesis

Holy Grail

© 199? Cheng Zhang

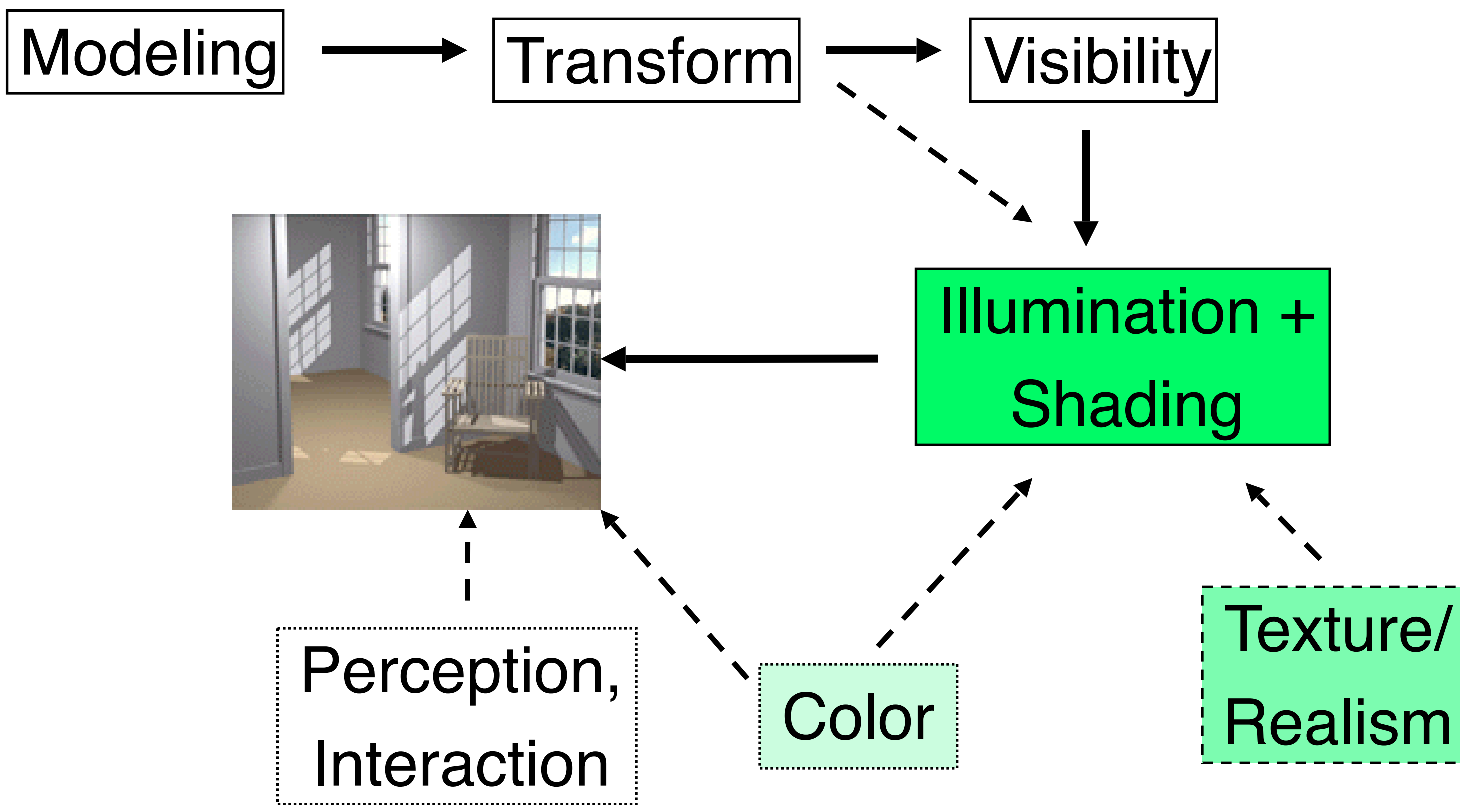




Photrealistic (Physically Based) Rendering

- Visibility - sampling
  - camera to surface
  - surface to surface
  - surface to light source
- Optics
  - Nature of Light & its Transport
  - Interaction with surface
- Display - resampling
  - Perception

Graphics Pipeline



Review & Looking ahead

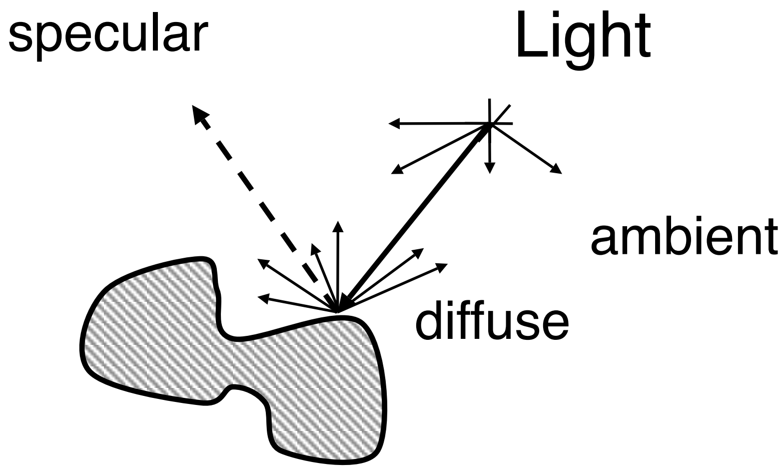
- Local illumination models
- Global illumination
- Ray tracing
- Light transport equations

Shading

- **Illumination Model:** determine the color of a surface (data) point by simulating some light attributes.
- **Local Illumination:** deals only with isolated surface (data) point and direct light sources.
- **Global Illumination:** takes into account the relationships between all surfaces (points) in the environment.
- **Shading Model:** applies the illumination models at a set of points and colors the whole scene.

Local illumination: Light & Surface

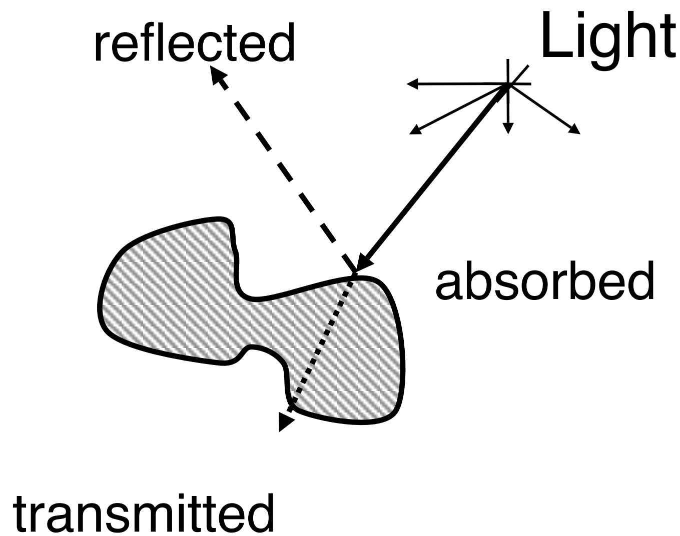
- Usually only considering reflected part



Light=ambient+diffuse+specular

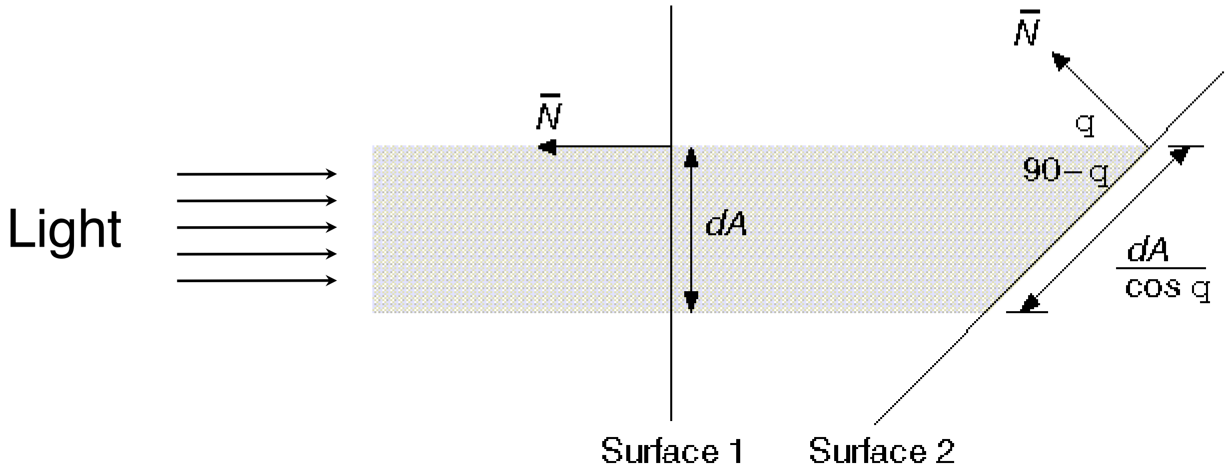
$$I = k_a I_a + k_d I_d + k_s I_s$$

Tracing Specular Light Path

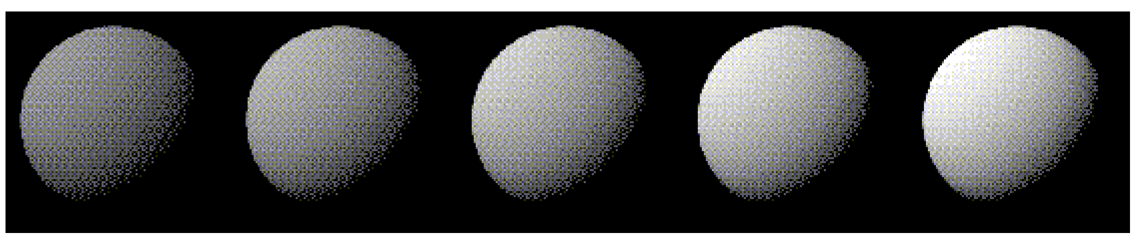


Light=reflected+absorbed+transmitted

Diffuse Light

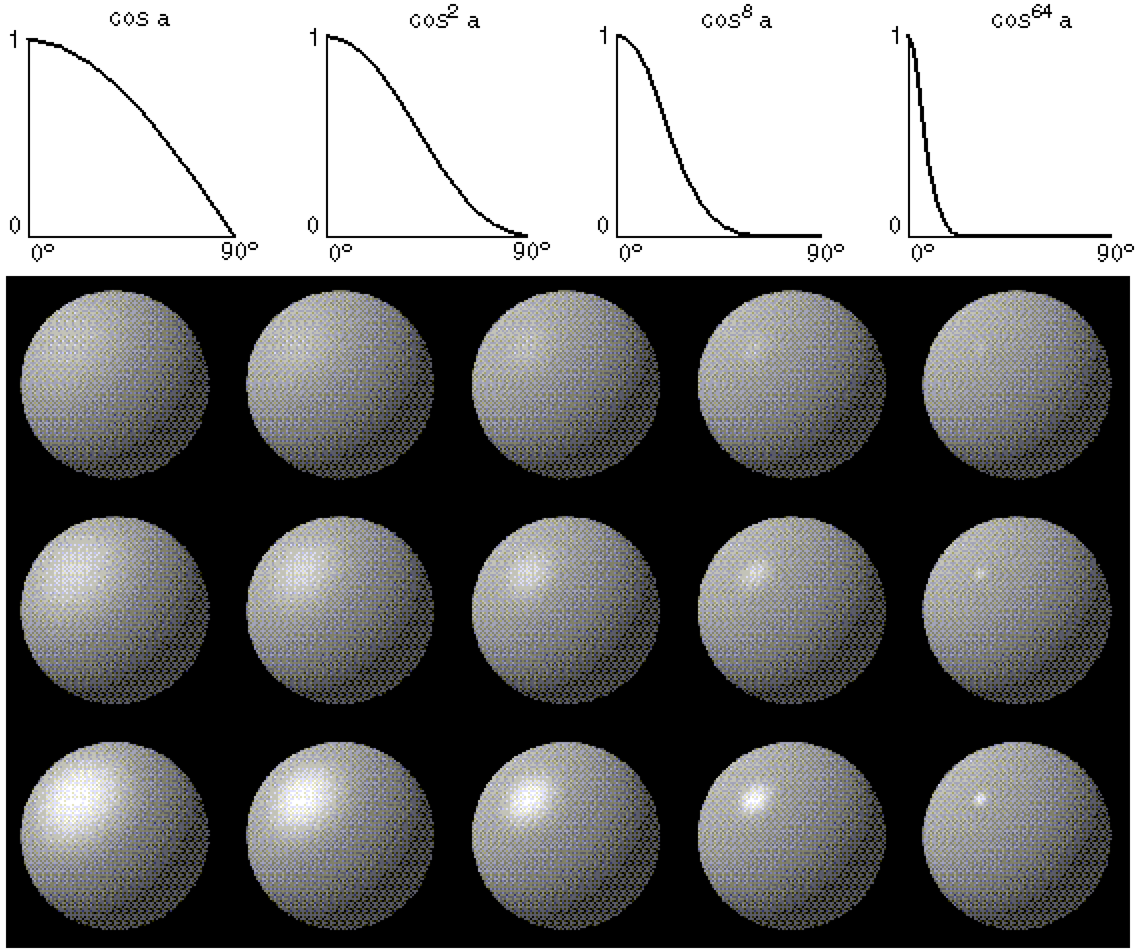


$$I_d = k_d(N \cdot L)$$

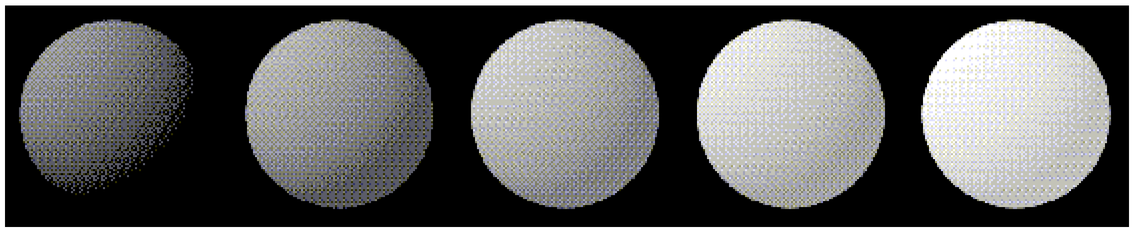


Specular Light

$$I_s = k_s(E \cdot L)^n$$



Ambient Light



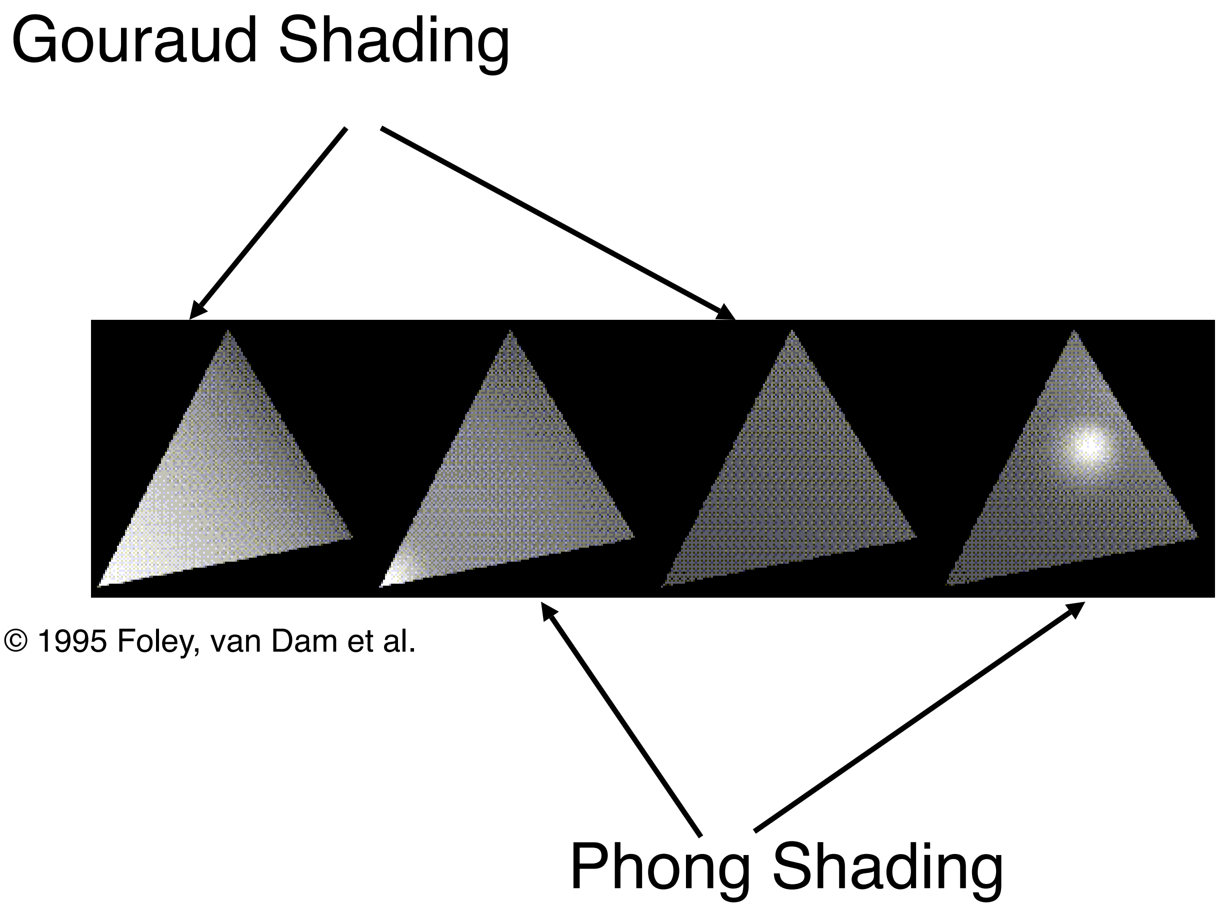
$$I_a = k_a$$

- I_A: ambient light
- k_a: material's ambient reflection coefficient
- Models general level of brightness in the scene
- Accounts for light effects that are difficult to compute (secondary diffuse reflections, etc)

Gouraud Shading

Flat Shading | Gouraud Shading

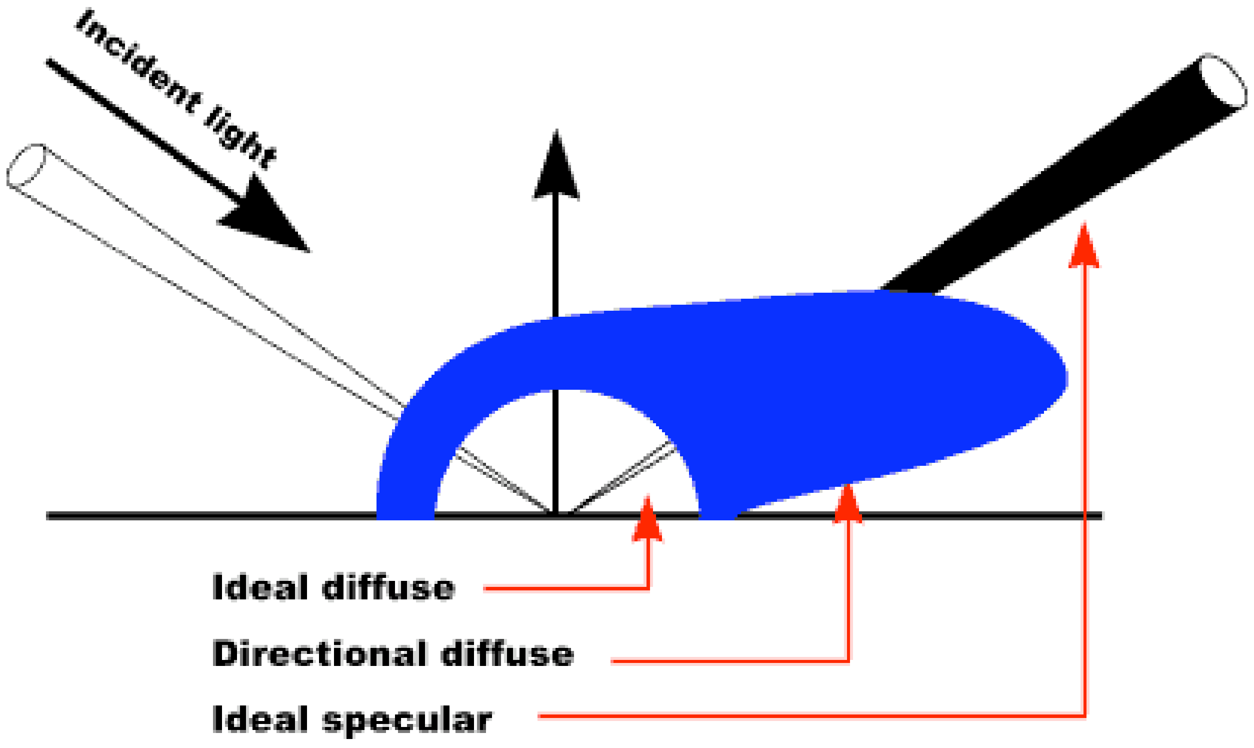
Phong Shading



Physically Based Illumination

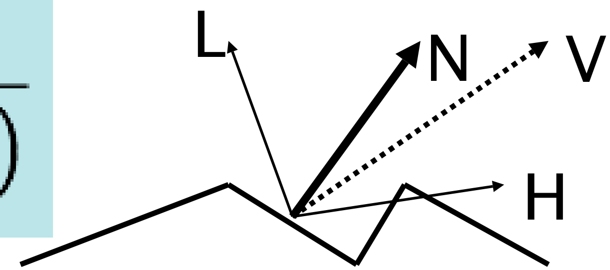
- Everything so far has been pretty heuristic
- Cannot model:
  - wavelength dependent phenomena
  - anisotropic behaviors
  - subsurface interactions of light & material
  - indirect diffuse illumination
  - many other physical phenomena (real physics)
- Ongoing research - main contributions
  - Blinn (1977), Cook, Torrance (1982)
  - Kajiya (1985), Cabral et al (1987)
  - Hanrahan, Krüger (1993)

Physically Based Illumination



Torrance-Sparrow

$$\rho = \frac{F_\lambda}{\pi} \frac{DG}{(N \times V)(N \times L)}$$

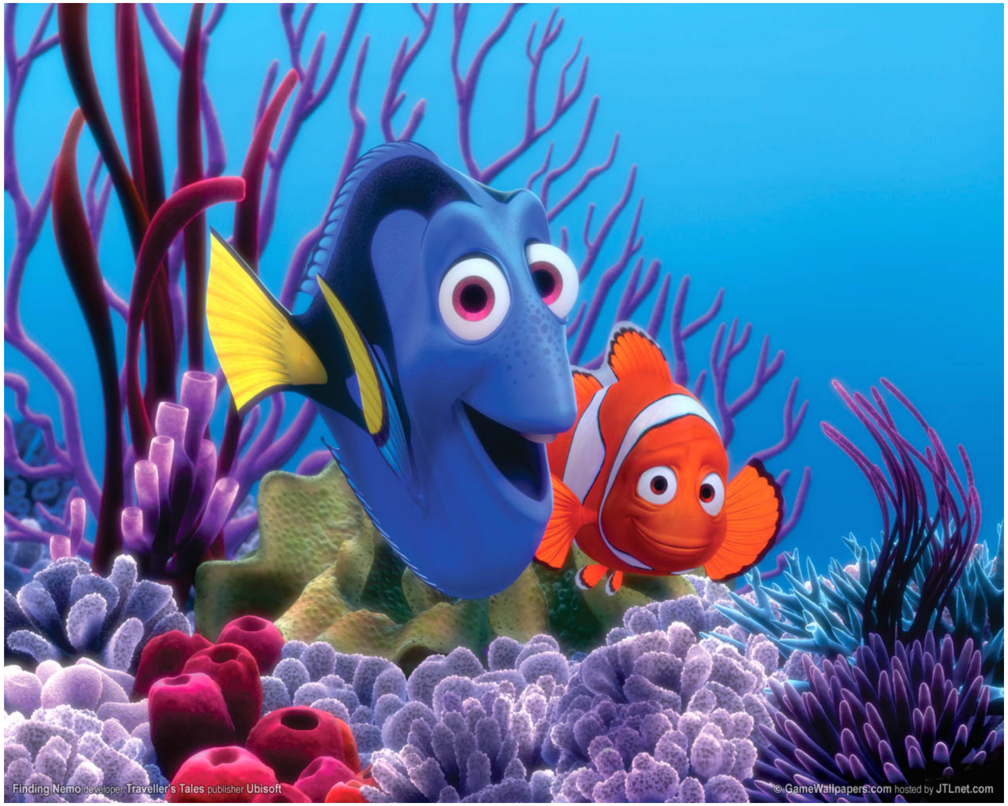


- D - Microfacet Distribution Function
  - how many “cracks” do we have that point in our (viewing) direction?
- G - Geometrical Attenuation Factor
  - light gets obscured by other “bumps”
- F - Fresnel Term
  - which portion of the incoming light gets reflected?
  - Grazing Angle !

Cook-Torrance

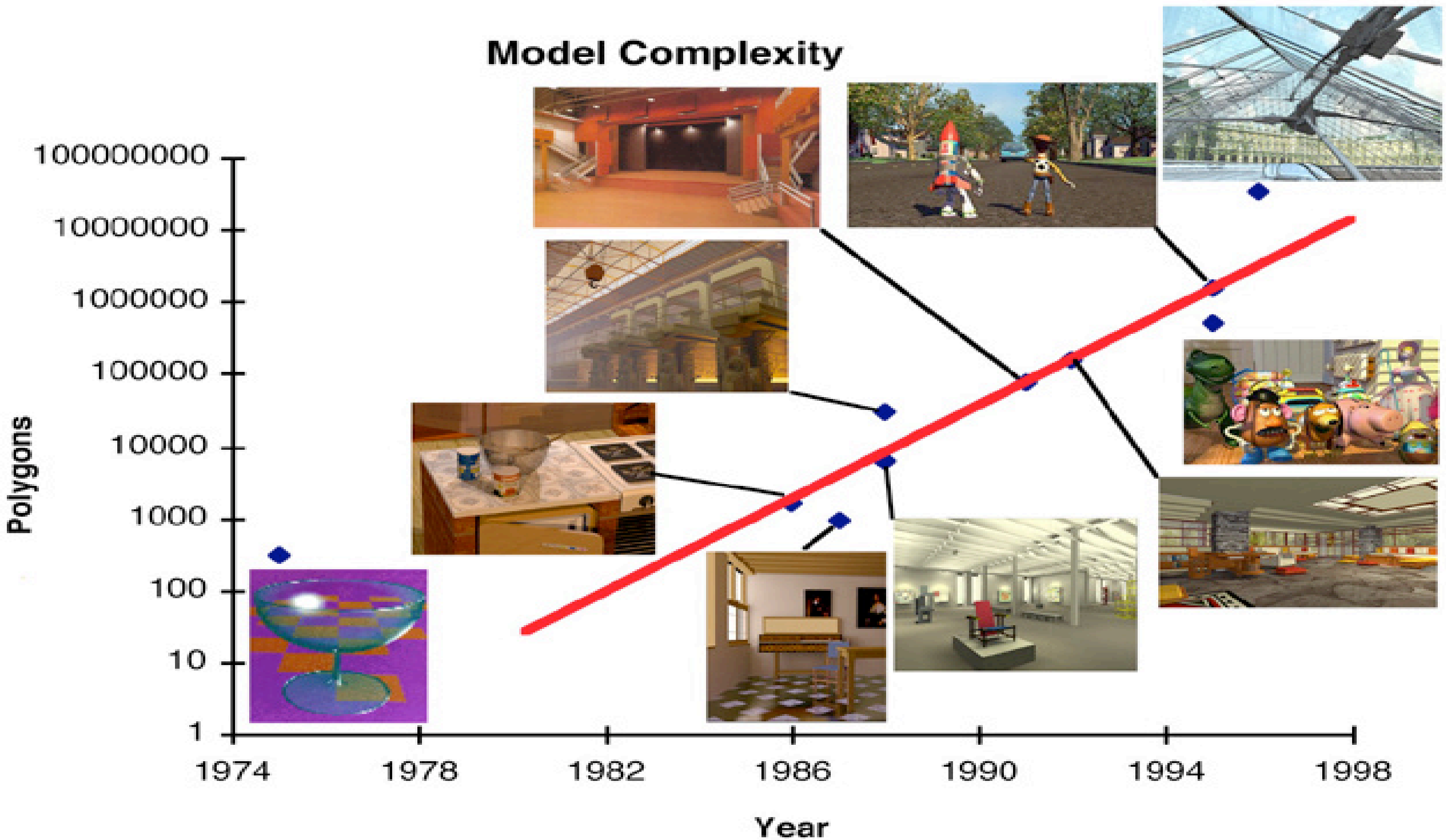
For now can do this

And This …

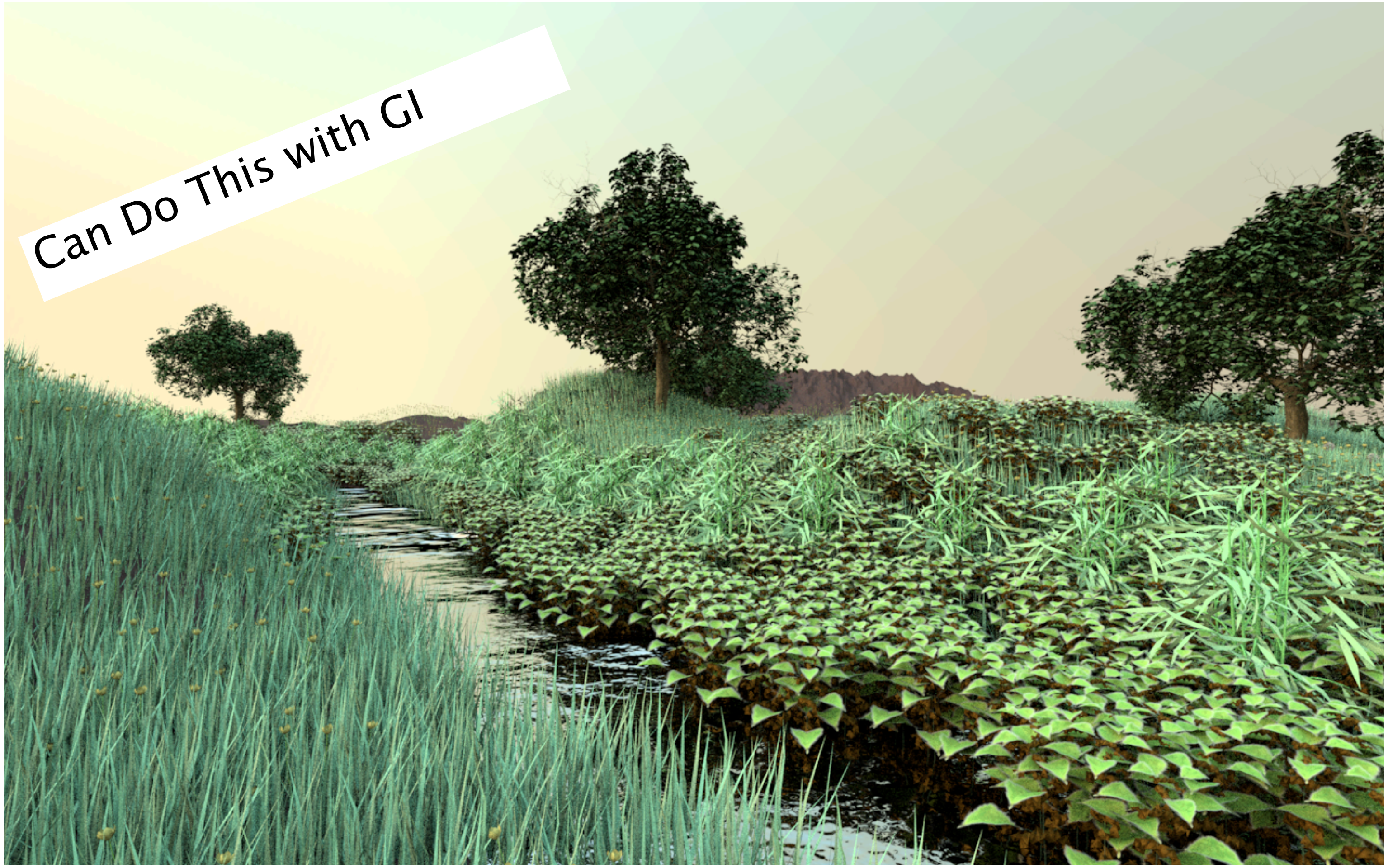


© 2003, Pixar, Finding Nemo

It's getting better …



Can We Do Better ?

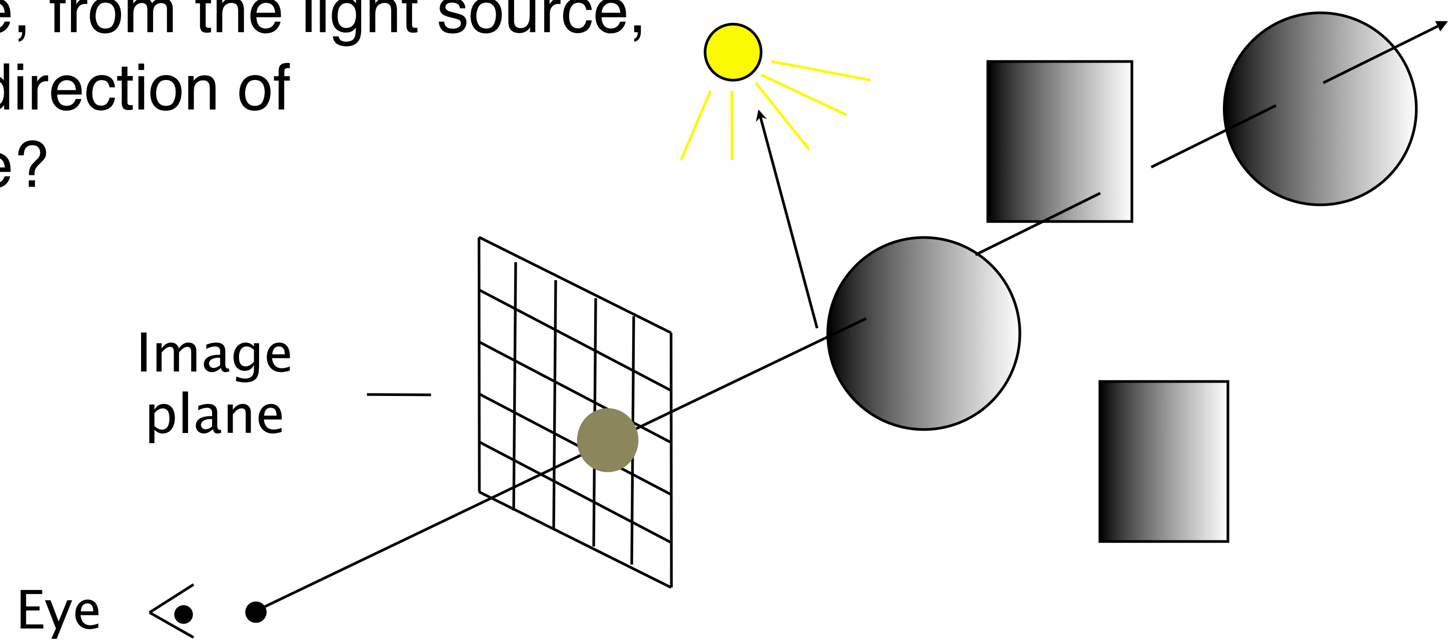


And Even Better ?

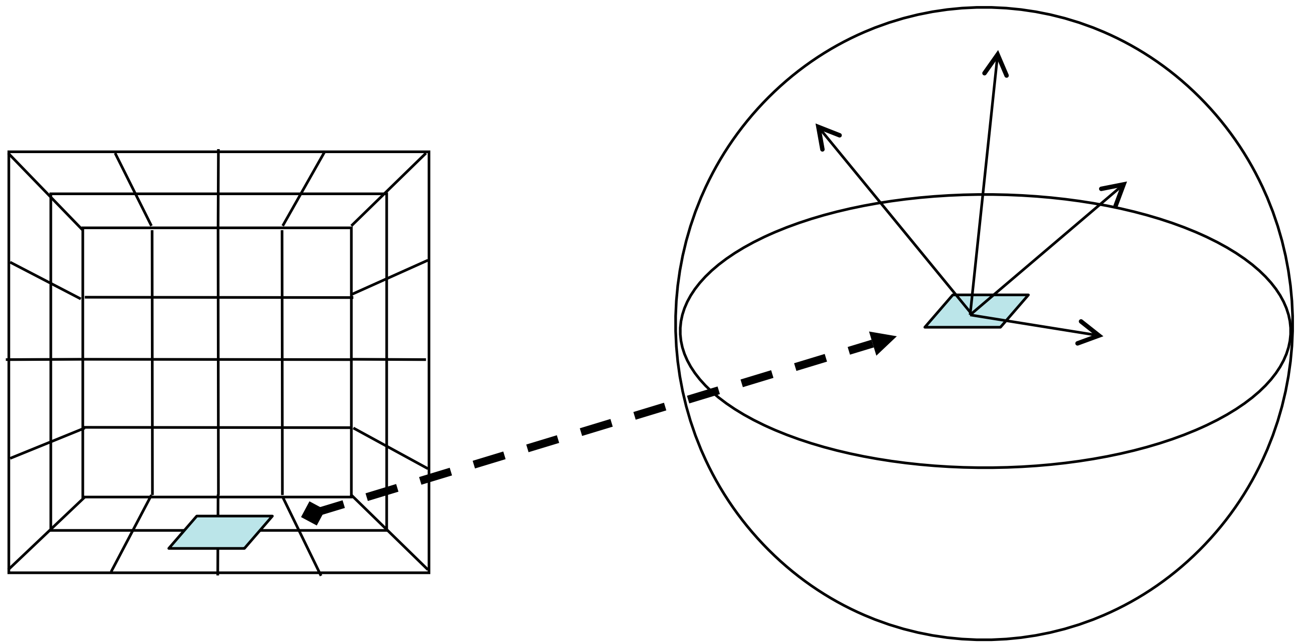
Holy Grail

Local Illumination Problem

What is the intensity of the surface, from the light source, in the direction of the eye?



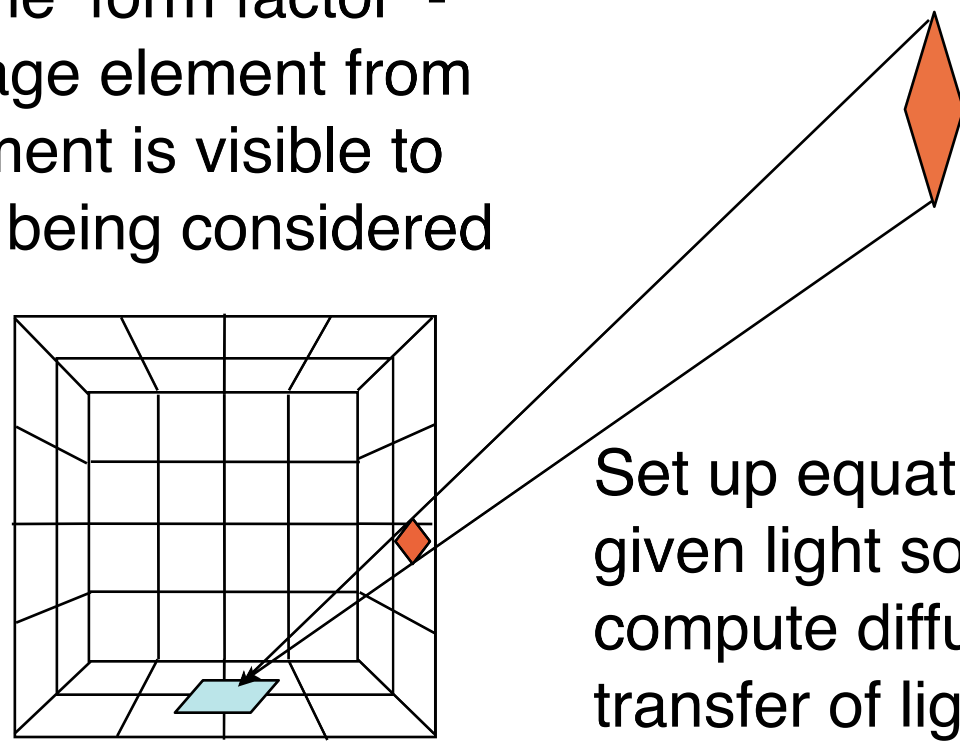
Global Illumination Problem



What is the “intensity” of this surface from all possible directions?

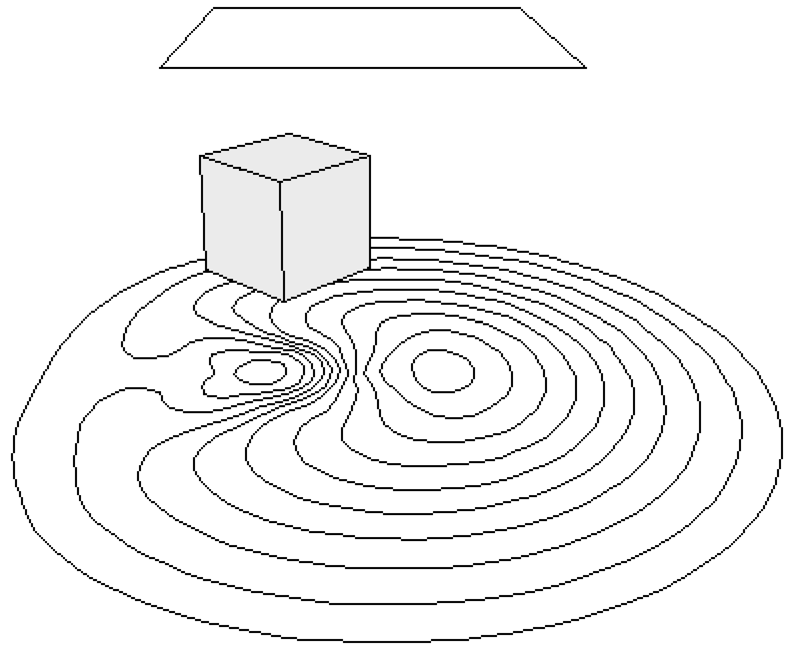
Global Illumination (Partial) Solution
Radiosity

Determine ‘form factor’ - percentage element from environment is visible to element being considered

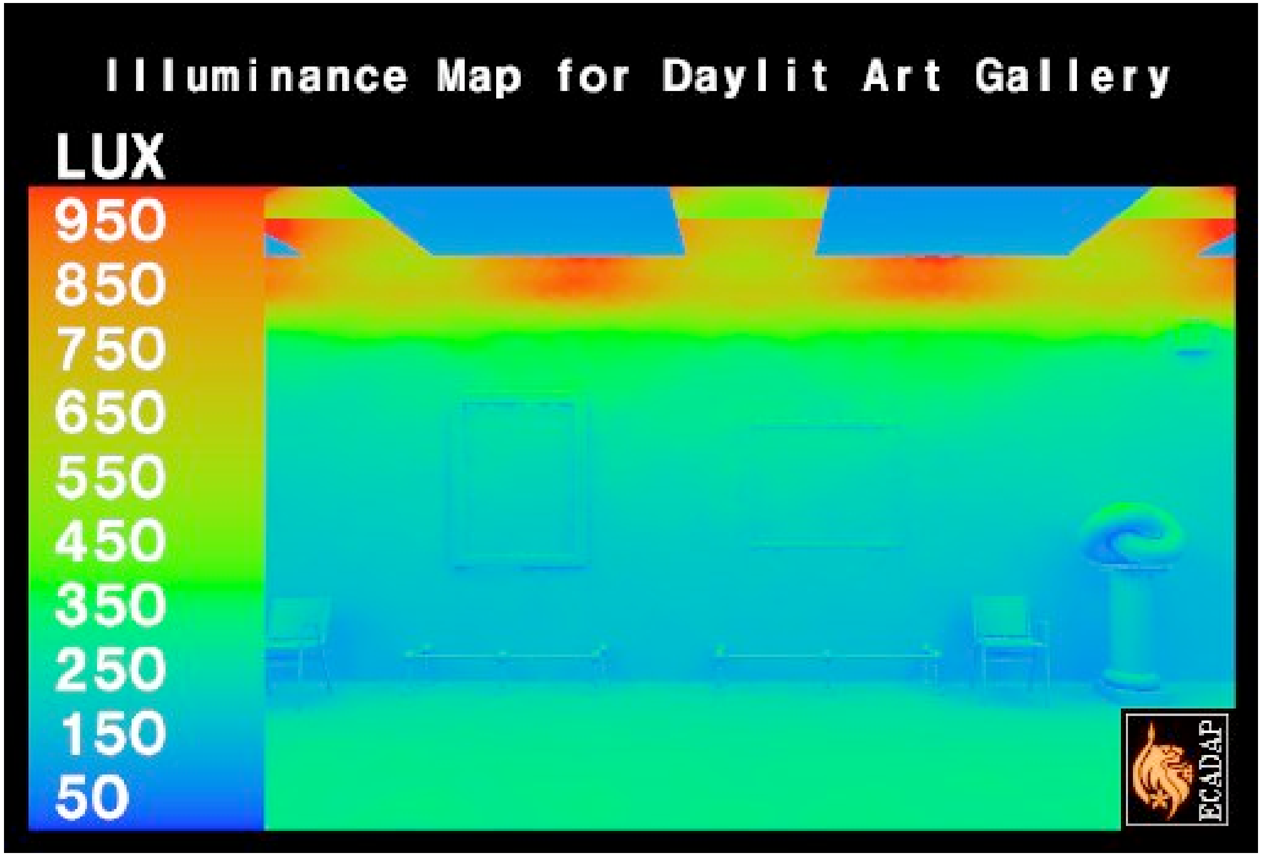


Set up equations so that, given light source intensities, compute diffuse-diffuse transfer of light from one surface to another

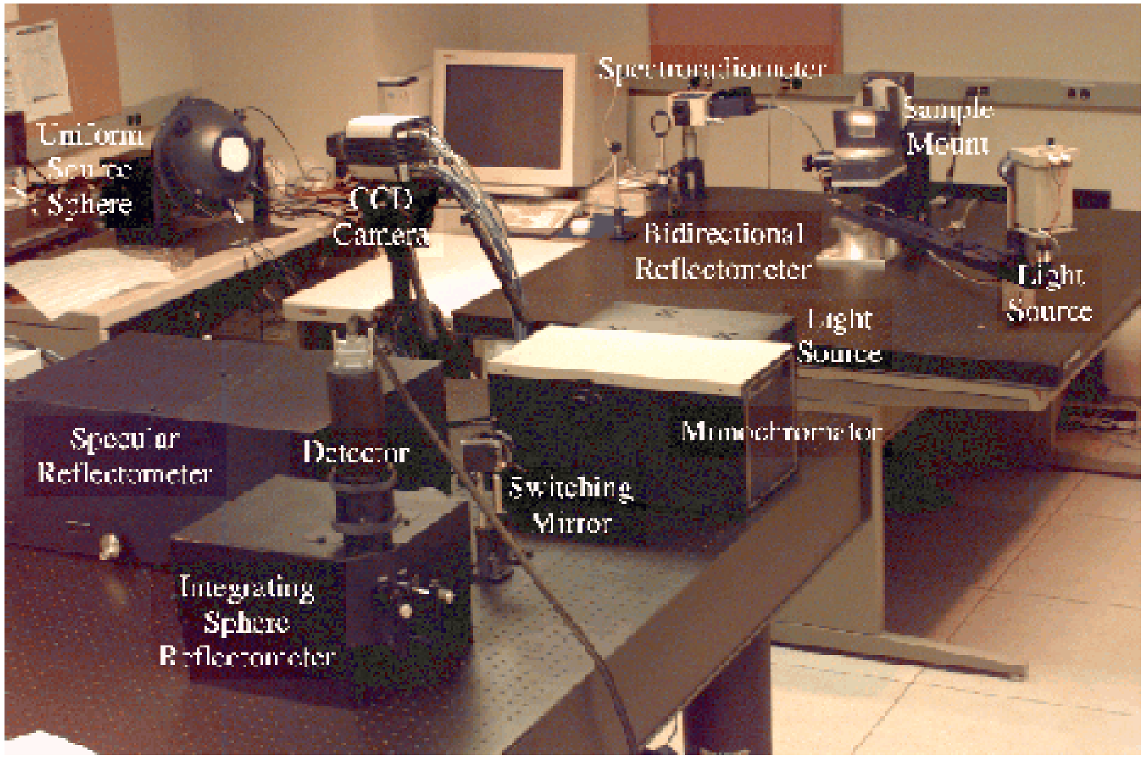
Energy Distribution



Energy Distribution



Measure It!



Equipment in the Light Measurement Laboratory (circa 1995) of the Cornell University Program of Computer Graphics

Light Transport Equation

Outgoing radiance from specific point at specific direction

Integrated over all possible incoming directions

$$L_o(p,\omega_o) = L_e(p,\omega_o) + \int_{S^2} f(p,\omega_o,\omega_i) L_i(p,\omega_i) |\cos\theta_i| d\omega_i$$

Emitted radiance

differential solid angle

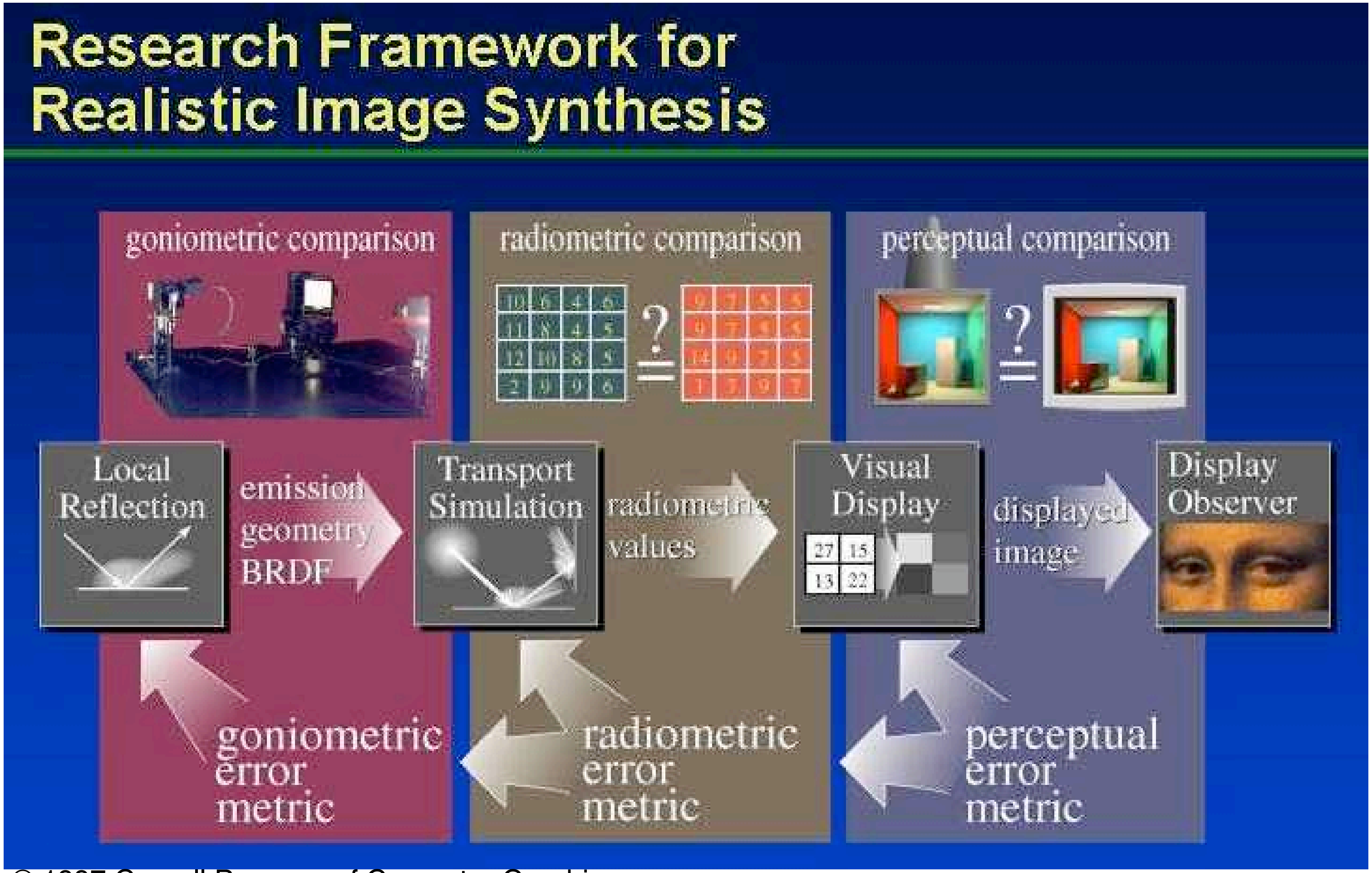
Bidirectional reflectance distribution function (BRDF)

Incoming radiance to specific point in specific direction

Challenges

- Complex primitives: area lights, materials, shapes
- Materials
  - Interfaces: reflectance and texture
  - Medium: scattering
- Camera - sampling
- Large number of paths that light can take
- Solutions:
  - Radiosity - Finite Elements
  - Ray Tracing - Monte Carlo - random sampling

Framework


Research Framework for
Realistic Image Synthesis
goniometric comparison
radiometric comparison
perceptual comparison
Local
Reflection
emission
geometry
BRDF
Transport
Simulation
radiometric
values
Visual
Display
27 15
13 22
displayed
image
Display
Observer
goniometric
error
metric
radiometric
error
metric
perceptual
error
metric

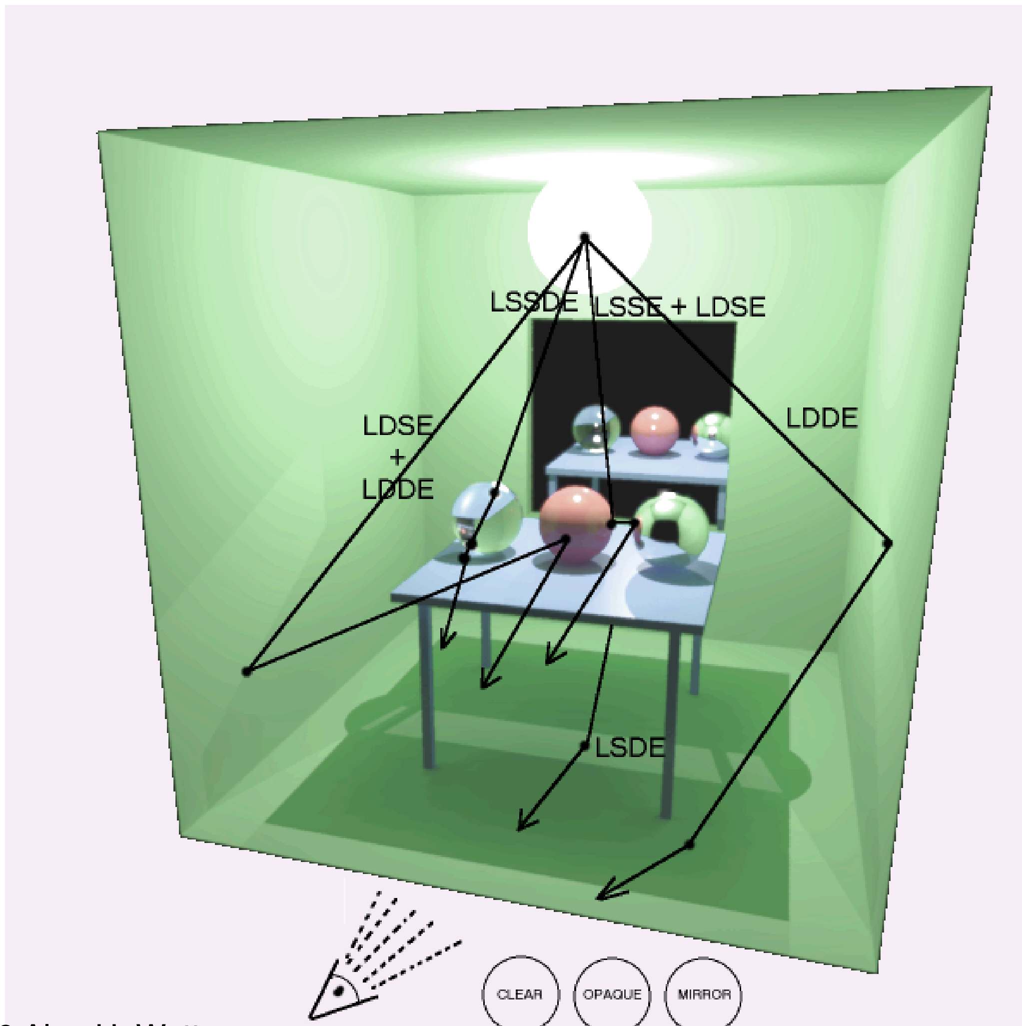
Global Illumination - path notation

- At a point incoming light may be scattered or reflected diffusely or specularly and may have come from a multitude of interactions itself.
- For pairs of surfaces we have 4 possible transfers of light:
  - diffuse to diffuse transfer
  - specular to diffuse transfer
  - diffuse to specular transfer
  - specular to specular transfer

Global Illumination - path notation

- Radiosity: diffuse to diffuse
- (Whitted) ray-tracing: specular to specular
- string notation (Heckbert 90):
  - L - light source
  - E - eye point
  - path: specify transfer mechanism
  - 4 possibilities: DD, DS, SD, SS

Global Illumination - path notation



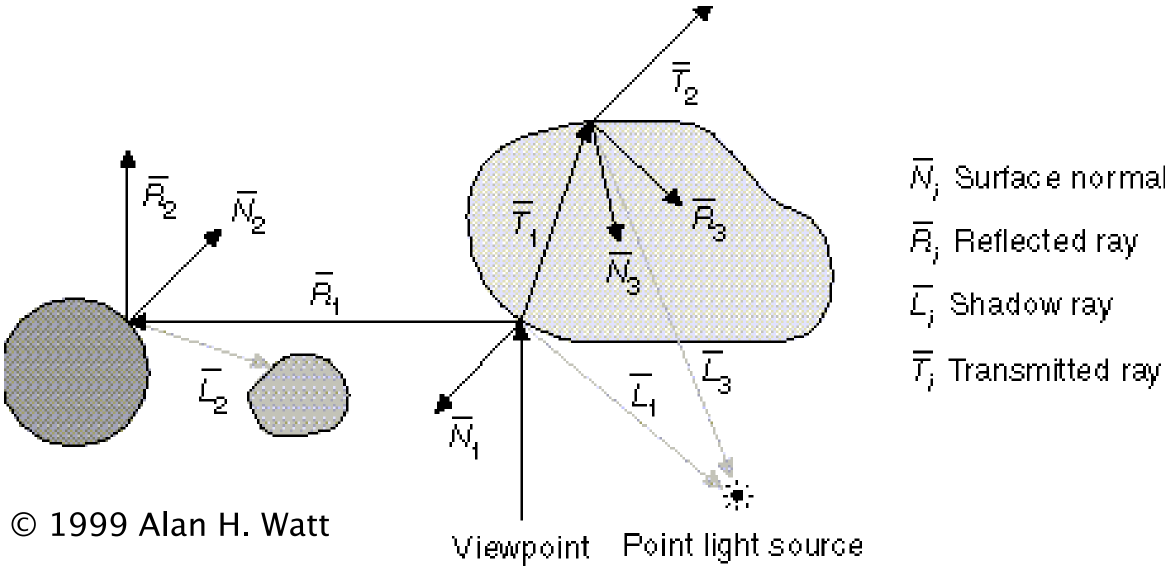
Global Illumination - path notation

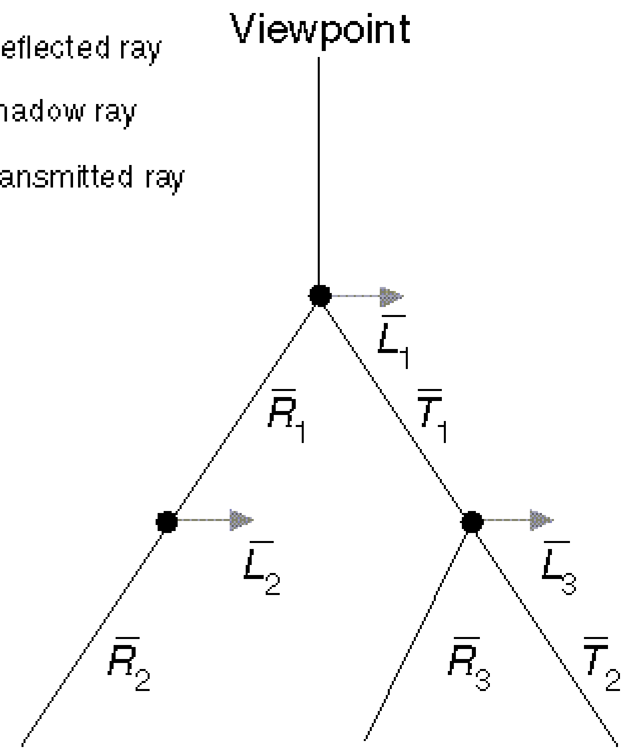
- Path of ‘complete’ algorithm: L(D|S)*E
  - e.g., LDE, LSE, LDDDE, LDDSDDE,
- local reflection model: L(D+S)
- typical Z-buffer: L(D+S)E - string of length 1
  - LDE+LSE

Global Illumination (Whitted) ray tracing

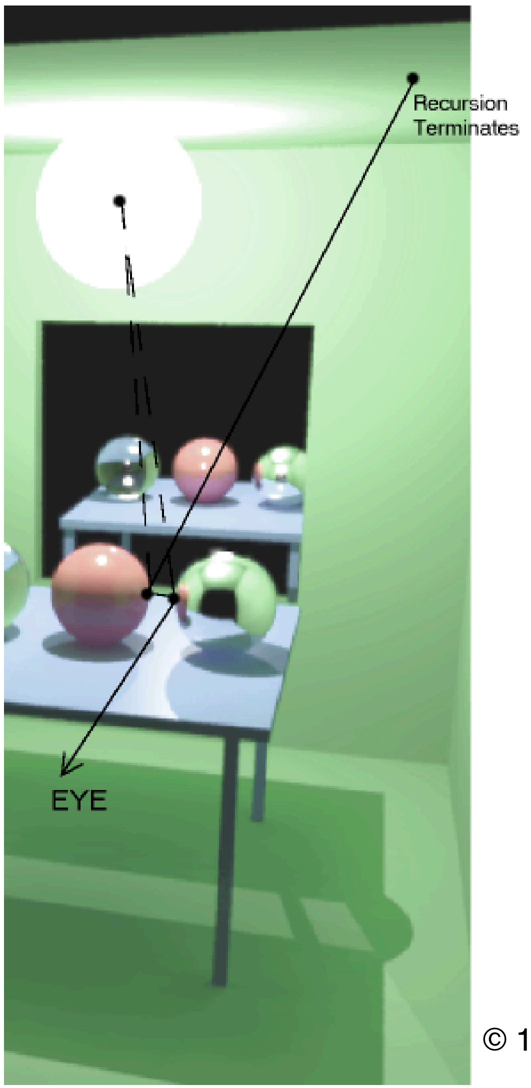
- Traces light rays in <u>reverse</u> direction
  - light rays specularly reflected
- hence is <u>view-dependent</u>
- for each hit point we include the contribution of the direct light before we continue with the reflected (or transmitted) ray

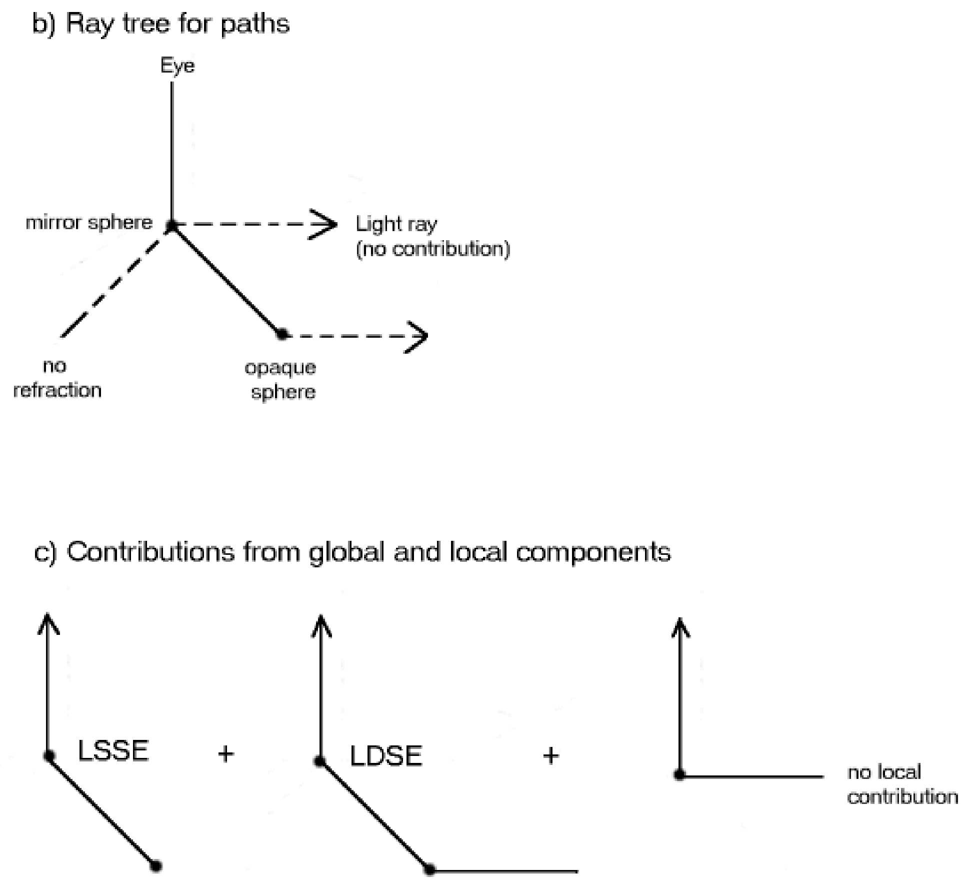
Global Illumination
(Whitted) ray tracing





Global Illumination (Whitted) ray tracing





Global Illumination (Whitted) ray tracing

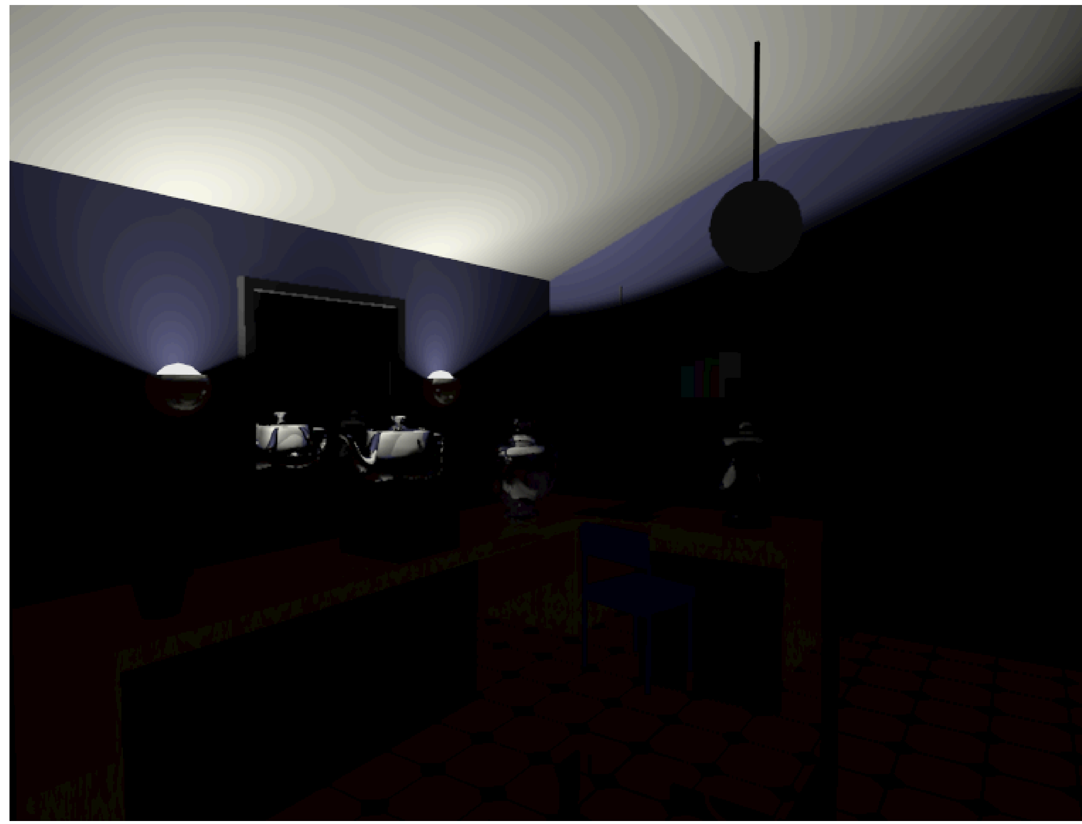
- Includes direct diffuse reflection (LD), but not diffuse-diffuse (DD)
- restricted to specular reflection
- path characterization:
  - LS*E or LDS*E
- rendering equation:
  - integral over sphere of all possible angles simplifies to two (three) specific directions - light direction and perfect reflected (refracted) ray

Global Illumination - Radiosity

- Implements diffuse-diffuse
- no rays - “patches” interact
  - scene needs to be divided into “patches”
- view-independent
  - one pass computes light distribution in the whole scene: radiosity
  - second pass renders one particular viewpoint

Global Illumination - Radiosity

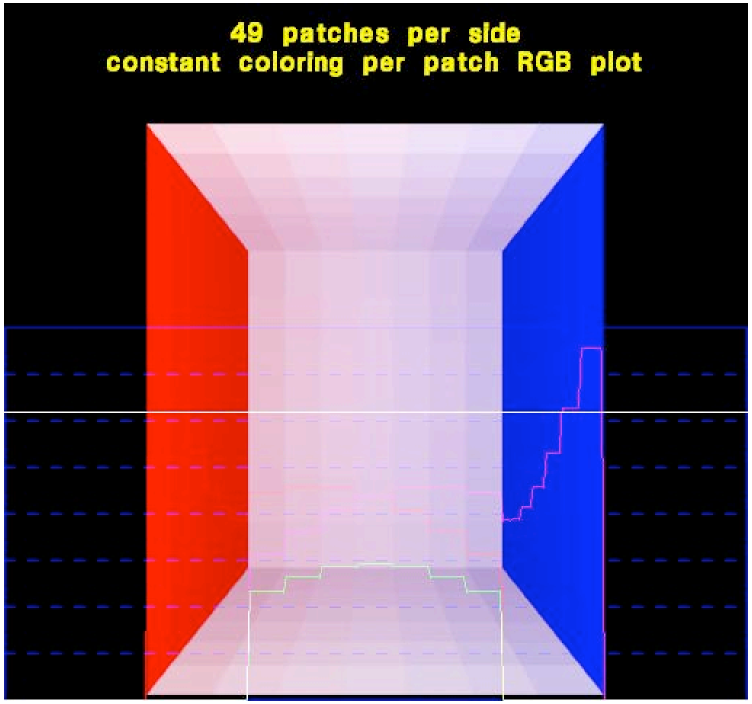
- Ray-traced with main light turned off
- typical for indoor scenes
- no diffuse interactions
  - problem!



Global Illumination - Radiosity

- Same scene as before - main light turned off
- computed using a radiosity method
- scene accounts for diffuse interactions

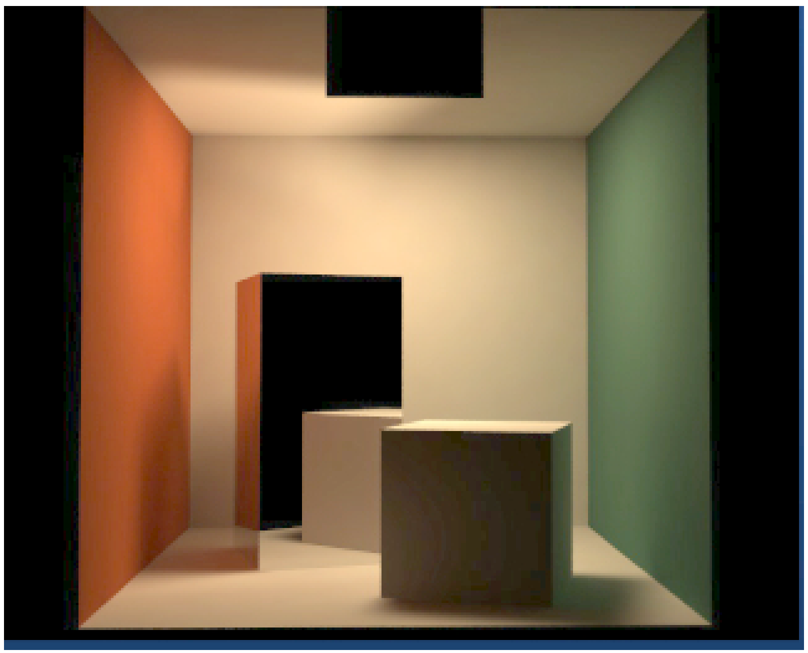
Test Object - Cornell Box



This is the original Cornell box, as simulated by Cindy M. Goral, Kenneth E. Torrance, and Donald P. Greenberg for the 1984 paper Modeling the interaction of Light Between Diffuse Surfaces, Computer Graphics (SIGGRAPH '84 Proceedings), Vol. 18, No. 3, July 1984, pp. 213-222.

This simulation of the Cornell box was done by Michael F. Cohen and Donald P. Greenberg for the 1985 paper The Hemi-Cube, A Radiosity Solution for Complex Environments, Vol. 19, No. 3, July 1985, pp. 31-40.

Does Radiance Work?

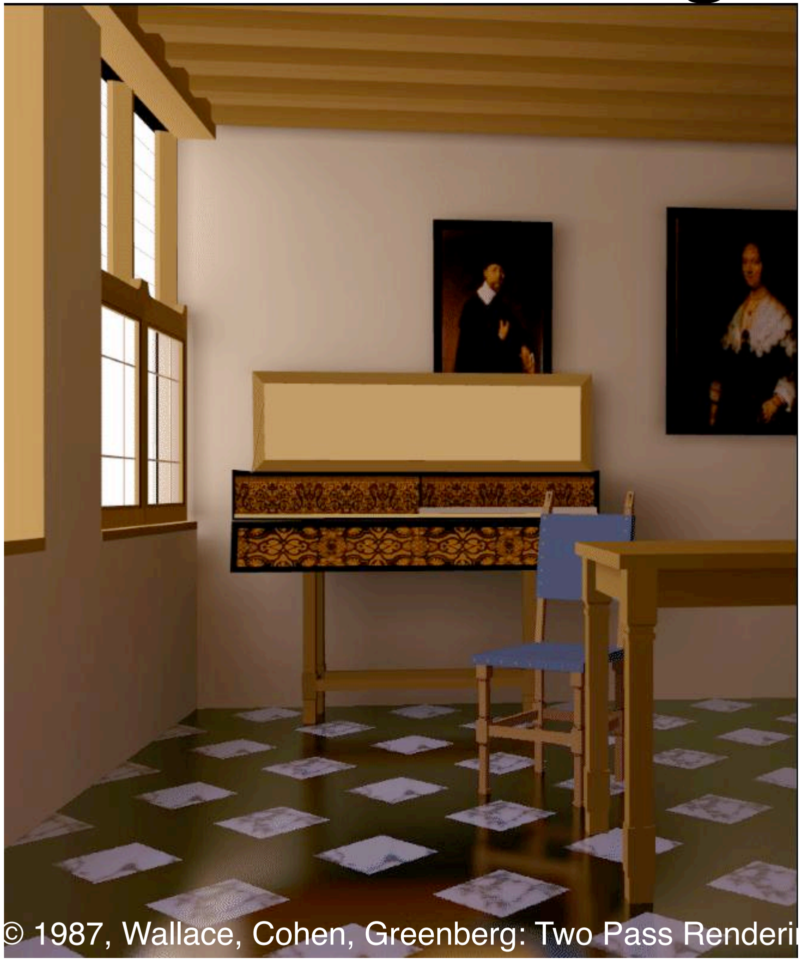


Measured

Simulated

Difference

Radiosity
indirect light & soft shadows



© 1987, Wallace, Cohen, Greenberg: Two Pass Renderi

© 1988 Cohen, Chen, Wallace, Greenberg: Radiosity Factory

Radiosity Equations

B_j Radiosity of element i

E_j energy emission of element j

ρ_j reflectivity of element j

F_{ij} form factor between element i and element j

$$B_j = E_j + \rho_j \sum_{i=1}^{N} B_i F_{ij} \qquad j = 1..N$$

Radiosity Matrix

$$\begin{bmatrix} 1-\rho_1 F_{11} & -\rho_1 F_{12} & \dots & -\rho_1 F_{1N} \\ -\rho_2 F_{21} & 1-\rho_2 F_{22} & \dots & -\rho_2 F_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ -\rho_N F_{N1} & -\rho_N F_{N2} & \dots & 1-\rho_N F_{NN} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_N \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ \vdots \\ E_N \end{bmatrix}$$

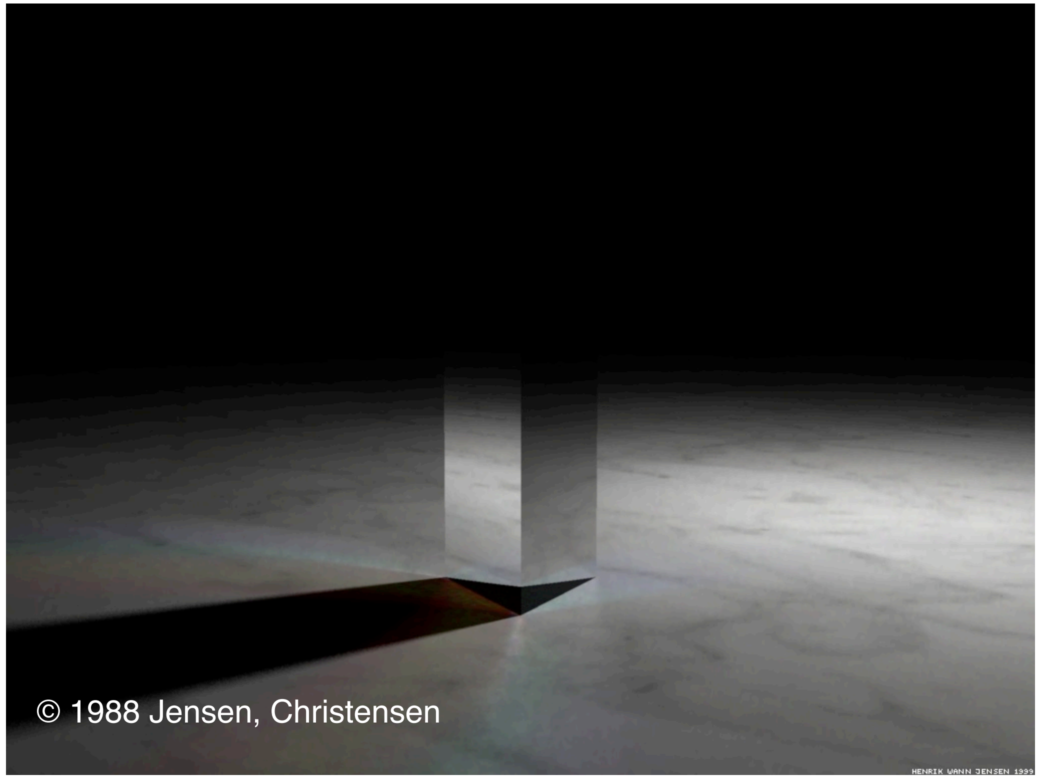
$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\theta_i \cos\theta_j}{\pi r^2} dA_j dA_i$$

Approximate form factor using projected hemicube method

Cannot do it all

- Finite element methods
- Not efficient - storage
- Meshing problems curved surfaces, hard shadows
- Complex effects beyond diffuse

Try This ?



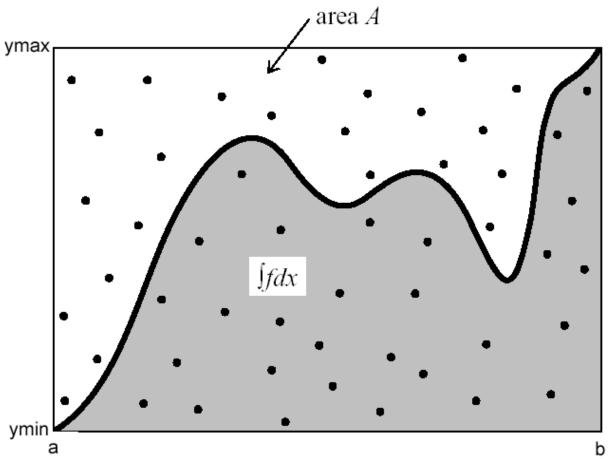
"Efficient Simulation of Light Transport in Scenes with Participating Media using Photon Maps“ Henrik Wann Jensen and Per H. Christensen, Proceedings of SIGGRAPH'98, pages 311-320, Orlando, July 1998

Monte Carlo Ray Tracing?

- Distributed Ray Tracing
  - distribute subsamples in time and space
- Path Tracing
  - incrementally generates paths of scattering events
- Metropolis Light Transport
  - distribute according to function's PDF
- Photon Maps
  - randomly sample rays leaving the light source
- Bi-Directional Path Tracing
  - trace paths both ways: from camera, from light

Monte Carlo Integration

Can be about computing integrals



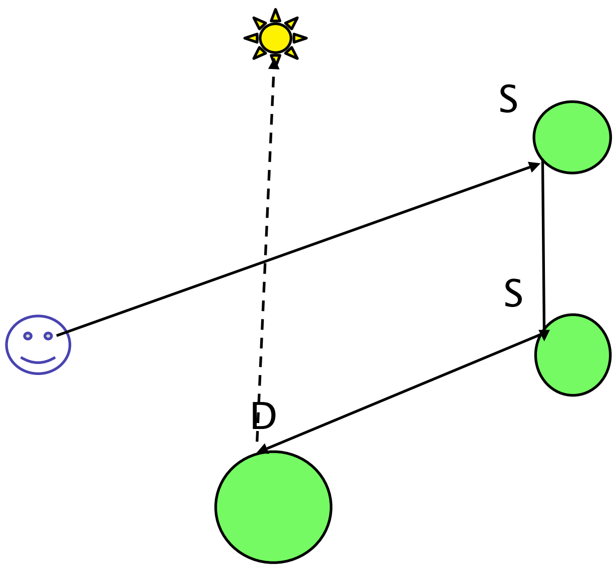
$$I = \int_a^b f(x)dx$$

$$I_m = (b-a)\frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

$$\lim_{N\to\infty} I_m = I$$

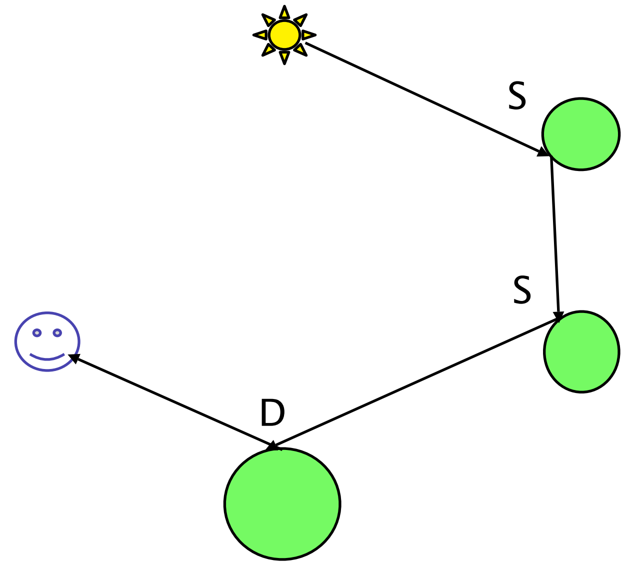
- I_m = Monte Carlo estimate
- N = number of samples
- $x_1, x_2, \ldots, x_N$ are uniformly distributed random variables in [a,b]

Ray Tracing
from eye, from light



Visibility/Ray Tracing

L[D]S*[E]

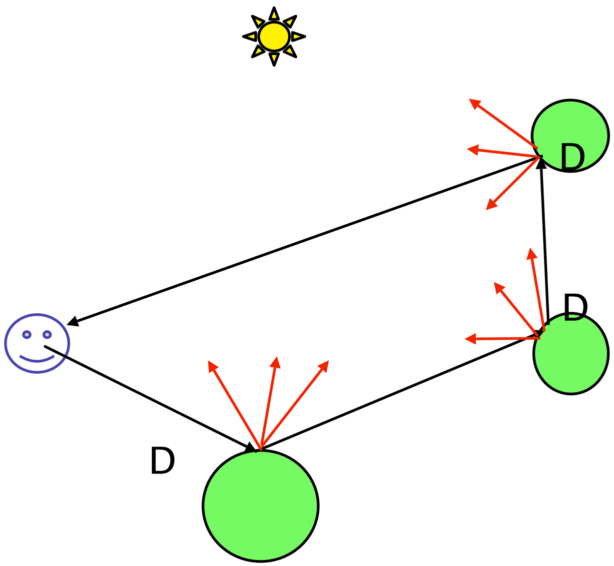


Photon Tracing

LS*[D][E]

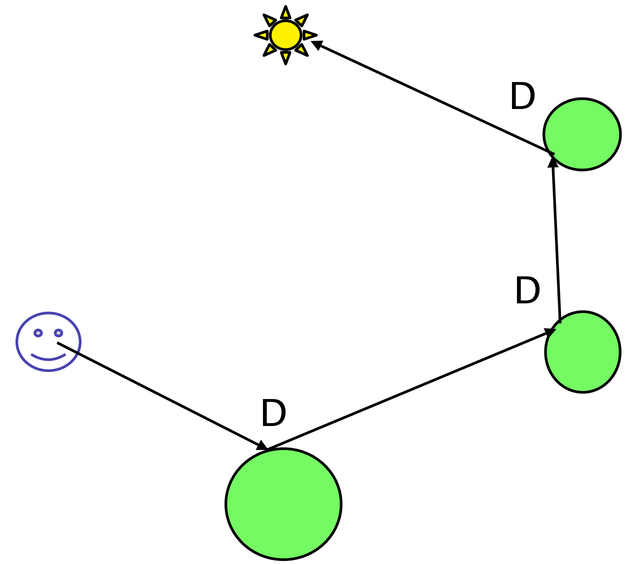
Deposit photons in the environment

Path Tracing



Distributed Ray Tracing

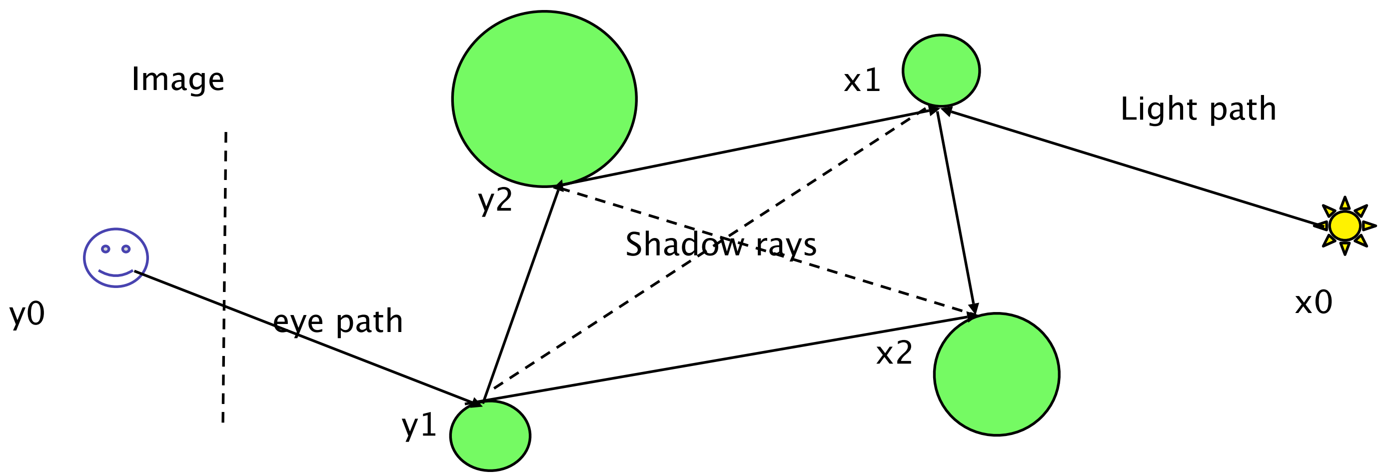
L[S|D]*E



Path history

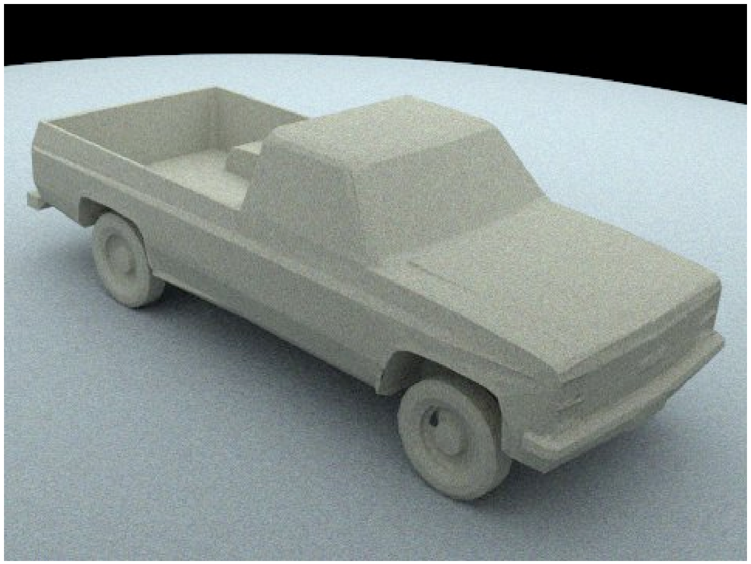
From eye, distribute rays until a light source is hit - save path

Bi-Directional Path Tracing

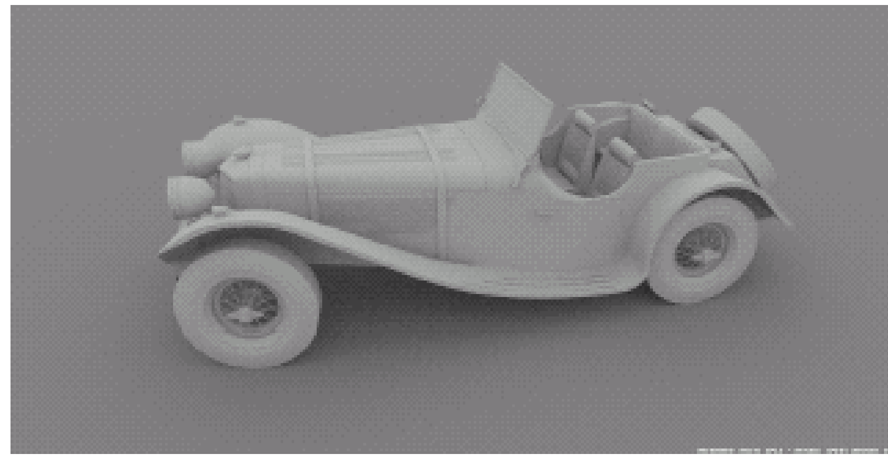


Combine photon mapping and path tracing

Path Tracing



http://www.winosi.onlinehome.de/83GMC.jpg



Photon Mapping Text of Henrik Wann Jensen

Path Tracing – Working ?

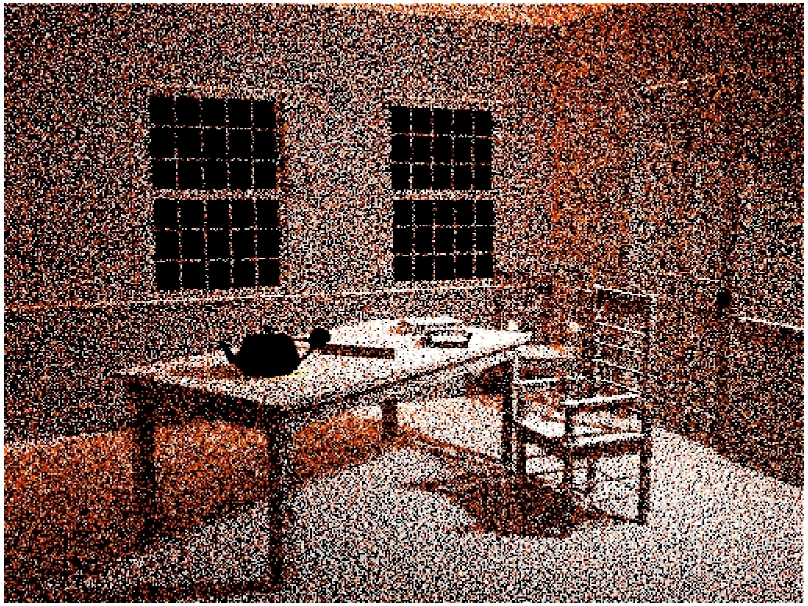
Often Noisy and Slow !

"Optimizing Path Tracing using Noise Reduction Filters“ Henrik Wann Jensen and Niels Jørgen Christensen, Proceedings of WSCG95, pages 134-142, Plzen, February 1995

Photon Map

- Two Pass
- Photon Hits are stored in various resolutions
- Essentially Monte Carlo Path Tracing
- No Dependence on Geometry
- Important Component is Data Structure
- Caustics, Shadow
- Rendering - Ray Tracing Algorithm
- Photon Maps can be large in size

Photon Map

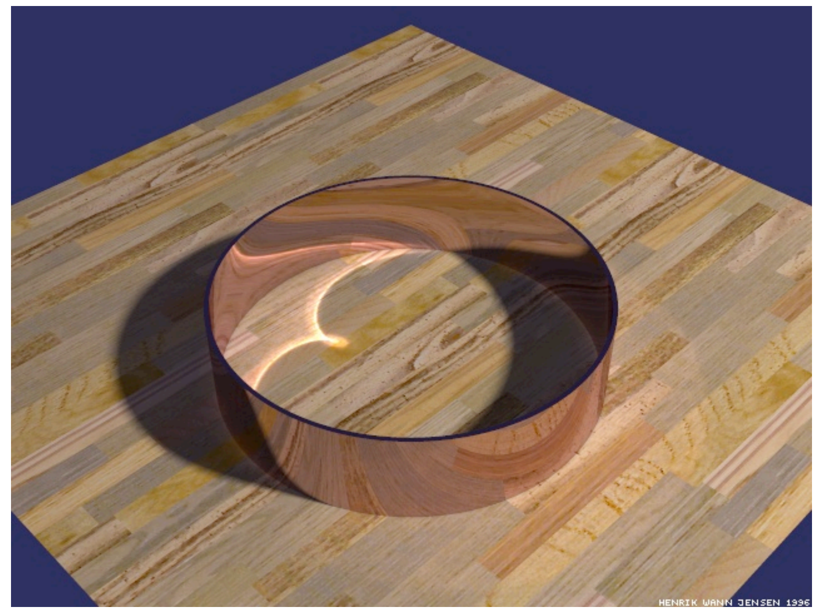


Photon Map at Work

Ray Tracing – No diffuse component

Per H. Christensen. "Faster Photon Map Global Illumination".
Journal of Graphics Tools, volume 4, number 3, pages 1-10. ACM, 1999. (Appeared April 2000.)

Caustics



"Rendering Caustics on Non-Lambertian Surfaces“ Henrik Wann Jensen,
Proceedings of Graphics Interface '96, pages 116-121, Toronto, May 1996

Indirect Illumination

Other Related Topics

- Light-surface interaction
- Perceptual-based display
- Image interpolation
- etc.

SubSurface Scattering

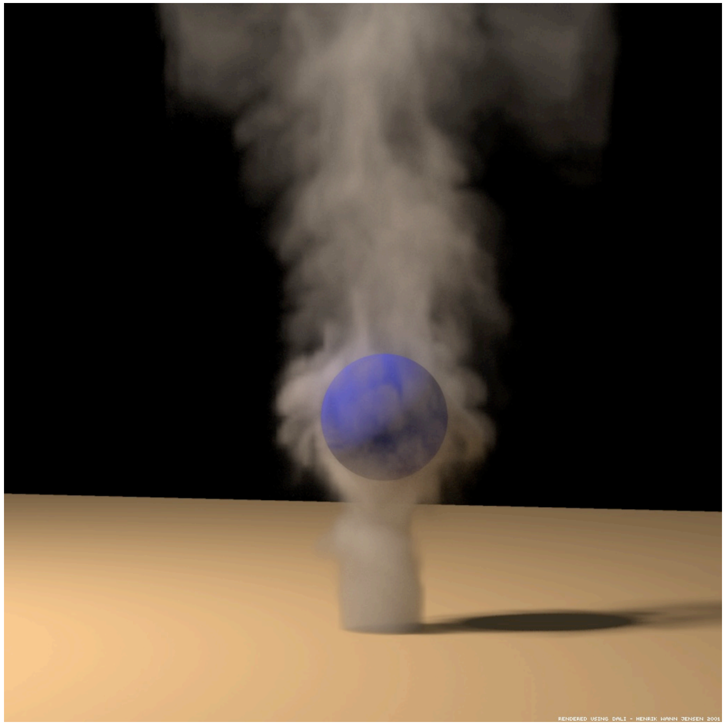
"A Practical Model for Subsurface Light Transport"
Henrik Wann Jensen, Steve Marschner, Marc Levoy, and Pat Hanrahan
Proceedings of SIGGRAPH'2001, pages 511-518, Los Angeles, August 2001

Translucency

© 2001 Jensen, Marschner, Levoy, Hanrahan

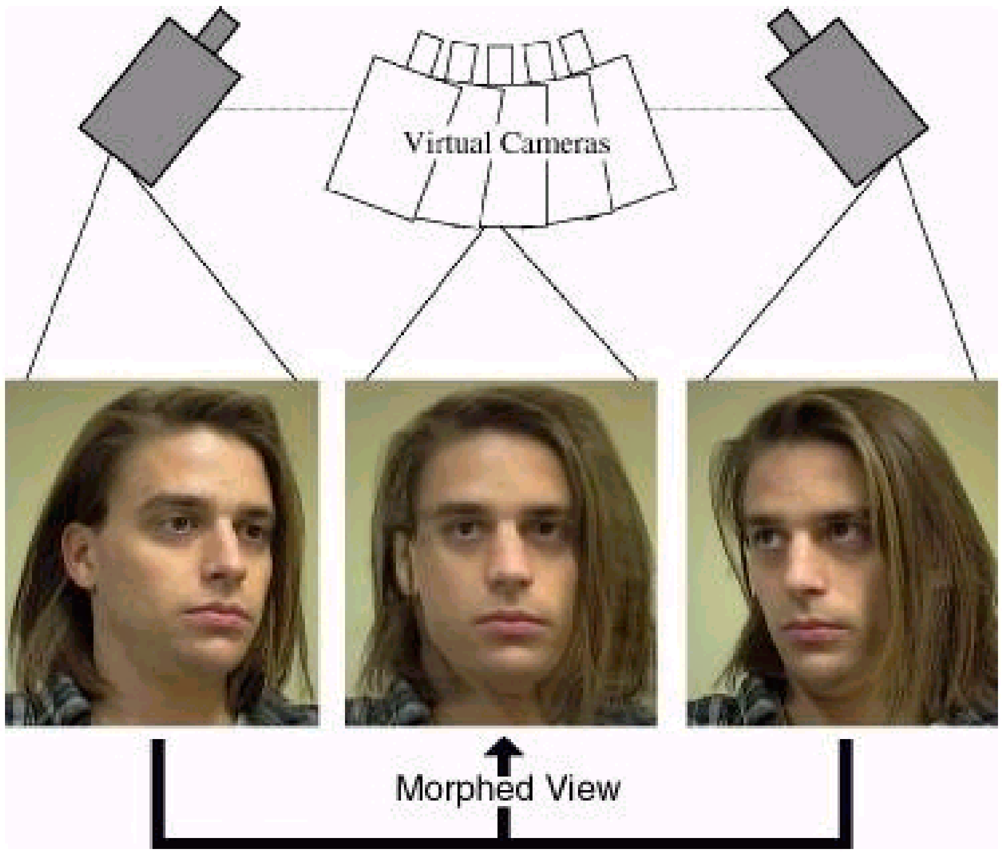

© 2003 Rui Wang

Combining With Modeling



"Visual Simulation of Smoke"
Ronald Fedkiw, Jos Stam, and Henrik Wann Jensen
Proceedings of SIGGRAPH'2001, pages 15-22, Los Angeles, August 2001

Image Based Modeling and Rendering



Display Limitations

Tone Reproductions

Ferwerda, J.A., Pattanaik, S., Shirley, P., and Greenberg, D.P. (1996) A model of visual adaptation for realistic image synthesis. Proceedings SIGGRAPH '96, 249-258.

Photo Modeling