Global Illumination

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:
  \[ B_i = E_i + \rho_i \sum_j (F_{ij} A_j / A_i) B_j \]
  \[ = E_i + \rho_i \sum_j F_{ij} B_j \]

- Variables
  - \( B_i \) = radiosity (unknown)
  - \( E_i \) = emittance of light sources (given)
  - \( \rho_i \) = 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)

Idealized Radiosity Computation

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

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
  \[ B_i^{(l)} = E_i + \sum_j F_{ij}B_j \]
- 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 \(B_j^{(l)} = \rho_j B_i F_{ij} (A_i / A_j)\)
  - 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 \(j\)
    - \(\Delta R = \rho_i \Delta B_i F_{ij} (A_i / A_j)\)
    - \(B_i = B_i + \Delta R\)
    - \(\Delta B_i = \Delta B_i + \Delta R\)
  - \(\Delta B_i = 0\)
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 object 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.

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

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

\[
f(\omega_i \rightarrow \omega_f) = \frac{L_i(\omega_i)}{L_i(\omega_i) \cos \theta_i} \, \cos \theta_f \, d\omega_i
\]

BRDF Examples
- Measure BRDFs for different materials

Material Examples
Marschner et al. 2000

Fig. 16. Assumed scattering diagram of the BRF measurements of two patches: a blue-colored (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

Outline

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

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 calculate 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

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

Preview

• Tuesday: Scientific Visualization