CSCI 420 Computer Graphics
Lecture 18

Global Illumination

BRDFs
Raytracing and Radiosity
Subsurface Scattering
Photon Mapping
[Angel Ch. 11]

Jernej Barbic
University of Southern California
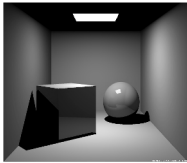
1

1

Global Illumination

- Lighting based on the full scene

- Lighting based on physics (optics)

- Traditionally represented by two algorithms
  – Raytracing – 1980
  – Radiosity – 1984

- More modern techniques include *photon mapping* and many variations of raytracing and radiosity ideas
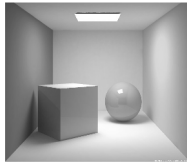
2

2

Direct Illumination vs. Global Illumination

- single (or few) bounces of the light only
- for example, ray casting
- no recursion (or shallow recursion only)
- fast lighting calculations based on light and normal vectors

- reflected, scattered and transmitted light
- many (infinite) number of bounces
- physically based light transport
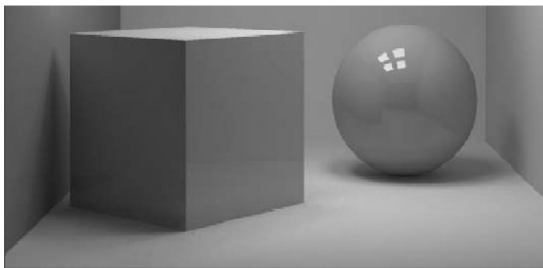
3

3

Indirect Illumination

Color Bleeding

4

4

Soft Shadows

Shadows are much darker where the direct and indirect illuminations are occluded. Such shadows are important for "sitting" the sphere in the scene. They are difficult to fake without global illumination.

5

5

Caustics

- Transmitted light that refocuses on a surface, usually in a pretty pattern

- Not present with direct illumination
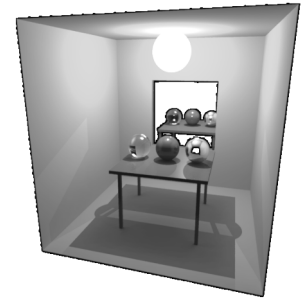

6

6

Light Transport and Global Illumination

- Diffuse to diffuse
- Diffuse to specular
- Specular to diffuse
- Specular to specular
- Ray tracing (viewer dependent)
  - Light to diffuse
  - Specular to specular
- Radiosity (viewer independent)
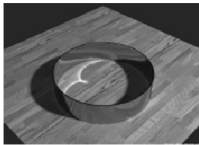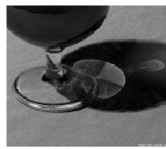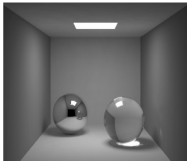 - Diffuse to diffuse

7

7

Path Types

- OpenGL
  - L(D|S)E

- Ray Tracing
  - LDS*E

- Radiosity
  - LD$^+$E

- Path Tracing
  - L(D|S)$^+$E
  - attempts to trace "all rays" in a scene

8

8

Images Rendered With Global Illumination

- Caustics

- Color bleeding

- Area light sources and soft shadows

9

9

Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

10

10

Solid Angle

- 2D angle subtended by object O from point x:
  - Length of projection onto unit circle at x
  - Measured in radians (0 to 2π)
- 3D solid angle subtended by O from point x:
  - Area of of projection onto unit sphere at x
  - Measured in steradians (0 to 4π)
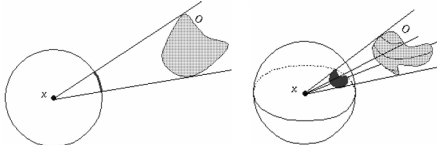
J. Stewart

11

11

Light Emitted from a Surface

- Radiance (*L*): Power (ϕ) per unit area per unit solid angle
  - Measured in W / m^{2}str
  - *dA is projected area* (perpendicular to given direction)

$$L = \frac{d\Phi}{dA\,d\omega}$$

- Radiosity (*B*): Radiance integrated over all directions
  - Power from per unit area, measured in W / m^2

$$B = \int_{\Omega} L(\theta,\phi)\cos\theta\,d\omega$$
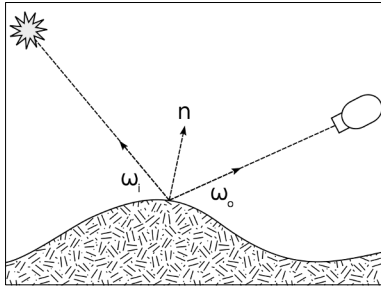
12

12
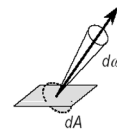
2

Bidirectional Reflectance Distribution Function (BRDF)

If a ray hits a surface point at angle ω_i, how much light bounces into the direction given by angle ω_o?
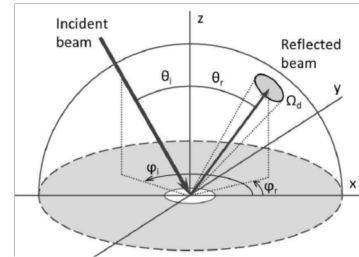
It depends on the type of material.

13

Bidirectional Reflectance Distribution

- General model of light reflection
- Hemispherical function
- 7-dimensional (location, 4 angles, wavelength)

N. Matsapey

14

BRDF Examples

- BRDF is a property of the material

- There is no formula for most materials

- Measure BRDFs for different materials (and store in a table)

Diffuse   Glossy   Mirror
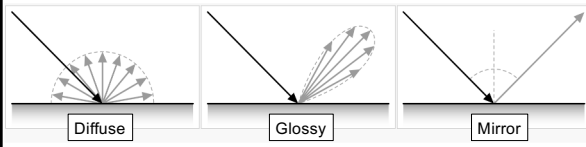
15

Material Examples

Marschner et al. 2000
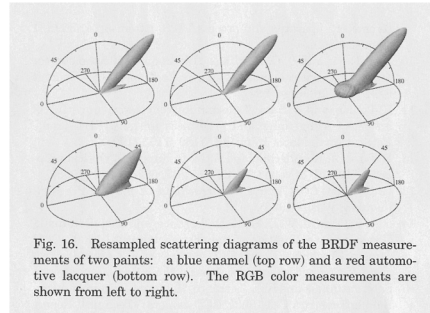
Fig. 16. Resampled scattering diagrams of the BRDF measurements of two paints: a blue enamel (top row) and a red automotive lacquer (bottom row). The RGB color measurements are shown from left to right.

16

Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

18

Raytracing

From: http://jedi.ks.uiuc.edu/~johns/raytracer/raygallery/stills.html

19

3

Raytracing

Albrecht Duerer,
Underweysung der Messung mit dem Zirkel und Richtscheyt
(Nurenberg, 1525), Book 3, figure 67.

20

20

Raycasting vs. Raytracing

Raycasting   Raytracing

21

21

Raytracing: Pros

- Simple idea and nice results

- Inter-object interaction possible
  - Shadows
  - Reflections
  - Refractions (light through glass, etc.)

- Based on real-world lighting

22

22

Raytracing: Cons

- Slow

- Speed often highly scene-dependent

- Lighting effects tend to be abnormally sharp, without soft edges, unless more advanced techniques are used
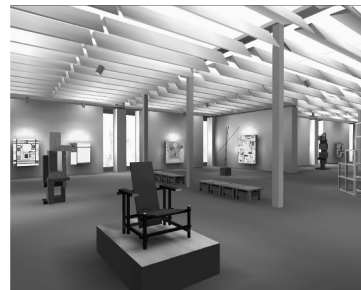
23

23

The Radiosity Method

Cornell University

26

26

Radiosity Example

Museum simulation. Program of Computer Graphics, Cornell University. 50,000 patches. Note indirect lighting from ceiling.

27

27

The Radiosity Method

- Divide surfaces into patches
  (e.g., each triangle is one patch)

- Model light transfer between patches as system
  of linear equations

- Important assumptions:
  - **Diffuse reflection only**
  - No specular reflection
  - No participating media (no fog)
  - No transmission (only opaque surfaces)
  - Radiosity is constant across each patch
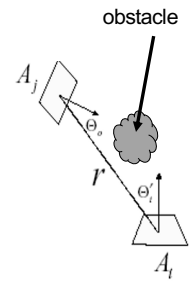 - Solve for R, G, B separately

28

The Radiosity Form Factor

$$F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{V_{ij} \cos\phi_i \cos\phi_j}{\pi r^2} dA_j dA_i$$

F_{ij} is dimensionless

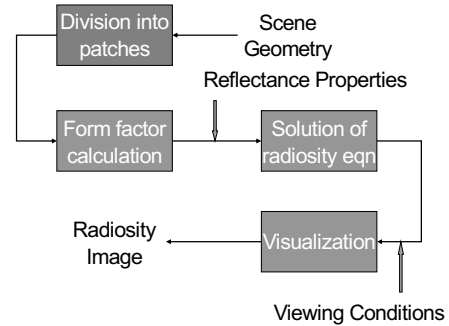V_{ij} = 0 if occluded
1 if not occluded
(visibility factor)

obstacle

29

Radiosity Equation

- For each patch i: $B_i = E_i + \rho_i \sum_j (F_{ji} A_j / A_i) B_j$

- Variables   *ou*

  - B_i = radiosity (unknown)
  - E_i = emittance of light sources (given; some patches are
        light sources)
  - ρ_i = reflectance (given)
  - F_{ij} = form factor from i to j (computed)
        fraction of light emitted from patch i arriving at patch j
  - A_i = area of patch i (computed)

30

(Idealized) Radiosity Computation

Division into patches

Scene Geometry

Reflectance Properties

Form factor calculation

Solution of radiosity eqn

Radiosity Image

Visualization

Viewing Conditions

31

Radiosity: Pros

- Can change camera position and re-render
  with minimal re-computation

- Inter-object interaction possible
  - Soft shadows
  - Indirect lighting
  - Color bleeding

- Accurate simulation of energy transfer

32

Radiosity: Cons

- Precomputation must be re-done if *anything*
  moves

- Large computational and storage costs

- Non-diffuse light not represented
  - Mirrors and shiny objects hard to include

- Lighting effects tend to be "blurry" (not sharp)

- Not applicable to procedurally defined surfaces

33

Rendering Equation

$$L(\mathbf{x},\omega) = E(\mathbf{x},\omega) + \int f_r(\mathbf{x},\omega,\omega')G(\mathbf{x},\mathbf{x}')V(\mathbf{x},\mathbf{x}')L(\mathbf{x}',\omega')dA'$$

- L is the radiance from a point x on a surface in a given direction ω

- E is the emitted radiance from a point: E is non-zero only if x is emissive

- V is the visibility term: 1 when the surfaces are unobstructed along the direction ω, 0 otherwise

- G is the geometry term, which depends on the geometric relationship (such as distance) between the two surfaces x and x'

- It includes contributions from light bounced many times off surfaces

- f_r is the BRDF

34

34

Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

35

35

Subsurface Scattering

- Translucent objects: skin, marble, milk

- Light penetrates the object, scatters and exits

- Important and popular in computer graphics

36

36

Subsurface Scattering
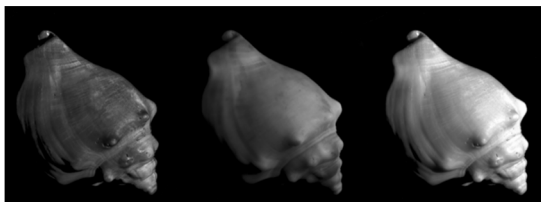
- Jensen et al. 2001

Using only BRDF   With subsurface light transport

37

37

Subsurface Scattering

direct only   subsurface scattered only   combined

Source: Wikipedia

38

38

Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

39

39

Photon Mapping

From http://graphics.ucsd.edu/~henrik/images/global.html

40
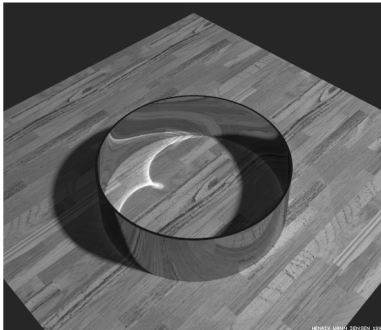
40

Photon Mapping Example

224,316 caustic photons, 3095 global photons
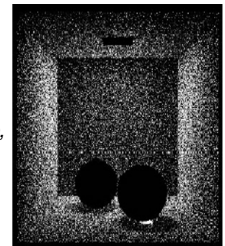
41

41

Photon Mapping Example

42

42

Photon Map

- "Photons" are emitted (raytraced) from light sources

- Photons either bounce or are absorbed

- Photons are stored in a *photon map,* with both position and incoming direction

- Photon map is decoupled from the geometry (often stored in a kd-tree)

Photon Map

43

43

Rendering with the Photon Map

- Raytracing step uses the closest *N* photons to each ray intersection and estimates the outgoing radiance

- Specular reflections can be done using "usual" raytracing to reduce the number of photons needed

- Numerous extensions to the idea to add more complex effects

44

44

Photon Mapping Assessment

- Enhancement to raytracing

- Can simulate caustics

- Can simulate diffuse inter-reflections (e.g., the "bleeding" of colored light from a red wall onto a white floor, giving the floor a reddish tint)

- Can simulate clouds or smoke

45

45

7

Photon Mapping: Pros

- The photon map is view-independent, so only needs to be re-calculated if the lighting or positions of objects change

- Inter-object interaction includes:
  - Shadows
  - Indirect lighting
  - Color bleeding
  - Highlights and reflections
  - Caustics – *current method of choice*

- Works for procedurally defined surfaces

46

46

Photon Mapping: Cons

- Still time-consuming, although not as bad as comparable results from pure raytracing

- Photon map not easy to update if small changes are made to the scene

47

47

Summary

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

48

48