

15-462 Computer Graphics I

Lecture 19

Global Illumination

Substructuring
Progressive Refinement
Bidirectional Reflectance Dist. Fcn.
Combining Radiosity and Ray Tracing
Handout: [Watt & Watt, Ch 12]

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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

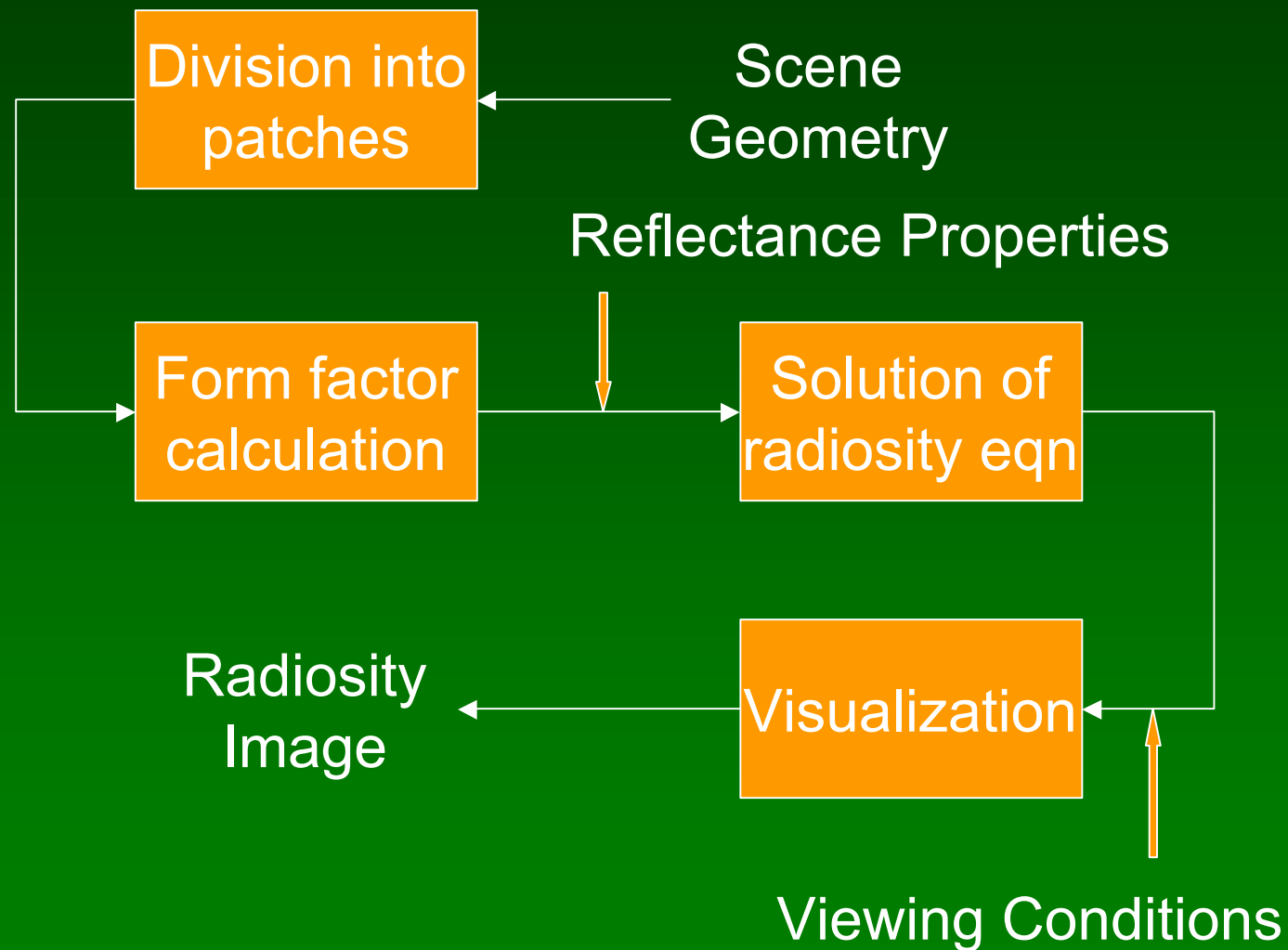
- For each patch i:

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

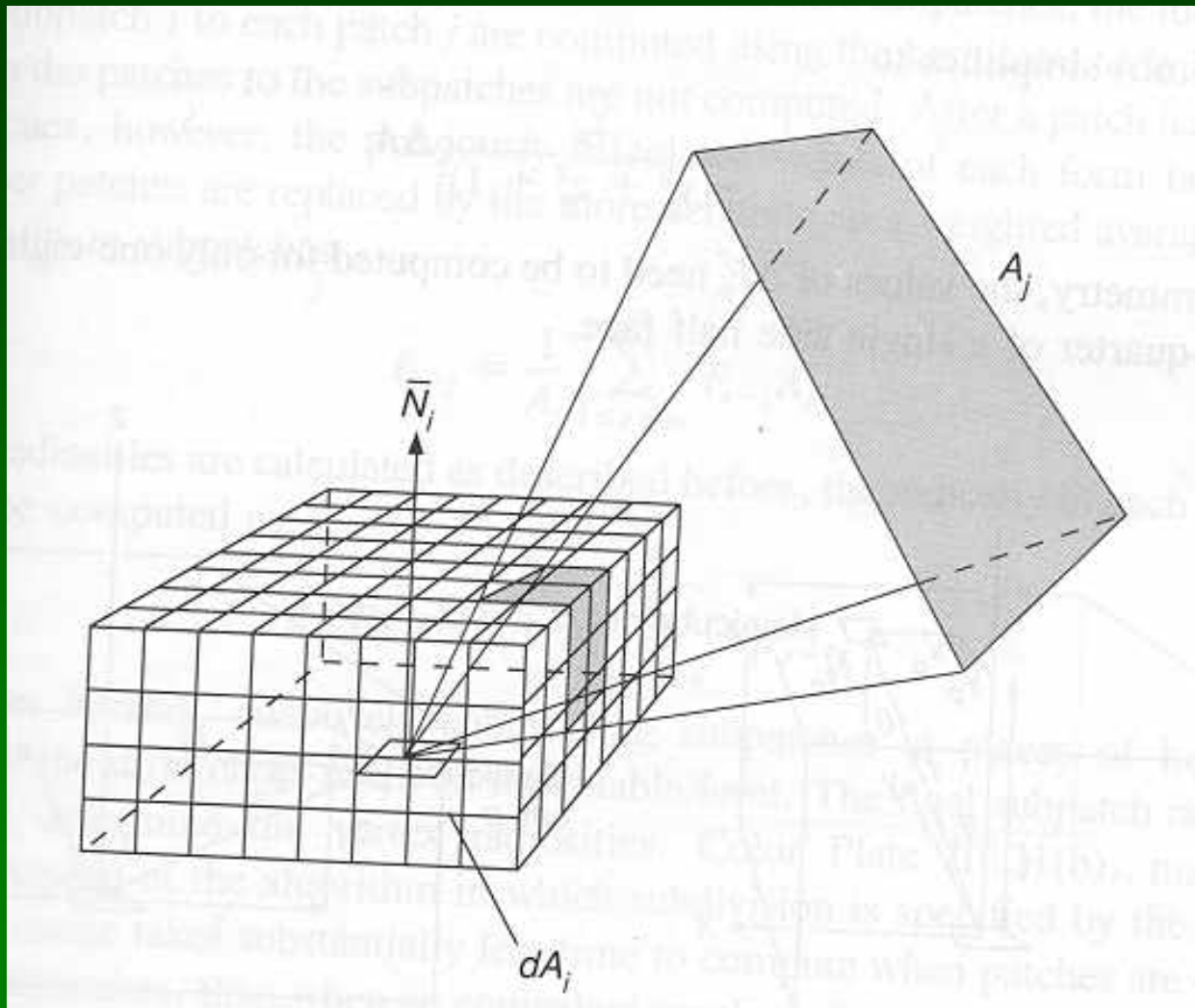
- Variables

- B_i = **radiosity** (unknown)
- E_i = **emittance** of light sources (given)
- ρ_i = **reflectance** (given)
- F_{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



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

- Substructuring
- **Progressive Refinement**
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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 $B_i = 0$
 - 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 (ΔB_i)
 - Initialize ΔB_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 refnt.

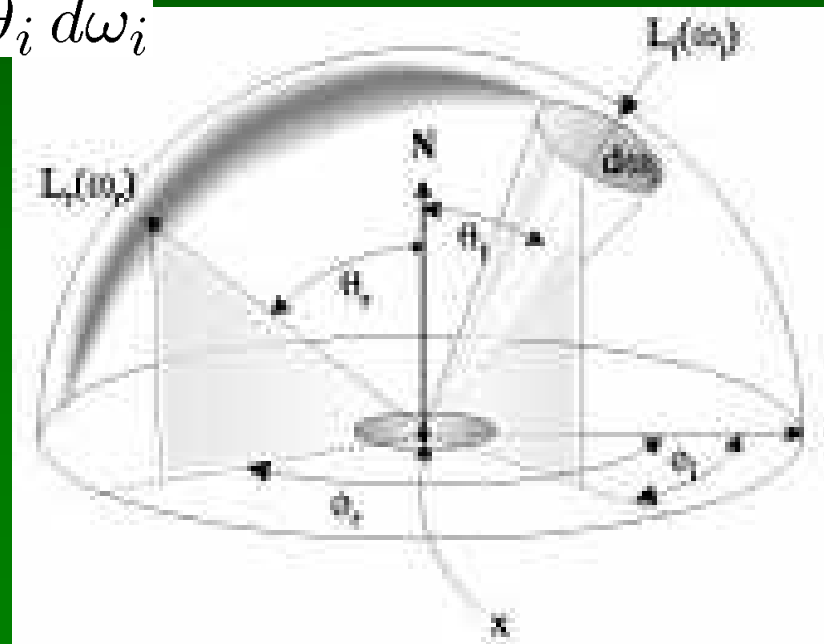
Outline

- 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)

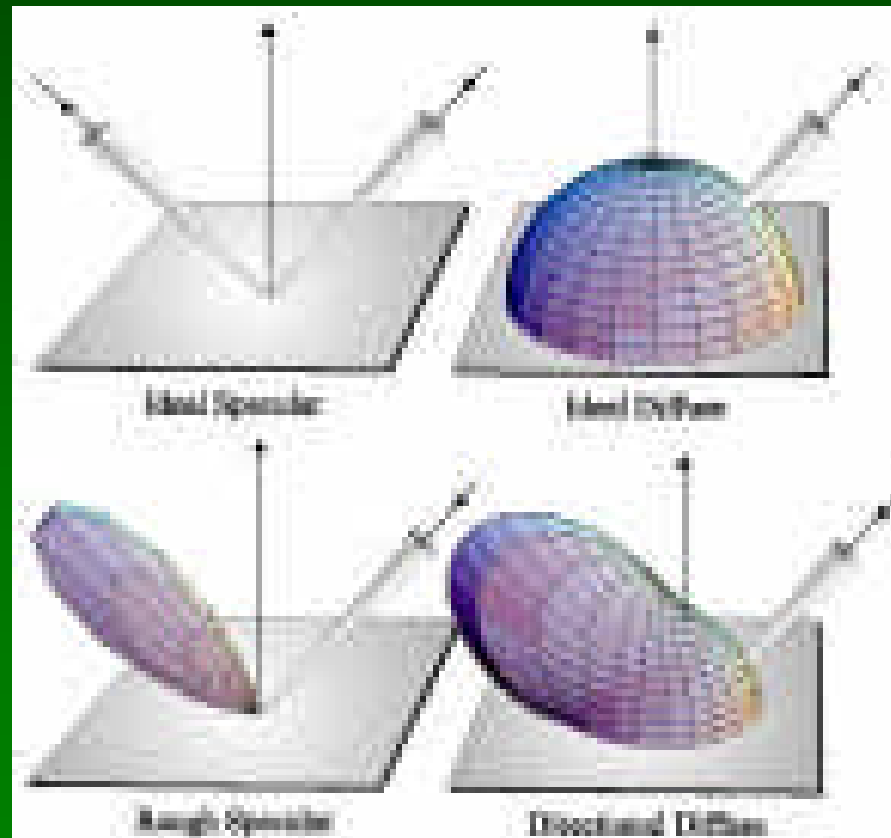
$$f(\omega_i \rightarrow \omega_r) = \frac{L_r(\omega_r)}{L_i(\omega_i) \cos \theta_i d\omega_i}$$



A. Wilkie

BRDF Examples

- Measure BRDFs for different materials



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?

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- **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 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

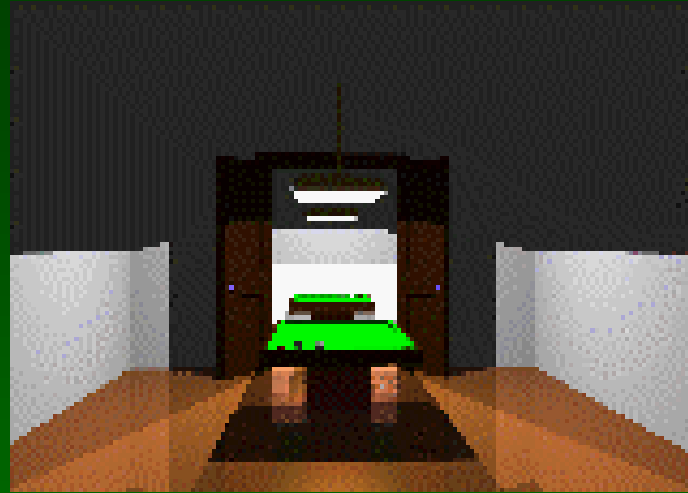
Pass 2: Enhanced Ray Tracing

- 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

Two-Pass Radiosity Example



Summary

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

Preview

- Tuesday: Guest Lecture by *Steve Sullivan*
 - <http://www.evenhouse.com/sullivan/>
 - Works at Industrial Light + Magic (ILM)
<http://www.ilm.com/>
- Next Lecture: Image Processing (tentative)