Radiosity

COS 526, Fall 2010

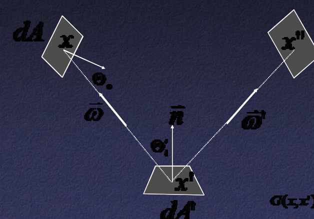
Radiosity

Overview

- Radiosity equation
- Solution methods
  - Computing form factors
  - Selecting basis functions for radiosities
  - Solving linear system of equations
  - Meshing surfaces into elements
  - Rendering images

Rendering Equation

$$L(x'\rightarrow x'') = L_e(x'\rightarrow x'') + \int_S f_r(x\rightarrow x'\rightarrow x'')L(x\rightarrow x')V(x,x')G(x,x')\,dA$$



$$G(x,x') = \frac{\cos\Theta'_i \cos\Theta_o}{\|x-x'\|^2}$$

Radiosity Equation

$$L(x'\rightarrow x'') = L_e(x'\rightarrow x'') + \int_S f_r(x\rightarrow x'\rightarrow x'')L(x\rightarrow x')V(x,x')G(x,x')\,dA$$

Assume everything is Lambertian

$$f_r(x\rightarrow x'\rightarrow x'') = \rho(x')/\pi$$

$$L(x') = L_e(x') + \frac{\rho(x')}{\pi}\int_S L(x)V(x,x')G(x,x')\,dA$$

Convert to Radiosities

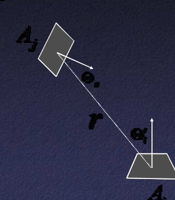
$$B = \int_\Omega L_o \cos\theta\, d\omega \qquad B = \pi L$$

$$B(x') = B_e(x') + \rho(x')\int_S B(x)V(x,x')G(x,x')\,dA$$

Radiosity Approximation

$$B(x') = B_e(x') + \rho(x')\int_S B(x)V(x,x')G(x,x')\,dA$$

Discretize surfaces into elements



$$B_i = E_i + \rho_i \sum_{j=1}^{N} B_j F_{ij}$$

where $F_{ij} = \frac{1}{A_i}\int_{A_i}\int_{A_j} \frac{V_{ij}\cos\Theta'_i \cos\Theta_o}{\pi r^2}\, dA_j\, dA_i$

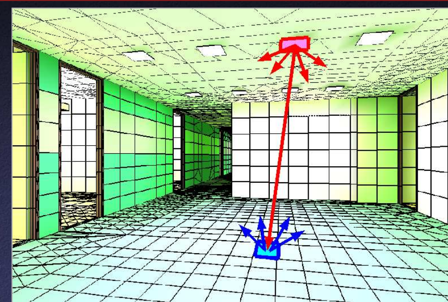
System of Equations

$$B_i = E_i + \rho_i \sum_{j=1}^{N} B_j F_{ij}$$

$$B_i - \rho_i \sum_{j=1}^{N} B_j F_{ij} = E_i$$

$$\begin{bmatrix}1-\rho_1F_{11} & - & \cdots & -\rho_1F_{1n}\\ -\rho_2F_{21} & 1-\rho_2F_{22} & \cdots & -\rho_2F_{2n}\\ \cdot & \cdot & \cdots & \cdot\\ \cdot & \cdot & \cdots & \cdot\\ -\rho_{n-1}F_{n-1,1} & - & \cdots & -\rho_{n-1}F_{n-1,n}\\ -\rho_nF_{n1} & - & \cdots & 1-\rho_nF_{nn}\end{bmatrix}\begin{bmatrix}B_1\\B_2\\ \cdot\\ \cdot\\ \cdot\\B_n\end{bmatrix}=\begin{bmatrix}E_1\\E_2\\ \cdot\\ \cdot\\ \cdot\\E_n\end{bmatrix}$$

Intuition



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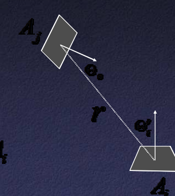
Form Factor

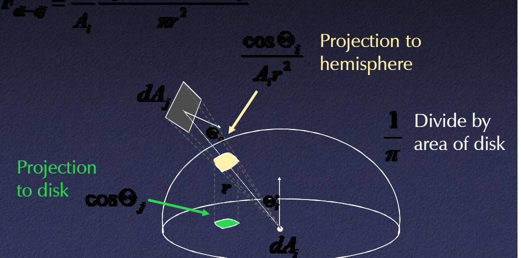
- Fraction of energy leaving element i that arrives at element j

$$F_{ij} = \frac{1}{A_i}\int_{A_i}\int_{A_j}\frac{V_{ij}\cos\Theta_i'\cos\Theta_o}{\pi r^2}\,dA_j\,dA_i$$

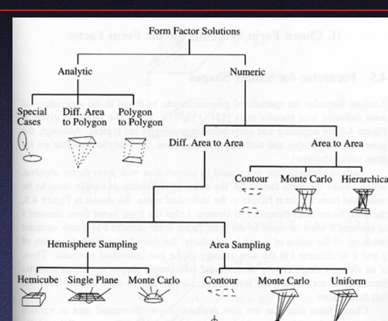


Form Factor Intuition

$$F_{di-dj} = \frac{1}{A_i}\frac{V_{ij}\cos\Theta_i\cos\Theta_j}{\pi r^2}$$



Computing Form Factors



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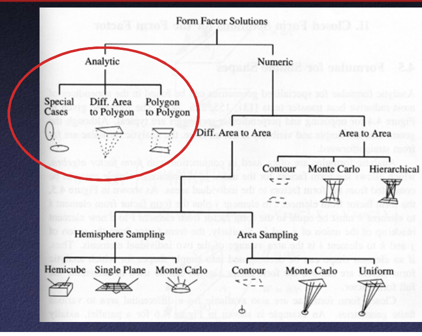
Computing Form Factors



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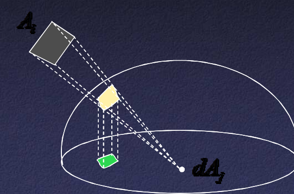
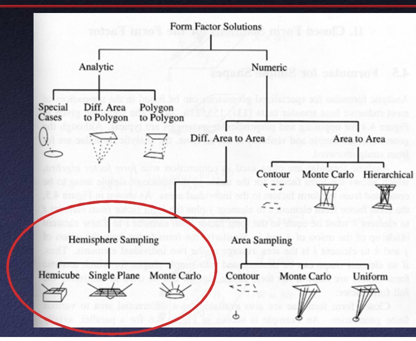
Analytic Form Factors

- Derive equation for projected area
  - Possible only for simple cases



Partial visibility is problematic

Computing Form Factors



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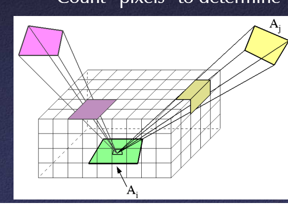
Hemicube

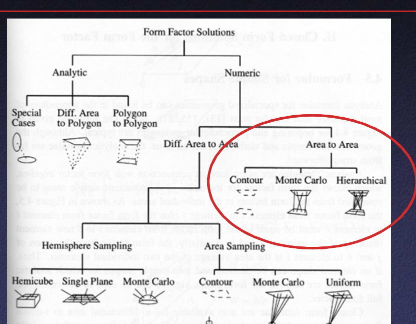
- Compute form factor with image-space precision
  - Render scene from centroid of A_i
  - Use z-buffer to determine visibility of other surfaces
  - Count "pixels" to determine projected areas



Approximating A_i with point leads to errors

Regular sampling leads to aliasing artifacts

Computing Form Factors



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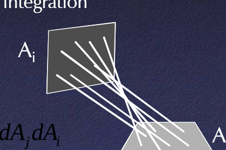
Monte Carlo Sampling

- Compute form factor by random sampling
  - Select random points on elements
  - Intersect line segment to evaluate V_{ij}
  - Evaluate F_{ij} by Monte Carlo integration

$$F_{ij} = \frac{1}{A_i}\int_{A_i}\int_{A_j} \frac{V_{ij}\cos\Theta_i'\cos\Theta_o}{\pi r^2}\, dA_j\, dA_i$$



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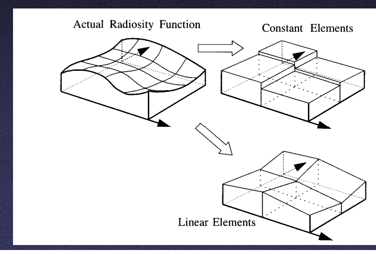
Selecting a Basis Function

- Store radiosity function on surface mesh
  - Piecewise-constant, piecewise-linear, wavelets, etc.



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Overview

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Solving the System of Equations

- Challenges:
  - Size of matrix
  - Cost of computing form factors
  - Computational complexity

$$\begin{bmatrix} 1-\rho_1 F_{1,1} & . & .\ . & -\rho_1 F_{1,n} \\ -\rho_2 F_{2,1} & 1-\rho_2 F_{2,2} & .\ . & -\rho_2 F_{2,n} \\ . & . & .\ . & . \\ . & . & .\ . & . \\ -\rho_{n-1} F_{n-1,1} & . & .\ . & -\rho_{n-1} F_{n-1,n} \\ -\rho_n F_{n,1} & . & .\ . & 1-\rho_n F_{n,n} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ . \\ . \\ . \\ B_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ . \\ . \\ . \\ E_n \end{bmatrix}$$

Solving the System of Equations

- Solution methods:
  - Invert the matrix – $O(n^3)$
  - Iterative methods – $O(n^2)$
  - Hierarchical methods – $O(n)$

Gauss-Seidel Iteration

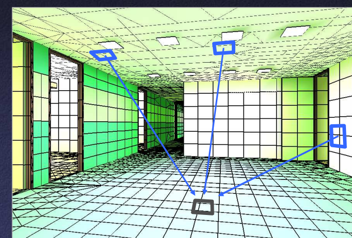
```
for all i
    B_i = E_i
while not converged
    for each i in turn
        B_i = E_i + ρ_i Σ_{j≠i} B_j F_ij
display the image using B_i as the intensity of patch i.
```

Gauss-Seidel Iteration

- Iteratively relax rows of linear system
- Effectiveness depends on sparsity of matrix

Gauss-Seidel Iteration

- Interpretation: gather radiosity to elements

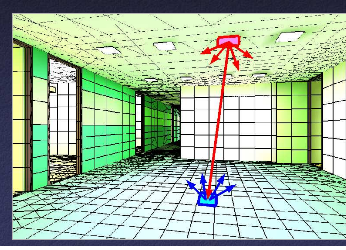


Progressive Radiosity

```
for all i
    B_i = E_i
    ΔB_i = E_i
while not converged
    pick i, such that ΔB_i * A_i is largest
    for every patch j
        Δrad = ΔB_i * ρ_j F_ji
        ΔB_j = ΔB_j + Δrad
        B_j = B_j + Δrad
    ΔB_i = 0
    display the image using B_i as the intensity of patch i.
```

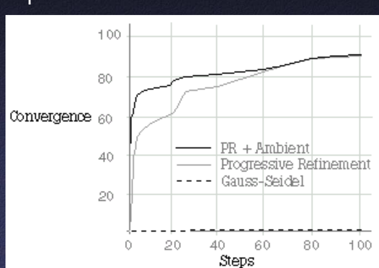
Progressive Radiosity

- Iteratively shoot "unshot" radiosity from elements
- Select shooters in order of unshot radiosity



Progressive Radiosity

- Adaptive refinement



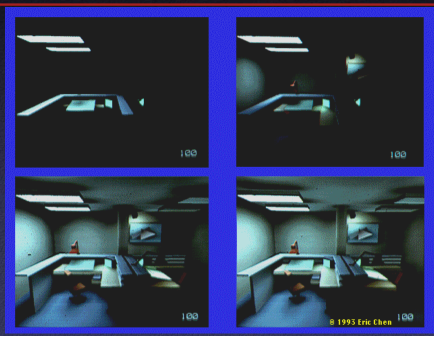
Yeap

Progressive Radiosity

PROGRESSIVE SOLUTION

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

Progressive Radiosity



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Surface Meshing Goals

- Store radiosity across surface
  - Represents function well
  - Few elements
  - Few visible artifacts

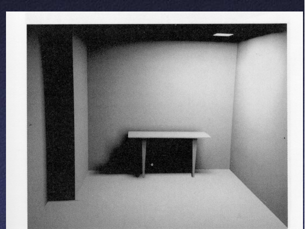
Figure 6.2: *A radiosity image computed using a uniform mesh.*

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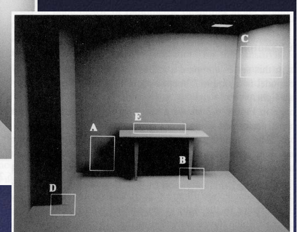
Artifacts of Bad Surface Meshing


(a) *Reference image.*



(b) *Artifacts introduced by the approximation.*

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Error Image

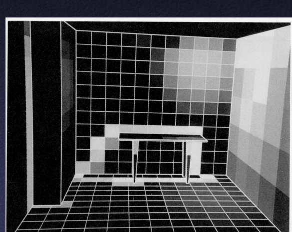
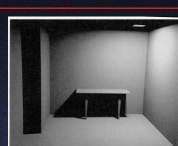
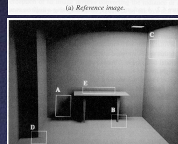


Figure 6.4: *Error image.*


(a) *Reference image.*


(b) *Artifacts introduced by the approximation.*

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Error Image

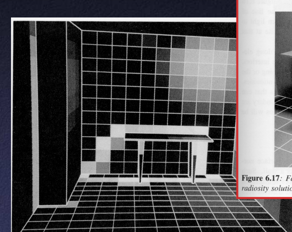
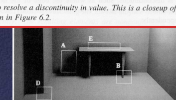


Figure 6.4: *Error image.*


Figure 6.17: *Failure to resolve a discontinuity in value. This is a closeup of the radiosity solution shown in Figure 6.2.*


(b) *Artifacts introduced by the approximation.*

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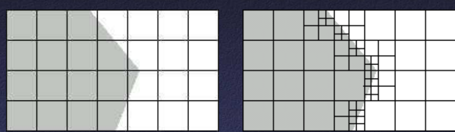
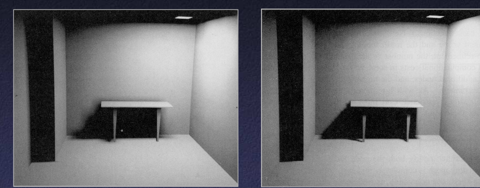
Adaptive Meshing

- Refine mesh in areas of high residual



Yeap

Adaptive Meshing



Uniform mesh | Adaptive mesh

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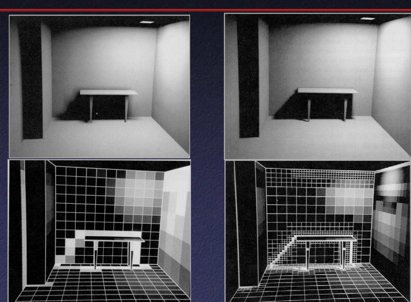
Error Comparison



Uniform | Adaptive

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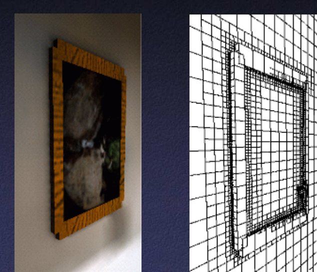
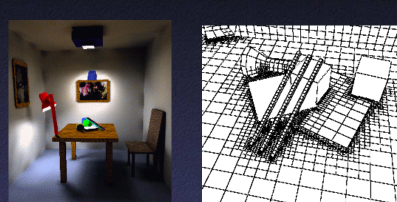
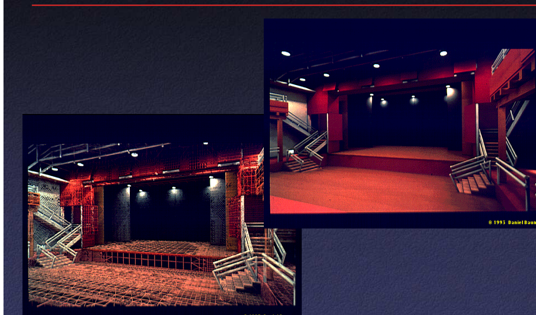
Adaptive Meshing



Adaptive Meshing



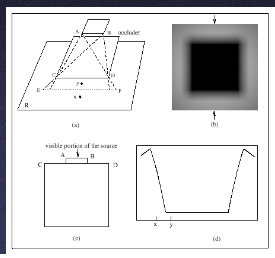
Adaptive Meshing



Baum

Discontinuity Meshing

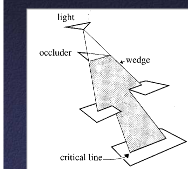
- Capture discontinuities in radiosity across a surface with explicit mesh boundaries



Lischinski

Discontinuity Meshing

- Capture discontinuities in radiosity across a surface with explicit mesh boundaries

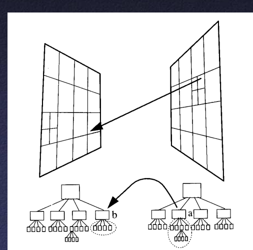


Discontinuity Mesh

Lischinski

Hierarchical Radiosity

- Estimate errors, refine elements if too large



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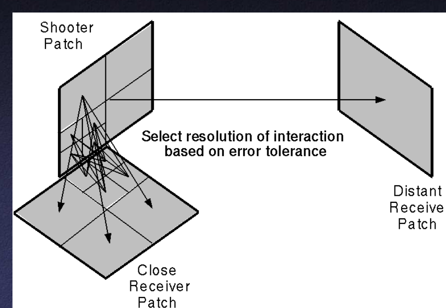
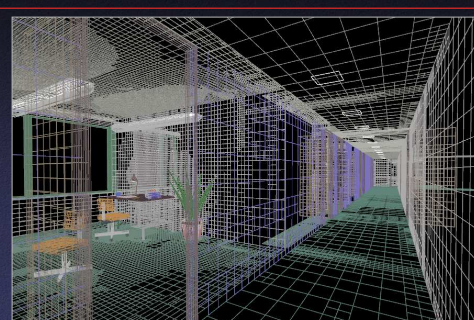
Hierarchical Radiosity



Hierarchical Radiosity

Hierarchical Radiosity



Hierarchical Radiosity

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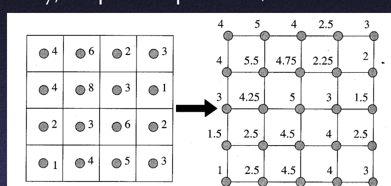
Displaying Radiosity

- Usually, simple interpolation (Gouraud shading)



computed displayed

- Can also try to preserve discontinuities…

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Extensions

- Non-diffuse environments
  - Directional radiosity functions
  - Extended form factors
  - Multipass methods
- Participating media
  - Path integrals in form factors
- Dynamic scenes
  - Incremental updates
- Parallel solvers
  - Decomposition
  - Scheduling