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 $i$:
  \[
  B_i = E_i + \rho_i \sum_j \left( \frac{F_{ij} A_j}{A_i} \right) B_j \\
  = E_i + \rho_i \sum_j F_{ij} B_j
  \]

- **Variables**
  - $B_i = \text{radiosity (unknown)}$
  - $E_i = \text{emittance of light sources (given)}$
  - $\rho_i = \text{reflectance (given)}$
  - $F_{ij} = \text{form factor from i to j (computed)}$
    - fraction of light emitted from patch i arriving at patch j
  - $A_i = \text{area of patch i (computed)}$
Idealized Radiosity Computation

- Division into patches
- Form factor calculation
- Solution of radiosity eqn
- Radiosity Image
- Visualization
- Scene Geometry
- Reflectance Properties
- Viewing Conditions
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
Outline

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Matrix Radiosity Revisited

• Compute all form factors $F_{ij}$
• 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 $F_{ij}$
  – For each $j \neq i$, approximate $B'_j = \rho_j B_i F_{ij} (A_i / A_j)$
  – Pick next source $i$ and iterate until convergence
• Each iteration is $O(n)$
• May or may not keep $F_{ij}$ 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 ($\Delta B_i$)
  - Initialize $\Delta B_i$, $B_i = E_i$
  - Pick source $i$ with maximum unshot power
  - Using hemicube, calculate $F_{ij}$ for each $j$
    - $\Delta R = \rho_j \Delta B_i \ F_{ij} (A_i / A_j)$
    - $B_j = B_j + \Delta R$
    - $\Delta B_j = \Delta B_j + \Delta R$
  - $\Delta B_i = 0$
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 refmt.
Outline

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Bidirectional Reflectance Distribution

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

\[
f(\omega_i \rightarrow \omega_r) = \frac{L_r(\omega_r)}{L_i(\omega_i) \cos \theta_i \ d\omega_i}
\]

A. Wilkie
BRDF Examples

- Measure BRDFs for different materials
Material Examples

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.
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 vs. 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