



## Radiosity

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## Radiosity Concept

**Global computation of diffuse interreflections among scene objects**

**Diffuse lighting changes fairly slowly across a surface**

- Break surfaces up into some number of patches
- Assume diffuse illumination constant across each patch

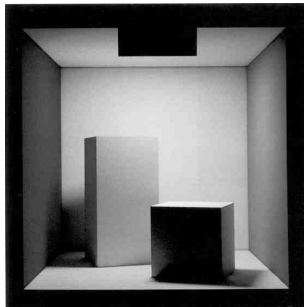
**Diffuse reflection independent of viewing direction**

- **Interactive rendering possible**

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## Cornell Box



from Sillion and Puech, *Radiosity & Global Illumination*, 1994.

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## Steel Mill (55,000 elements)



from Watt and Watt, *Advanced Animation and Rendering Techniques*, 1992.

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## Radiosity - fundamentals

**Radiosity: energy per unit area leaving a surface patch per unit time**

**Radiosity  $\times$  area = emitted energy + reflected energy**

$$B_i dA = E_i dA_i + R_i \int_j B_j F_{ji} dA_j$$

**Radiosity will be color of rendered surface**

- total energy generated by rendering some number of pixels

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## Form Factor

**Describes geometric relationship between two surface patches**

$F_{ij}$  = energy leaving  $A_i$  that strikes  $A_j$  directly  
energy leaving  $A_i$  over entire hemisphere

$$\sum_i F_{ij} = 1 \text{ for all } j$$

$$F_{ii} = 0 \text{ for planar patches}$$

$$\text{Reciprocity relationship: } F_{ij} dA_i = F_{ji} dA_j$$

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**Form Factor Diagram**

from Watt, *3D Computer Graphics*, 1993.

$$F_{ij} = 1/A_i \int_{A_i} \int_{A_j} \cos\phi_i \cos\phi_j / (\pi r^2) dA_j dA_i$$

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**Differential-Finite Area Form Factor**

$$F_{dA_i A_j} = \int_{A_j} \cos\phi_i \cos\phi_j / (\pi r^2) dA_j$$

Form factor between  $dA_i$  and  $A_j$

Position  $dA_i$  at center of  $A_i$  and assume result is valid for entire patch

- reasonable when  $r$  is large with respect to areas

Now reasonable to consider projection of patch rather than patch itself...

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**Patch Projections**

All three representations have the same form factor

A: patch itself  
B: patch on hemicube  
C: patch on hemisphere

from Watt, *3D Computer Graphics*, 1993.

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**Hemicube Illustration**

from Watt, *3D Computer Graphics*, 1993.

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**Hemicube Form Factor Method**

For each patch,  $i$

For each patch,  $j$

Render patches into item buffer for each hemicube face (with Z-buffering)

For each hemicube pixel

Look up pixel form factor

Accumulate into form factor for appropriate patch pair  $(i, j)$

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**Radiosity Computation**

Compute form factors

Solve  $N \times N$  matrix equation

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

$$\begin{bmatrix} 1 - R_1 F_{11} & -R_1 F_{12} & \dots & -R_1 F_{1n} \\ -R_2 F_{21} & 1 - R_2 F_{22} & \dots & -R_2 F_{2n} \\ \dots & \dots & \dots & \dots \\ -R_n F_{n1} & -R_n F_{n2} & \dots & 1 - R_n F_{nn} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \dots \\ B_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ \dots \\ E_n \end{bmatrix}$$

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## Gathering Method of Radiosity Computation

- Compute form factors
- Solve matrix equation using Gauss-Seidel iteration
- Solve for one patch radiosity at a time
- Plug solution into matrix for solutions to future radiosities
- Iterate until it converges

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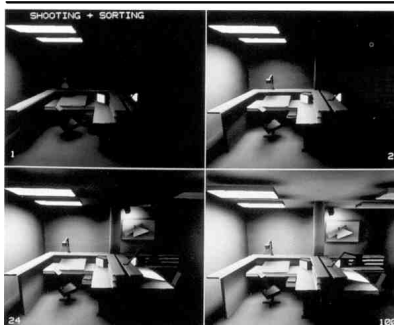
## Shooting Method of Radiosity Computation

- At each iteration, emit from one patch to all other patches
  - Useful for progressive radiosity
  - Possibly add ambient when viewing preliminary results
- Order the patch emissions by magnitude of energy to be emitted

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## Shooting Example

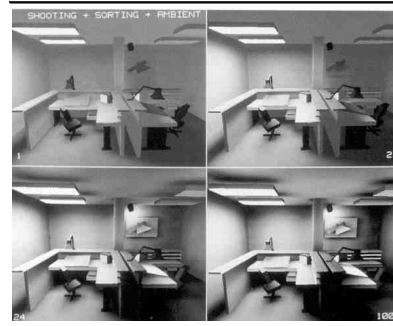


from Sillion and Puech, *Radiosity & Global Illumination*, 1994.

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## Shooting + Ambient Example



from Sillion and Puech, *Radiosity & Global Illumination*, 1994.

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## Creating Patches from Polygons

- Uniform subdivision (pre-process)
- Adaptive regular subdivision (on-line)
- Adaptive irregular subdivision (on-line)

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## Uniform Subdivision

- Subdivide polygons with regular grid before any radiosity computation
- Set some threshold to determine level of subdivision
  - number of patches per polygon
  - maximum patch size
- Doesn't provide much control in error of form factor or radiosity computation

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## Adaptive Regular Subdivision

Begin with coarse (or no) uniform subdivision of polygons

After computing radiosity, measure gradient between adjacent patches (using differences)

Subdivide patches with high gradient

Incrementally update radiosity solution

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## Reducing Subpatch Computations

Initialize subpatch radiosities from patch radiosity

Compute only subpatch-patch form factors

- not patch-subpatch form factors
- not subpatch-subpatch form factors

Subdivision effectively increases matrix from  $N \times N$  to  $M \times N$  (but not  $M \times M$ )

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## Hierarchical Radiosity

Apply regular subdivision to patches that require refinement

For each patch-patch interaction, use an appropriate level of subdivision

Can be implemented using matrix block operations

- portions of matrix are computed as block
- bounds on computational error used to determine which computations may be grouped

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## Irregular Subdivision (Discontinuity Meshing)

Subdivide patches along discontinuities, rather than regular subdivision

Discontinuities

- 0 order: contacts between surfaces
- 1st, 2nd order: changes in visibility

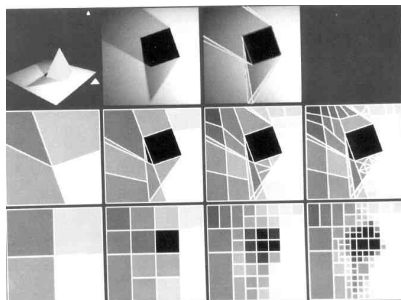
Requires less refinement along discontinuities than regular subdivision

Typically try to subdivide so most patch elements completely visible or invisible

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## Discontinuity Mesh Examples



From Lischinski et al., "Combining Hierarchical Radiosity and Discontinuity Meshing," *Proceedings of SIGGRAPH 93*.

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## Discontinuity vs. Regular Subdivision

From Lischinski et al., "Combining Hierarchical Radiosity and Discontinuity Meshing," *Proceedings of SIGGRAPH 93*.



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## Other Topics of Interest

Combining effects of initial polygons

Using non-constant patch radiosities

Rendering polygons with higher-order color interpolation

Radiosity as textures

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## Combining Polygon Contributions

For polygonal curved surfaces, simplification allows hierarchical representation

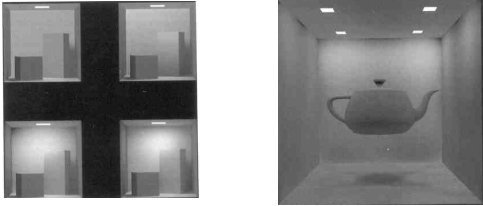
Possibly combine light contributions through volumes of space

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## Non-constant Patch Radiosities

Require fewer patches by allowing radiance to vary across a patch



from Zatz, "Galerkin Radiosity," *Proceedings of SIGGRAPH 93*.

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## Higher-order Color Interpolation

Using higher-order color interpolation decreases number of polygons rendered

Higher-order color interpolated polygons take longer to render

Determine optimum mode for rendering each patch based on number of polygons and rendering cost

Explored on Pixel-Planes 5 hardware ~1995

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## Radiosity as Textures

Accurate radiosity dramatically increases polygon count

- Extra geometry is redundant
- All new information is about colors

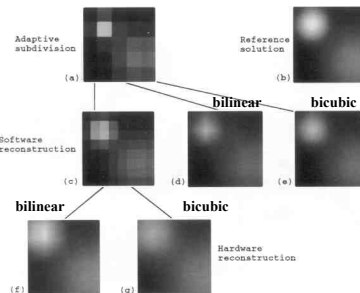
Create textures for new color information and use original geometry

Like higher-order interpolation, texture-mapping is more expensive than color interpolation, so optimize cost/benefit

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## Radiosity as Textures Resampling



From Bastos et al., "Efficient Radiosity Rendering using Textures and Bicubic Reconstruction," *Proceedings of the 1997 Symposium on Interactive 3D Graphics*.

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## Video

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**Bastos, Rui. Michael Goslin, and Hansong Zhang.**  
**“Efficient Radiosity Rendering using Textures  
and Bicubic Reconstruction.”** *Proceedings of the  
1997 Symposium on Interactive 3D Graphics.*

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