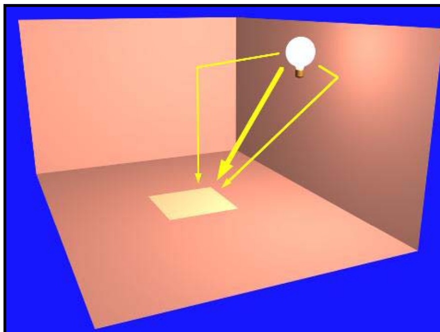
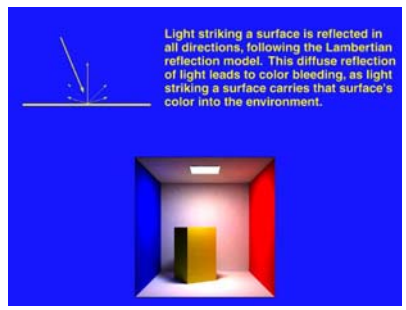
Radiosity

Not
Radio City



The illumination at a given point in the environment is a combination of the light received directly from a light source and the light which is reflected one or more times from the surfaces of the environment.



Radiosity

- Equilibrium of energy balances within an enclosure.
- Based on radiative heat transfer (thermodynamics)

What is Radiosity?

The radiosity of a surface is the rate at which energy leaves that surface (energy per unit time per unit area). It includes the energy emitted by a surface as well as the energy reflected from other surfaces.

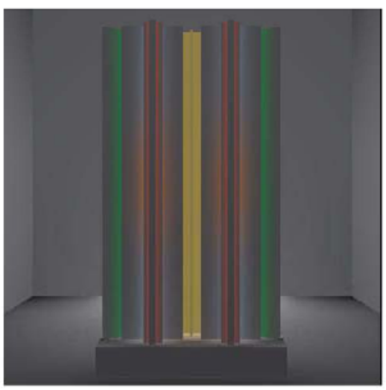
Techniques of modeling the transfer of energy between surfaces based upon radiosity were first used in analyzing heat transfer between surfaces in an enclosed environment. The same techniques can be used to analyze the transfer of radiant energy between surfaces in computer graphics.

Radiosity methods allow the intensity of radiant energy arriving at a surface to be computed. These intensities can then be used to determine the shading of the surface.

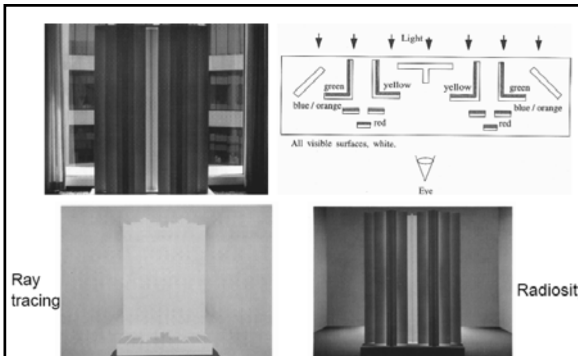
From Cohen, Chen, Wallace and Greenberg 1988

Slide 25 : Steel Mill.

This image of a steel rolling mill was created using progressive radiosity. The original model contains about 30,000 polygons, which were subdivided into about 55,000 elements during the solution. It was computed on a DEC VAX 8700 and displayed using a Hewlett-Packard SRX graphics device.

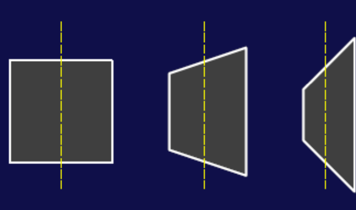


From Goral, Torrance, Greenberg, Battaile 1984



John Ferren, Construction in Wood, A Daylight Experiment, © Cornell

Diffuse surfaces have one radiance (color) for all viewing directions



Radiosity Enclosures

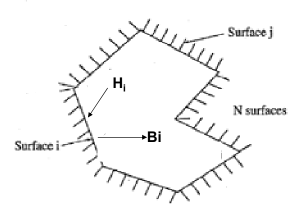


Figure 5–81 A hypothetical enclosure.

B_i – total rate of energy leaving surface i per unit area, sometimes called flux

Flux contains 2 parts:

$$B_i = E_i + p_i H_i$$

E_i – rate at which the surface I emits energy as a source

$p_i H_i$ – rate at which the incident light (energy) is reflected back into the environment

p_i – reflectivity of the surface

H_i – radiant energy incident on surface I

Incident flux = $\sum$ flux from all surfaces

Energy leaving patch j

$$H_i = \sum_{j=1}^{N} B_j \frac{A_j F_{ji}}{A_i}$$

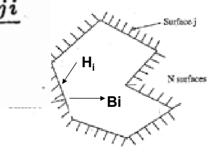


Figure 5-81 A hypothetical enclosure.

That reaches patch i

$$H_i = \sum_{j=1}^{N} B_j \frac{A_j F_{ji}}{A_i}$$

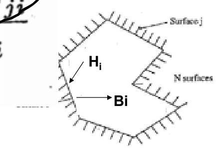


Figure 5-81 A hypothetical enclosure.

Per unit area of patch i

$$H_i = \sum_{j=1}^{N} B_j \frac{A_j F_{ji}}{A_i}$$

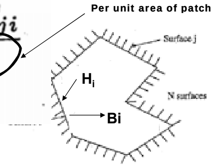


Figure 5-81 A hypothetical enclosure.

Energy leaving patch j

That reaches patch i

Per unit area of patch i

$$H_i = \sum_{j=1}^{N} B_j \frac{A_j F_{ji}}{A_i}$$

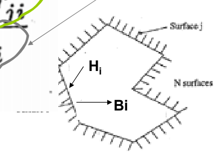


Figure 5-81 A hypothetical enclosure.

Radiosity reciprocity relation

$$A_i F_{ij} = A_j F_{ji}$$

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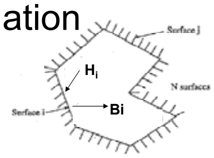
Radiosity Equation



Bi = Ei + piHi

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

Radiosity Enclusures

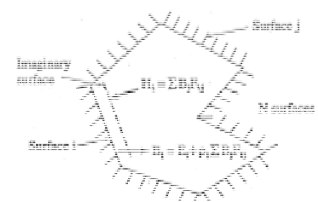


Figure 5–81 A hypothetical enclosure.

Classic Radiosity

Power balance

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

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

Linear system of equations

$$\begin{pmatrix} 1-\rho_1 F_{11} & -\rho_1 F_{12} & \cdots & -\rho_1 F_{1n} \\ -\rho_2 F_{21} & 1-\rho_2 F_{22} & \cdots & -\rho_2 F_{21} \\ \vdots & \vdots & \ddots & \vdots \\ -\rho_n F_{n1} & -\rho_n F_{n2} & \cdots & 1-\rho_n F_{nn} \end{pmatrix} \begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_n \end{pmatrix} = \begin{pmatrix} E_1 \\ E_2 \\ \vdots \\ E_n \end{pmatrix}$$

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Radiosity Form Factors

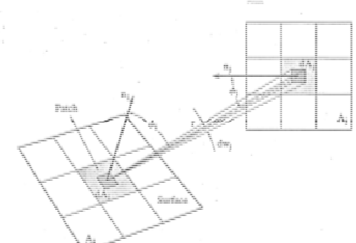
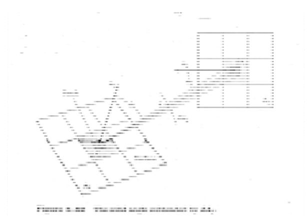
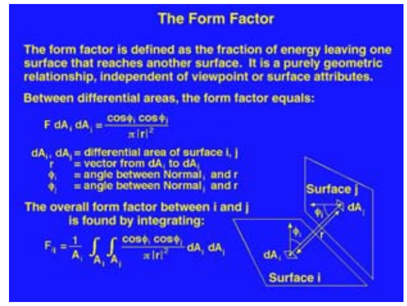


Figure 5–82 The solid angle subtended by dA_j.

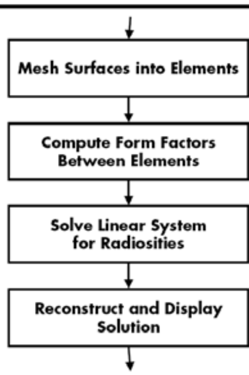
Radiosity Form Factors



$$F_{A_i - A_j} = F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\phi_i \cos\phi_j}{\pi r^2} H_{ij}\, dA_i\, dA_j$$



Classic Radiosity Algorithm



Simple Room Scene

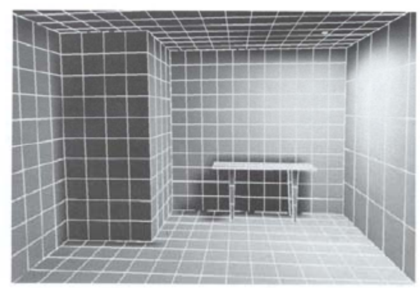
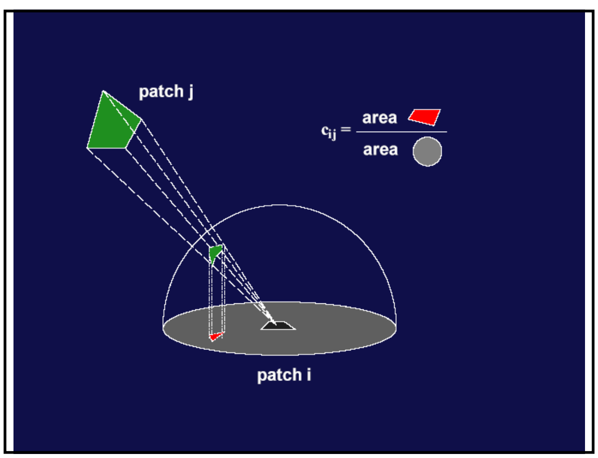
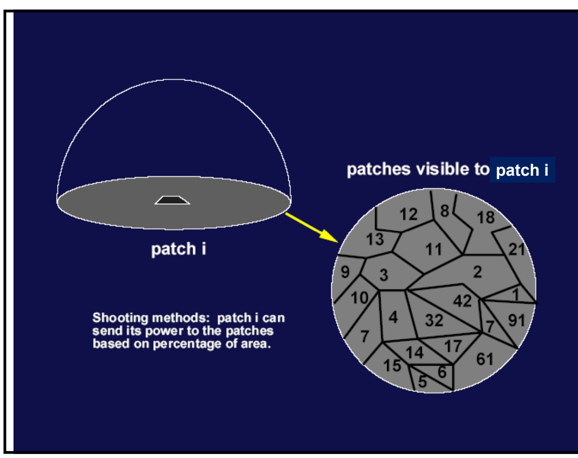


Table in room sequence from Cohen and Wallace





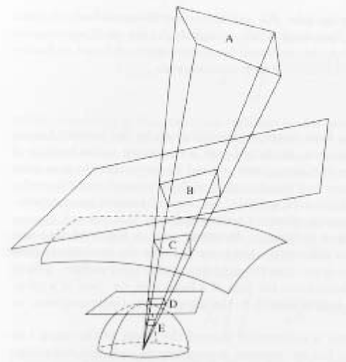


Figure 5–84 The equivalence of projected areas: areas A, B, C, D and E all have the same form factor.

How Does OpenGL Fit In?

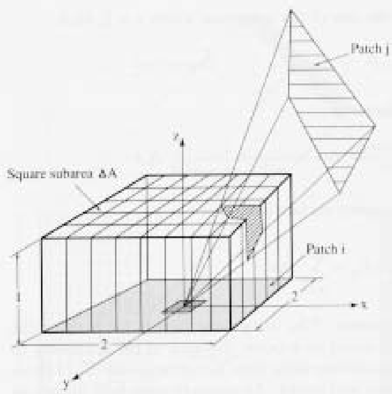


Figure 5–86 A patch projected onto a subdivided hemicube.

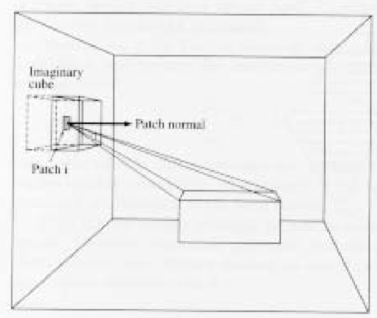
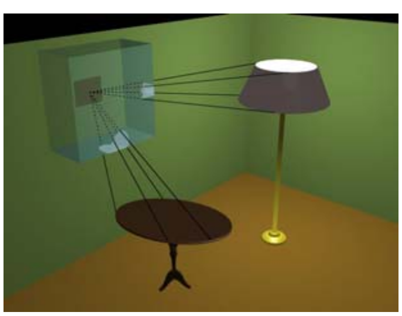
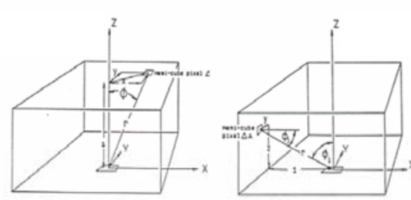


Figure 5–85 Projection of the environment onto the hemicube covering a patch.



Hemicube Delta Form Factors



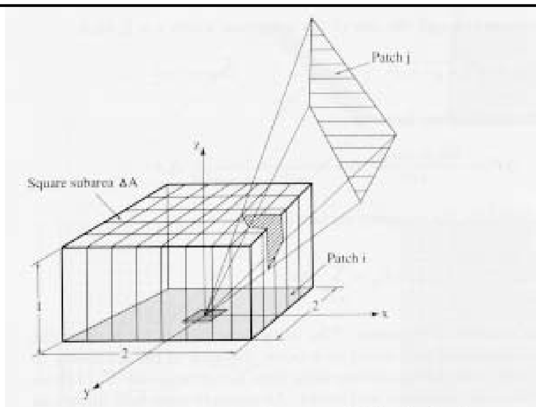


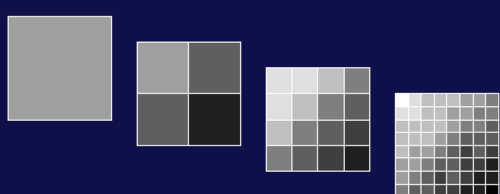
Figure 5–86 A patch projected onto a subdivided hemicube.

Distributing the Energy

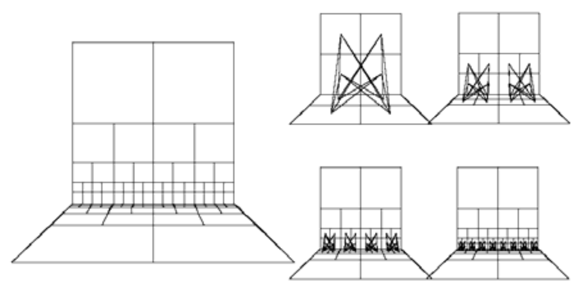
- Solve linear system
  - Diagonal dominant
  - Use Gauss-Seidel or other method
- Hierarchical methods
  - Do interaction between 2 far-away groups of patches all at once

$$\begin{pmatrix}1-\rho_1F_{11} & -\rho_1F_{12} & \cdots & -\rho_1F_{1n}\\ -\rho_2F_{21} & 1-\rho_2F_{22} & \cdots & -\rho_2F_{2n}\\ \vdots & \vdots & \ddots & \vdots \\ -\rho_nF_{n1} & -\rho_nF_{n2} & \cdots & 1-\rho_nF_{nn}\end{pmatrix}\begin{pmatrix}B_1\\B_2\\ \vdots\\B_n\end{pmatrix}=\begin{pmatrix}E_1\\E_2\\ \vdots\\E_n\end{pmatrix}$$

For hierarchical methods, each path is multi-resolution



Hierarchical Radiosity



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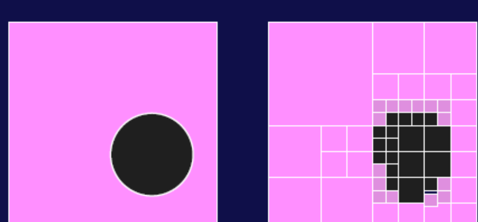
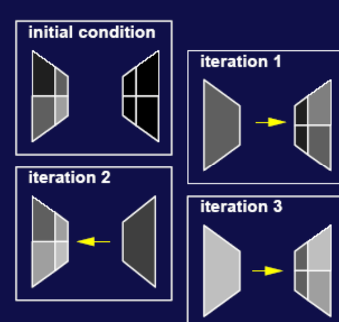
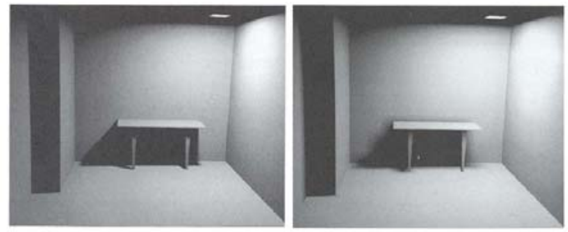
Usually an adaptive hierarchy is used



Hierarchical methods



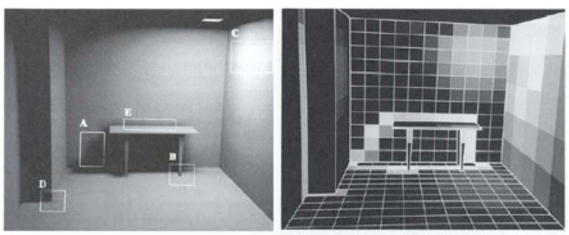
Accuracy



Reference Solution   Uniform Mesh

Table in room sequence from Cohen and Wallace

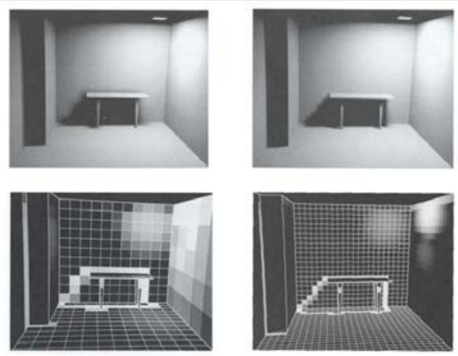
Artifacts



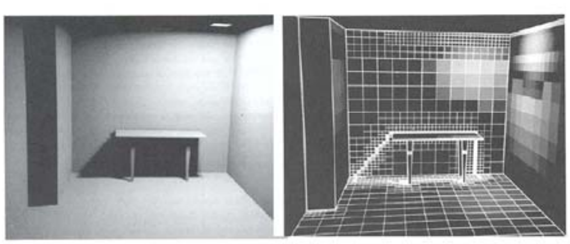
Error Image

A. Blocky shadows
B. Missing features
C. Mach bands
D. Inappropriate shading discontinuities
E. Unresolved discontinuities

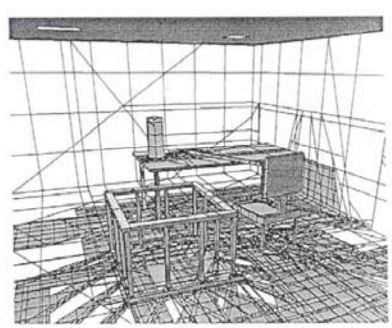
Increasing Resolution



Adaptive Meshing



Discontinuity Mesh



From Campbell et al.

Summary

Remember assumptions

- Diffuse reflectance
- Polygons

Difficult to relax assumptions

Computation challenges

- Meshing
  - Complex input geometry
  - Complexity due to shadows
- Dense coupling
  - $O(n^2)$ matrix elements
  - HR leads to $O(n)$ algorithm (ignoring discontinuities)

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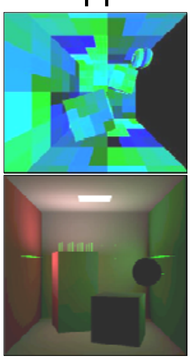
OpenGL to do more?

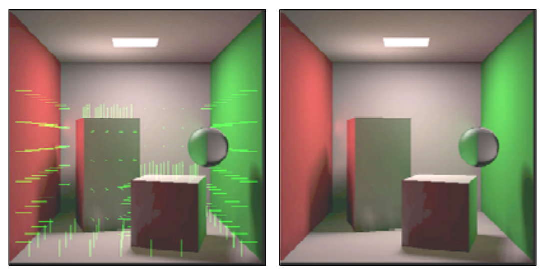
- Relook at equations

Approximate one-bounce

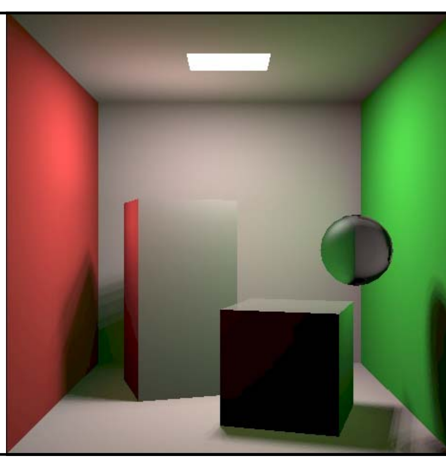


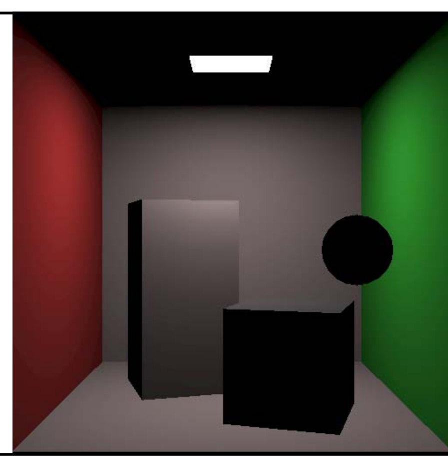
- Item buffer rendered from light.
- Item buffer is scanned by multiple CPUs to determine polygons which reflect maximum energy.
- First bounce of brightest polygons approximated by point lights.
- Only one pass. If *p* is number of pipes, then *8p* virtual lights used.
- No visibility. Since intensity of virtual lights is low, incorrect illumination is not noticeable in most scenes.

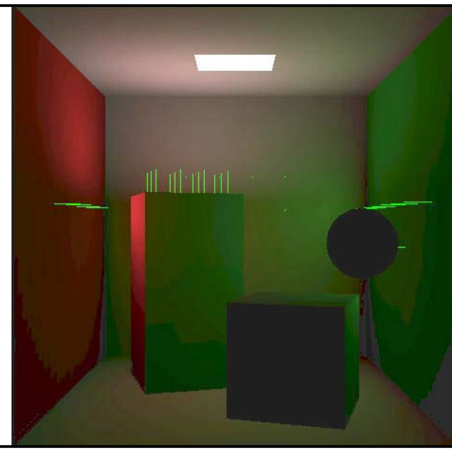
Indirect lighting

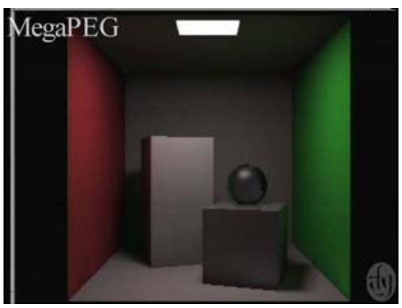


Location of 240 virtual lights — Result









Slide Credits

- Pat Hanrahan, Stanford CS348B
- Pete Shirley, Siggraph 98 Radiosity Course