CSC418 Computer Graphics

- Raytracing
- Shadows
- Global Illumination

Local vs. Global Illumination

Local Illumination Models
- e.g. Phong
- Model source from a light reflected once off a surface towards the eye
- Indirect light is included with an ad hoc “ambient” term which is normally constant across the scene

Global Illumination Models
- e.g. ray tracing or radiosity (both are incomplete)
- Try to measure light propagation in the scene
- Model interaction between objects and other objects and objects and their environment
All surfaces are not created equal

- Specular surfaces
  - e.g. mirrors, glass balls
  - An idealized model provides ‘perfect’ reflection
    - Incident ray is reflected back as a ray in a single direction
    - No scattering (unrealistic)

- Diffuse surfaces
  - e.g. flat paint, chalk
  - Lambertian surfaces
  - Incident light is scattered in all directions
    - Also unrealistic for most surfaces

Categories of light transport

- Specular-Specular
- Specular-Diffuse
- Diffuse-Diffuse
- Diffuse-Specular
Real surfaces are more complex...

Reflectance: BRDF

Bidirectional
Reflectance
Distribution
Function

general

Ray Tracing

- Traces path of specularly reflected or transmitted (refracted) rays through environment
- Rays are infinitely thin
- Don’t disperse
- Signature: shiny objects exhibiting sharp, multiple reflections
Ray Tracing

- Unifies in one framework
  - Hidden surface removal
  - Shadow computation
  - Reflection of light
  - Refraction of light
  - Global specular interaction

Raytracing slides borrowed from...

Ray Tracing — Some Slides

All images by Michael Sweeney
with the help of David Forsey,
David Martindale, and Robert Krieger

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In Ray Tracing, a virtual screen and a virtual viewpoint are defined in the same coordinate system as the objects to be rendered.
A line ("ray") is projected from the viewpoint through every pixel in this screen, and on into the object space.

Ray does not intersect objects
This ray is tested for intersection against every object in the scene. If no object is hit, you see:

...... background.
Otherwise, you see the closest object to the viewpoint.
Ray hits object
If an object is hit, a ray is projected from the intersection point towards the simulated light source.

Shadow test
If this ray hits another object on its way, the intersection point is in shadow.

Point in shadow

- With a simple lighting model, apply the ambient term for the shadow region
If the object happens to be reflective, a "secondary ray" is projected from the intersection point (angle of incidence equals angle of reflection).
Reflected ray is sent out from intersection point

Reflected ray has hit object

- Local illumination model calculated where ray intersects with second object
- Result carried back to origin of ray on first object, contributes to object’s colour
If the object is transparent, the secondary ray is projected in the direction indicated by the index of refraction.

Transmitted ray generated for transparent objects
Transmitted ray hit object

- Local illumination model calculated where the ray hit object
- Result carried back to the point of first intersection

Of course, if the secondary ray hits something reflective, tertiary rays are generated. And so on, and so on, and so on....
No reflection

Single reflection
Double reflection

Ray Tracing Deficiencies

- Local specular illumination model spreads rays in specular reflection, but global model doesn’t
- Ignores major light transport mechanisms
  - Interaction of diffuse surfaces
- Intersection computation time is very long
Ray Tracing Efficiency Improvements

- Bounding volumes
- Spatial subdivision
  - Octrees
  - SEADS
  - BSP

Ray Tracing Improvements: Image Quality

- Backwards ray tracing
  - Trace from the light to the surfaces and then from the eye to the surfaces
  - “shower” scene with light and then collect it
  - “Where does light go?” vs “Where does light come from?”
  - Good for caustics
Ray Tracing Improvements: Image Quality

- Cone tracing
  - Models some dispersion effects
- Distributed Ray Tracing
  - Super sample each ray
  - Blurred reflections, refractions
  - Soft shadows
  - Depth of field
  - Motion blur

Radiosity

- Diffuse interaction within a closed environment
- Theoretically sound
- View independent
- No specular interactions
Global Illumination

Examining Radiosity

Direct light is only part of the story

The illumination at a given point in the environment is a combination of the light received directly from a light source and the light which is reflected one or more times from the surfaces of the environment.
Ambient light

The ambient light in the upper-right image is approximated by a constant value. This is typical of most sampling algorithms. The middle and lower-left images were rendered with a ray tracing global illumination algorithm.

The middle image was rendered with no ambient light calculations. The lower-left image was rendered with several levels of diffuse re-reflection to give a better approximation of the ambient light in this scene.

Lambertian Reflection and Colour Bleeding

Light striking a surface is reflected in all directions, following the Lambertian reflection model. This diffuse reflection of light leads to color bleeding, as light striking a surface carries that surface's color into the environment.
Radioisity

What is Radiosity?

The radiosity of a surface is the rate at which energy leaves that surface (energy per unit time per unit area). It includes the energy emitted by a surface as well as the energy reflected from other surfaces.

Techniques of modeling the transfer of energy between surfaces based upon radiosity were first used in analyzing heat transfer between surfaces in an enclosed environment. The same techniques can be used to analyze the transfer of radiant energy between surfaces in computer graphics.

Radiosity methods allow the intensity of radiant energy arriving at a surface to be computed. These intensities can then be used to determine the shading of the surface.

Radioisity Equation

The Radiosity Equation

\[ B_i = E_i + \rho_i \sum B_j F_{ij} \]

- \( B_i \) = Radiosity of surface \( i \)
- \( E_i \) = Emissivity of surface \( i \)
- \( \rho_i \) = Reflectivity of surface \( i \)
- \( B_j \) = Radiosity of surface \( j \)
- \( F_{ij} \) = Form Factor of surface \( j \) relative to surface \( i \)

\[ \sum B_j F_{ij} \] (energy reaching this surface from other surfaces)

\[ E_i \] (energy emitted by this surface)

\[ \rho_i \sum B_j F_{ij} \] (energy reflected by this surface)
The Form Factor

The form factor is defined as the fraction of energy leaving one surface that reaches another surface. It is a purely geometric relationship, independent of viewpoint or surface attributes.

Between differential areas, the form factor equals:

\[ F \ dA_i \ dA_j = \frac{\cos \phi_i \cos \phi_j}{\pi |r|^2} \]

- \( dA_i, dA_j \) = differential area of surface \( i, j \)
- \( r \) = vector from \( dA_i \) to \( dA_j \)
- \( \phi_i \) = angle between Normal \( i \) and \( r \)
- \( \phi_j \) = angle between Normal \( j \) and \( r \)

The overall form factor between \( i \) and \( j \) is found by integrating:

\[ F_{ij} = \frac{1}{A_i} \int \int \frac{\cos \phi_i \cos \phi_j}{\pi |r|^2} \ dA_i \ dA_j \]

Techniques for Calculating Form Factors

Nusselt developed a geometric analog to the differential form factor, to aid in form factor calculations. The "Nusselt analog" is shown here in two and three dimensions.

In both diagrams, the form factor equals the projected area divided by the area of the base, or \( A / B \).
Techniques for Calculating Form Factors

THE HEMICUBE APPROXIMATION

- The contribution of each cell on the surface of the hemicube to the form factor value is computed. This is the delta form factor for each cell.
- The polygon is projected onto the hemicube.
- The delta form factors for the covered cells are summed to get the approximation to the true form factor.

The "full matrix" radiosity solution requires form factors between each surface to be calculated, and the following equation to be solved:

\[
\begin{bmatrix}
1 - \rho_1 F_{11} & -\rho_1 F_{12} & \cdots & -\rho_1 F_{1n} \\
-\rho_2 F_{21} & 1 - \rho_2 F_{22} & \cdots & -\rho_2 F_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
-\rho_m F_{m1} & -\rho_m F_{m2} & \cdots & 1 - \rho_m F_{mn}
\end{bmatrix}
\begin{bmatrix}
B_1 \\
B_2 \\
\vdots \\
B_m
\end{bmatrix}
=
\begin{bmatrix}
E_1 \\
E_2 \\
\vdots \\
E_m
\end{bmatrix}
\]

- \(\rho_i\) is the reflectivity of surface \(i\).
- \(F_{ij}\) is the form factor from surface \(i\) to surface \(j\).
- \(B_i\) is the radiosity of surface \(i\), and
- \(E_i\) is the emission of surface \(i\).
The “progressive” radiosity solution provides an incremental method, at each step requiring form factors from one surface to all others to be calculated:

for each iteration:
   select a surface $i$
   calculate $F_{ij}$ for all surfaces $j$
   for each surface $j$:
      update radiosity of surface $j$
      update emission of surface $j$
      set emission of surface $i$ to zero

PROGRESSIVE SOLUTION
The above images show increasing levels of global diffuse illumination. From left to right: 0 bounces, 1 bounce, 3 bounces.
Where to next?

- The general rendering equation (not part of this course!)
- Next class…Curves and Surfaces