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

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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

Source: Dianne Hansford,
Arizona State Univ.

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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

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Indirect Illumination

Color Bleeding

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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.

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Caustics

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

- Not present with direct illumination
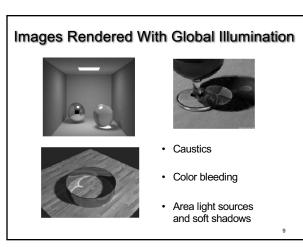

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Light Transport and Global Illumination

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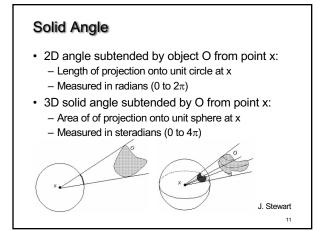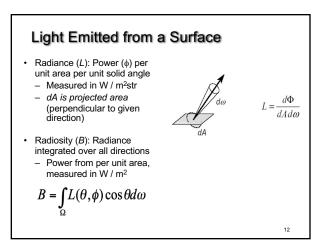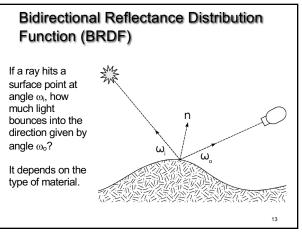- Radiosity (viewer independent)
  - Diffuse to diffuse

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Path Types

- OpenGL
  - L(D|S)E

- Ray Tracing
  - L(D|S)S*E

- Radiosity
  - LD+E

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

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Images Rendered With Global Illumination

- Caustics

- Color bleeding

- Area light sources and soft shadows

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Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

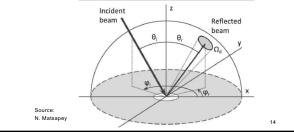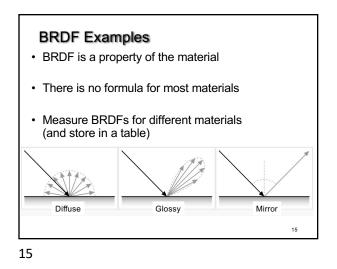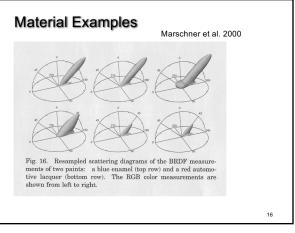10

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

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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)

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

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

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

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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.

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Bidirectional Reflectance Distribution

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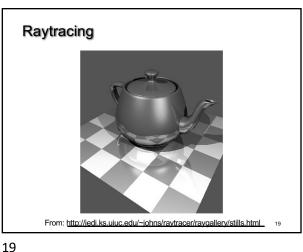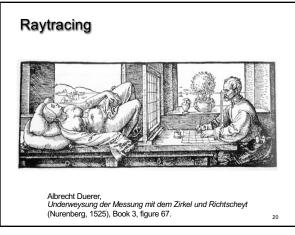- 7-dimensional (location, 4 angles, wavelength)

Source: N. Matsapey

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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

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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.

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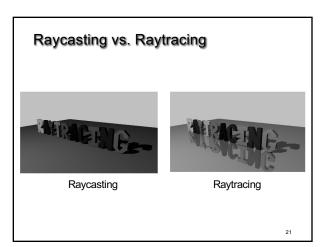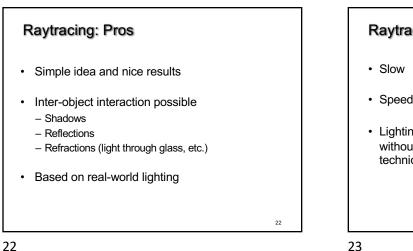## Outline

- Direct and Indirect Illumination

- Bidirectional Reflectance Distribution Function

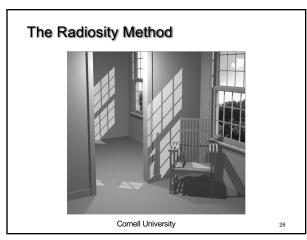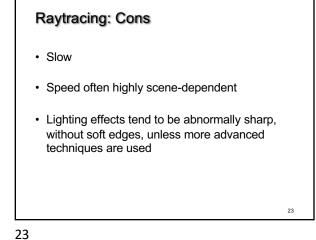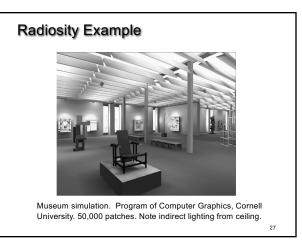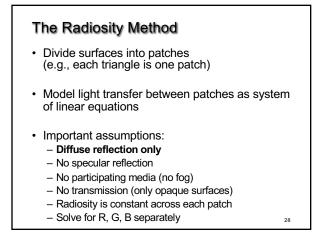- Raytracing and Radiosity

- Subsurface Scattering

- Photon Mapping

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Raytracing

From: http://jedi.ks.uiuc.edu/~johns/raytracer/raygallery/stills.html   19

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Raytracing

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

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Raycasting vs. Raytracing

Raycasting   Raytracing

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Raytracing: Pros

- Simple idea and nice results

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

- Based on real-world lighting

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Raytracing: Cons

- Slow

- Speed often highly scene-dependent

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

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The Radiosity Method

Cornell University   26

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Radiosity Example

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

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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

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The Radiosity Form Factor

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

obstacle

F_{ij} is dimensionless

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

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Radiosity Equation

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

- Variables
  - 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)

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(Idealized) Radiosity Computation

Division into patches

Scene Geometry
Reflectance Properties

Form factor calculation

Solution of radiosity eqn

Radiosity Image

Visualization

Viewing Conditions

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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

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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)

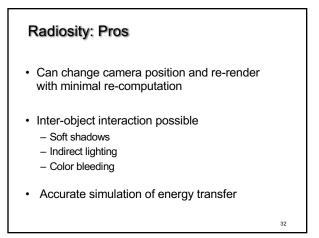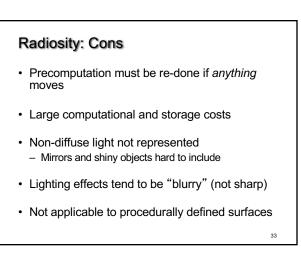- Not applicable to procedurally defined surfaces

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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

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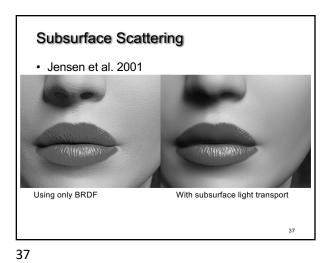- Raytracing and Radiosity
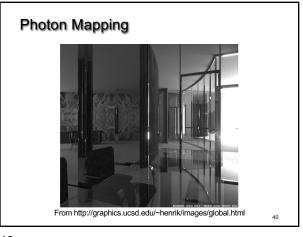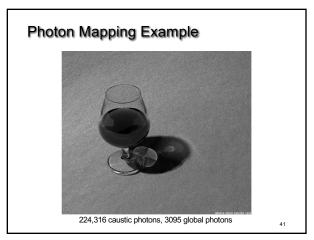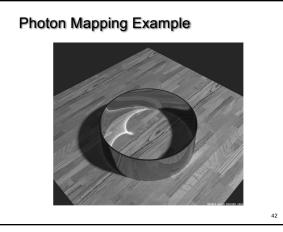
- Subsurface Scattering

- Photon Mapping

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Subsurface Scattering

- Translucent objects: skin, marble, milk

- Light penetrates the object, scatters and exits

- Important and popular in computer graphics

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Subsurface Scattering

- Jensen et al. 2001

Using only BRDF   With subsurface light transport

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Subsurface Scattering

direct only   subsurface scattered only   combined

Source: Wikipedia

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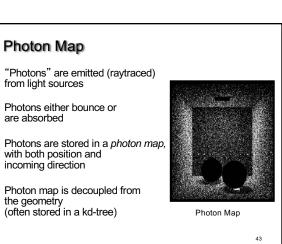
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Photon Mapping

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

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Photon Mapping Example

224,316 caustic photons, 3095 global photons

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Photon Mapping Example

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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

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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

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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

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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

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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

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Summary

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