15-462 Computer Graphics I
Lecture 19

Global Illumination

Substructuring
Progressive Refinement
Bidirectional Reflectance Dist. Fcn.
Combining Radiosity and Ray Tracing
[Angel, Ch 13.5]

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http://www.cs.cmu.edu/~fp/courses/graphics/

Classical Radiosity Method

- Divide surfaces into patches
- Model light transfer between patches as system of linear equations
- Important assumptions (so far):
  - Reflection and emission are diffuse
  - No participating media (no fog)
  - No transmission (only opaque surfaces)
  - Radiosity is constant across each patch
  - Solve for R, G, B separately

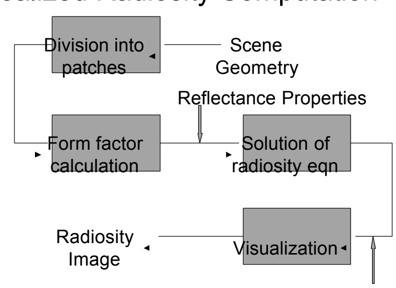
Radiosity Equation

- For each patch i:

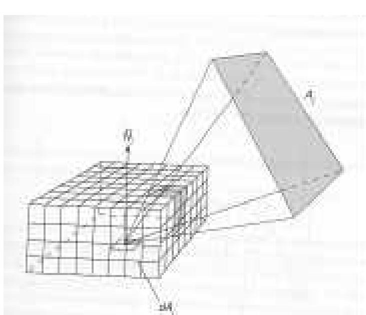
$$\begin{aligned} B_i &= E_i + \rho_i \sum_j (F_{ji} A_j / A_i) B_j \\ &= E_i + \rho_i \sum_j F_{ij} B_j \end{aligned}$$

- Variables
  - B_i = radiosity (unknown)
  - E_i = emittance of light sources (given)
  - ρ_i = reflectance (given)
  - $F_{i\,j}$ = 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)

Idealized Radiosity Computation



Form Factors via Hemicubes



R. Ramamoorthi

Outline

- Substructuring
- Progressive Refinement
- Bidirectional Reflectance Distribution Function
- Combining Radiosity and Ray Tracing

Substructuring

- Radiosity assumed constant across patch
- Impact of number of patches
  - Few: fast, but very inaccurate (blocky)
  - Many: slow $O(n^2)$, but much more accurate
- Substructuring
  - Introduce elements as a substructure for patches
  - Use adaptively where radiosity varies rapidly
  - Distinguish elements and patches to avoid explosion

Elements vs. Patches

- Analyse transport from patch onto elements
- Do not analyze element-to-element detail
- This means
  - Compute form factors from elements to patches
  - Do not compute form factors from patches to elements
  - Use weighted patch to parent-of-element
  - Complexity $O(m \cdot n)$ for m elements, n patches
- Typically substructured areas
  - Near lights
  - Shadow boundaries

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Matrix Radiosity Revisited

- Compute all form factors $F_{i\,j}$
- Make initial approximation to radiosity
  - Emitting elements $B_i = E_i$
  - Other elements $B_i = 0$
- Apply equation to get next approximation

$$B_i' = E_i + \rho_i \sum_j F_{ij} B_j$$

- Iterate with new approximation
- Intuitively
  - Gather incoming light for each element i
  - Base new estimate on previous estimate

Progressive Refinement

- Shoot light instead of gathering light
- Basic algorithm
  - Initialize emitting element with $B_i = E_i$
  - Initialize others with with $B_i = 0$
  - Pick source i (start with brightest)
  - Using hemicube around source, calculate $F_{i\,j}$
  - For each $j \neq i$, approximate $B'_j = \rho_j B_i F_{i\,j} (A_i / A_j)$
  - Pick next source i and iterate until convergence
- Each iteration is $O(n)$
- May or may not keep $F_{i\,j}$ after each iteration

Progressive Refinement Corrected

- Problem: double-count if source is used more than once as source
- Solution: compute and use difference from last time a patch was used as a source (ΔB_i)
  - Initialize ΔB_i, $B_i = E_i$
  - Pick source i with maximum unshot power
  - Using hemicube, calculate $F_{i\,j}$ for each j
    - $\Delta R = \rho_j \Delta B_i \; F_{i\,j} (A_i / A_j)$
    - $B_j = B_j + \Delta R$
    - $\Delta B_j = \Delta B_j + \Delta R$
  - $\Delta B_i = 0$

Some Special Cases

- Image after we have iterated through all light sources?
  - Shadows, but no interreflections
- Can incrementally display image while iterating
  - Add ambient light at each stage for visibility
  - Ambient shading if progressively refined
- Incremental form factor computation

Radiosity Algorithms Summary

- Matrix radiosity algorithm
  - Pre-compute all form factors
  - Iterative solution (Gauss-Seidel)
    - Start with emission
    - Each objects gathers light from all other objects
- Progressive refinement
  - Pick brightest patch
  - Compute outgoing form factors
  - Shoot light from this patch to all other patches
  - Repeat for next brightest batch
- Combine substructuring and progressive refnt.

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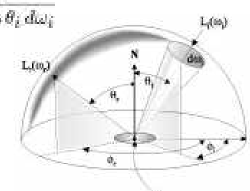
Bidirectional Reflectance Distribution

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

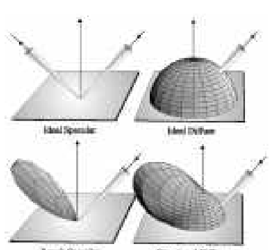
$$f(\omega_i \to \omega_r) = \frac{L_r(\omega_r)}{L_i(\omega_i)\,\cos\theta_i\,d\omega_i}$$



A. Wilkie

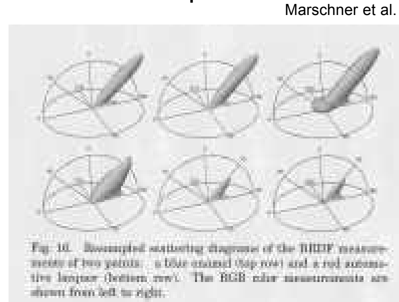
BRDF Examples

- Measure BRDFs for different materials



Material Examples

Marschner et al. 2000



BRDF Isotropy

- Rotation invariance of BRDF
- Reduces 4 angles to 2
- Holds for a wide variety of surfaces
- Anisotropic materials
  - Brushed metal
  - Others?
- How many parameters for
  - Ideal specular?
  - Ideal diffuse?

Subsurface Light Transport

- Jensen et al. 2001

Using only BRDF With subsurface light transport

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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
- Inherent limitations

Specular Radiosity

- Diffuse radiosity
  - Light reflected equally in all directions
  - Relationship between patches limited to form factor
- Specular radiosity
  - Retain viewer independence (unlike ray tracing)
  - Light reflected differently in different directions
  - For each source and each direction, need to calculation interaction
  - Not practical

Two-Pass Approach

- View-dependent specular is tractable
- View-independent diffuse is tractable
- First pass view independent
  - Enhanced radiosity
- Second pass is view dependent
  - Enhanced ray tracing

Pass 1: Enhanced Radiosity

- Diffuse transmission (translucent surfaces)
  - Backwards diffuse form factor
- Specular transmission
  - Extended form factor computation
  - Consider occluding translucent surfaces
  - Window form factor
- Specular reflection
  - Create “virtual” (mirror-image) environment
  - Use specular transmission technique
  - Mirror form factor

Pass 1 Result

- Account only for one specular reflection between surfaces (diffuse-specular-diffuse)
- Accurate diffuse component
- Solve enhanced radiosity equation as before
- Viewer independent solution

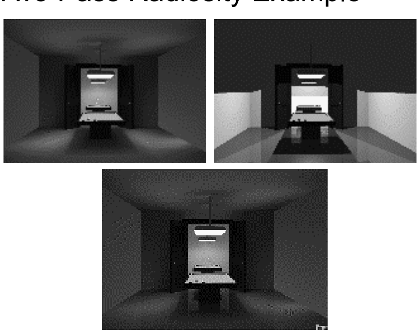
Pass 2: Enhanced Ray Tracing

- Classical ray tracing
  - Specular to specular light transport
- For diffuse-to-specular transport:
  - Should integrate incoming light over hemisphere
  - Approximate by using small frustum in direction of ideal reflection
  - Use radiosity of pixels calculated in Pass 1
  - Apply recursively if visible surface is specular

Two-Pass Global Illumination

- Still several approximating assumptions
- Appropriate for scenes with few specular reflecting or transmitting surfaces
- More expensive than already expensive methods
- Photon Mapping: another two-pass algorithm

Two-Pass Radiosity Example



Photon Mapping Example

Jensen 1996

Summary

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Preview

- Tuesday: Scientific Visualization