CMSC 435
Global Illumination

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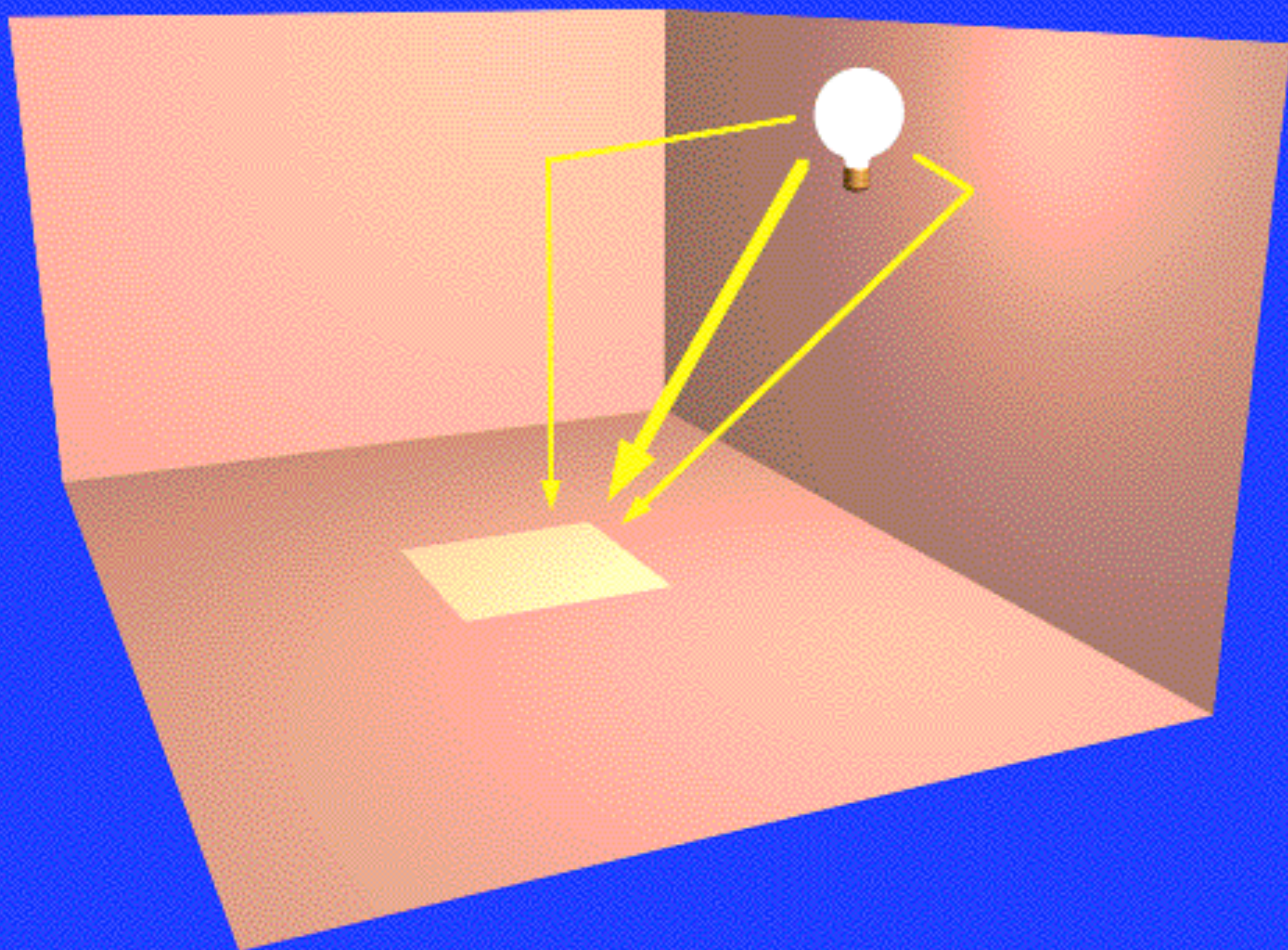
Traditional Illumination

- Local illumination: light, surface, eye
  - Phong -- simple model of reflection
  - Cook and Torrance -- more accurate reflection
- Global illumination
  - Whitted -- ray tracing for specular interactions between surfaces
  - Cook -- distributed ray tracing for area light sources

Radiosity Approach

- Assume all surfaces are ideal diffuse reflectors; light sources all diffuse emitters
- Consider all interactions between lights and surface elements
- Based on theory from radiative heat transfer



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

- Goral, Torrance, Greenberg, and Battaile:
  - Modeling the Interaction of Light Between Diffuse Surfaces, SIGGRAPH 84
- Cohen and Greenberg:
  - The Hemi-Cube, A Radiosity Solution for Complex Environments, SIGGRAPH 85
- Cohen, Chen, Wallace, and Greenberg:
  - A Progressive Refinement Approach to Fast Radiosity Image Generation, SIGGRAPH 88

Radiosity Concepts

- Radiant intensity
  - energy which emanates in all directions from a differential area of surface
- Enclosure
  - set of surfaces which completely define the illumination environment
- Form factor
  - fraction of the radiant energy from one surface striking another

The Radiosity Equation

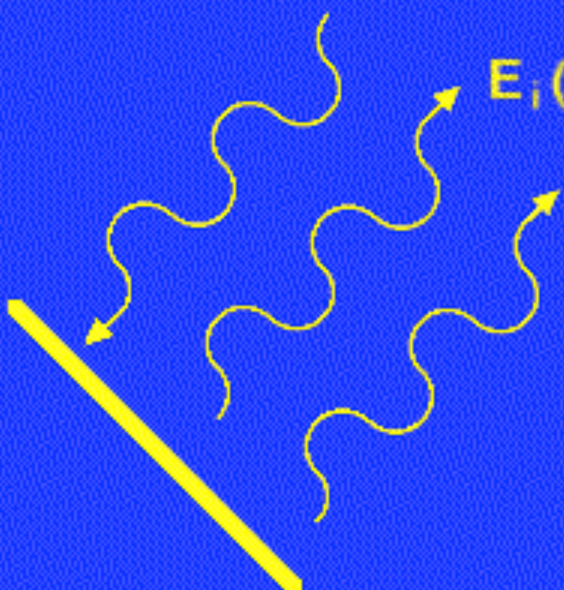
$$B_i = E_i + \rho_i \Sigma B_j F_{ij}$$

B_i = Radiosity of surface i
E_i = Emissivity of surface i
ρ_i = Reflectivity of surface i
B_j = Radiosity of surface j
F_{ij} = Form Factor of surface j relative to surface i

$\Sigma B_j F_{ij}$ (energy reaching this surface from other surfaces)

E_i (energy emitted by this surface)

$\rho_i \Sigma B_j F_{ij}$ (energy reflected by this surface)



The Form Factor

The form factor is defined as the fraction of energy leaving one surface that reaches another surface. It is a purely geometric relationship, independent of viewpoint or surface attributes.

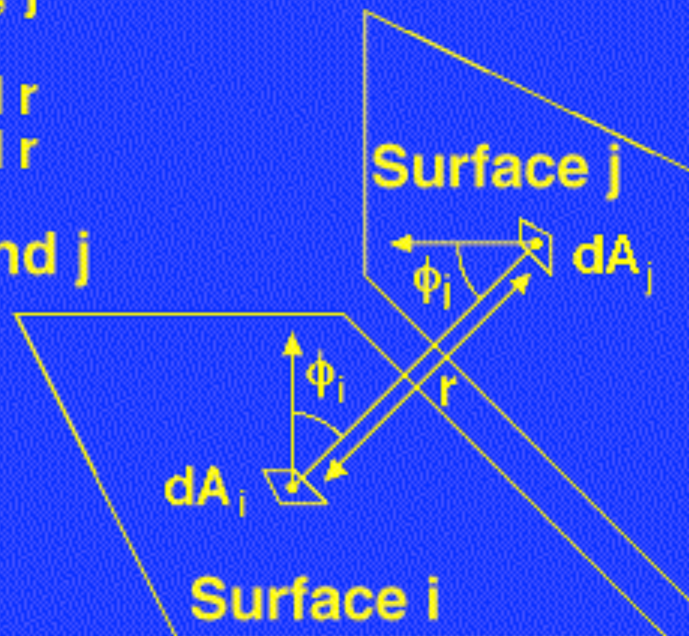
Between differential areas, the form factor equals:

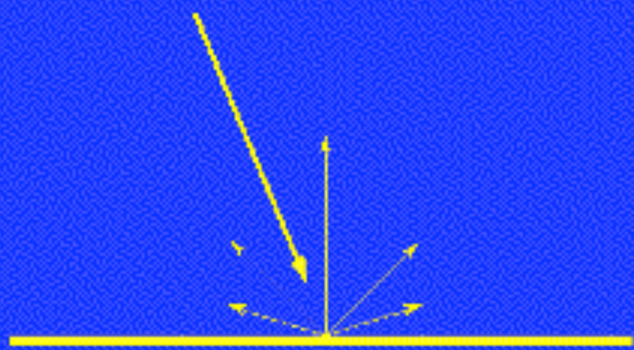
$$F_{dA_i\,dA_j} = \frac{\cos\phi_i \cos\phi_j}{\pi |r|^2}$$

dA_i, dA_j = differential area of surface i, j
r = vector from dA_i to dA_j
ϕ_i = angle between Normal_i and r
ϕ_j = angle between Normal_j and r

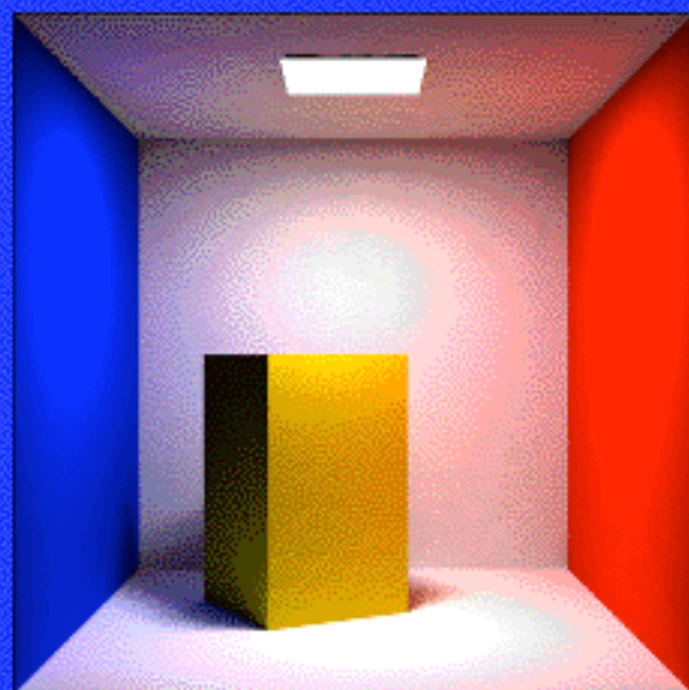
The overall form factor between i and j is found by integrating:

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





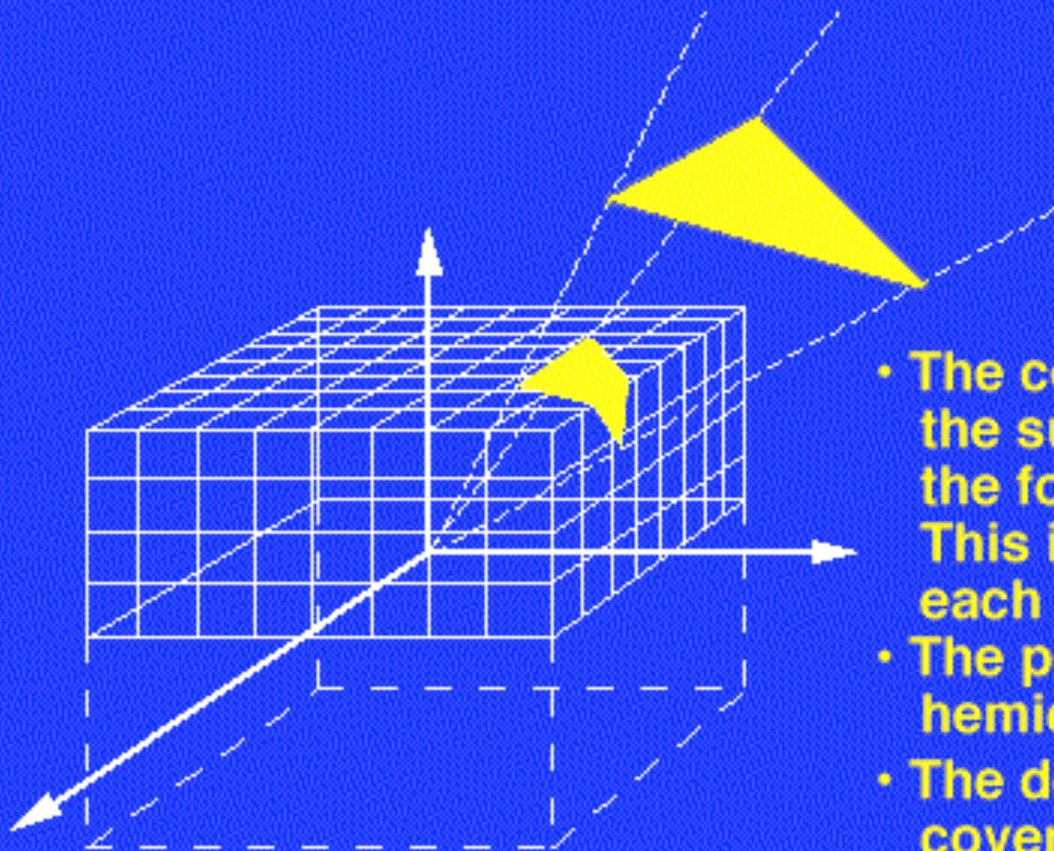
Light striking a surface is reflected in all directions, following the Lambertian reflection model. This diffuse reflection of light leads to color bleeding, as light striking a surface carries that surface's color into the environment.



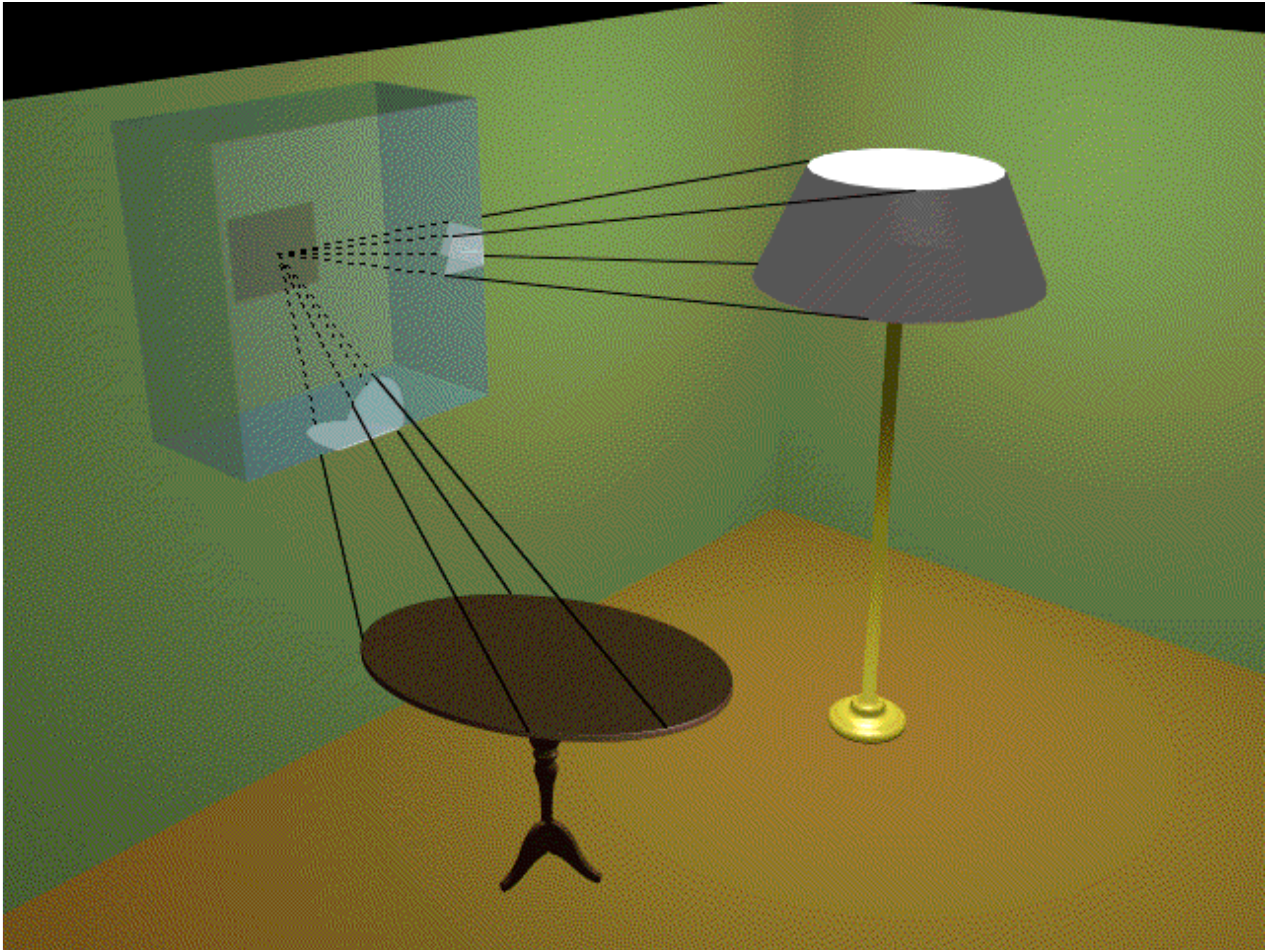
Results

- Compared well with physical model of test environment
- Limitations
  - uniform subdivision not very efficient
  - VERY compute-intensive
  - only polygonal models

THE HEMICUBE APPROXIMATION



- The contribution of each cell on the surface of the hemicube to the form factor value is computed. This is the delta form factor for each cell.
- The polygon is projected onto the hemicube.
- The delta form factors for the covered cells are summed to get the approximation to the true form factor.



The "full matrix" radiosity solution requires form factors between each surface to be calculated, and the following equation to be solved:

$$\begin{bmatrix} 1-\rho_1 F_{11} & -\rho_1 F_{12} & \cdots & -\rho_1 F_{1n} \\ -\rho_2 F_{21} & 1-\rho_2 F_{22} & \cdots & -\rho_2 F_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -\rho_n F_{n1} & -\rho_n F_{n2} & \cdots & 1-\rho_n F_{nn} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ \vdots \\ E_n \end{bmatrix}$$

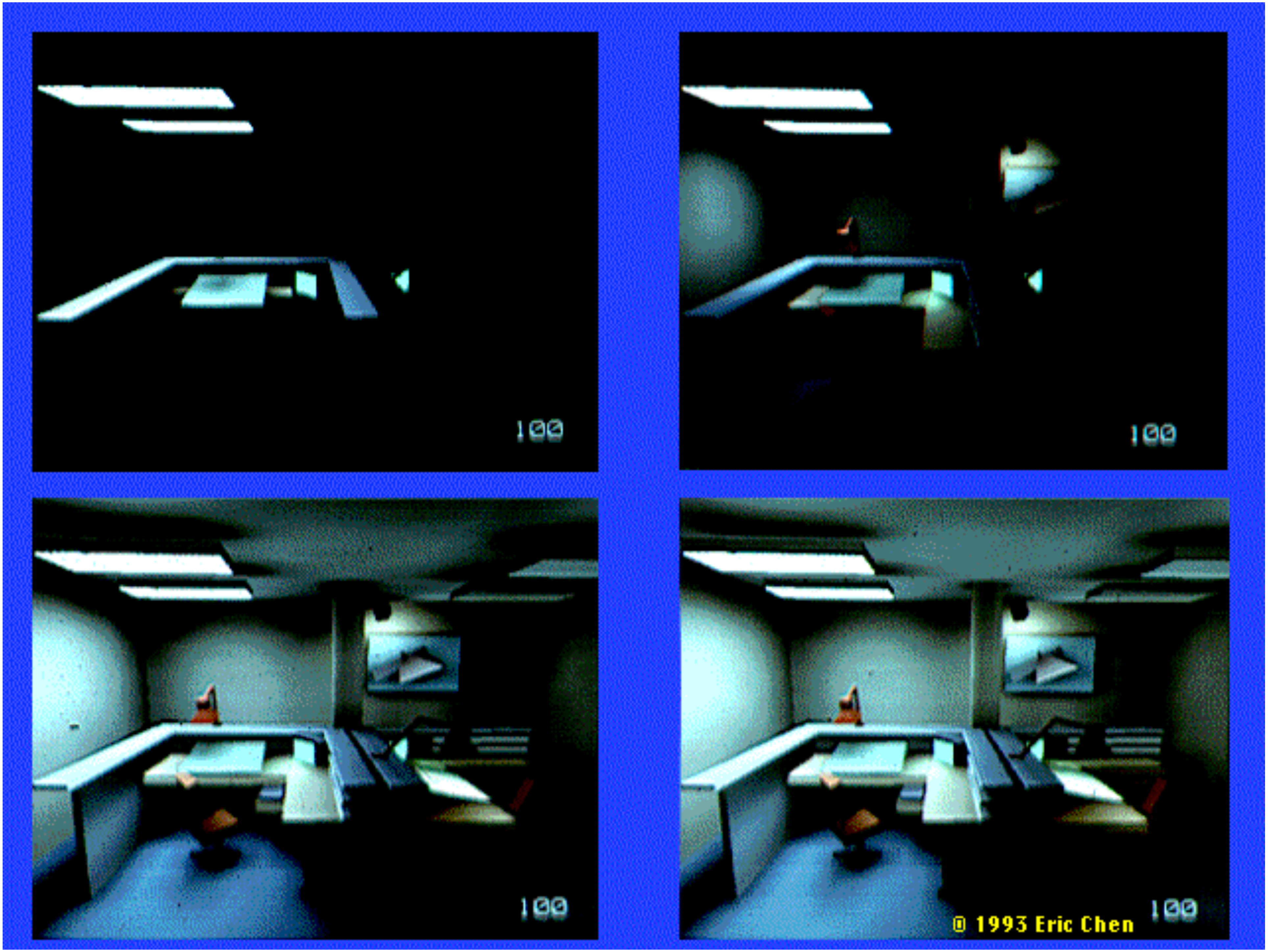
ρ_i is the reflectivity of surface i,
F_{ij} is the form factor from surface i to surface j,
B_i is the radiosity of surface i, and
E_i is the emission of surface i.

The "progressive" radiosity solution provides an incremental method, at each step requiring form factors from one surface to all others to be calculated:

```
for each iteration:
    select a surface i
    calculate F_ij for all surfaces j
    for each surface j:
        update radiosity of surface j
        update emission of surface j
    set emission of surface i to zero
```

PROGRESSIVE SOLUTION

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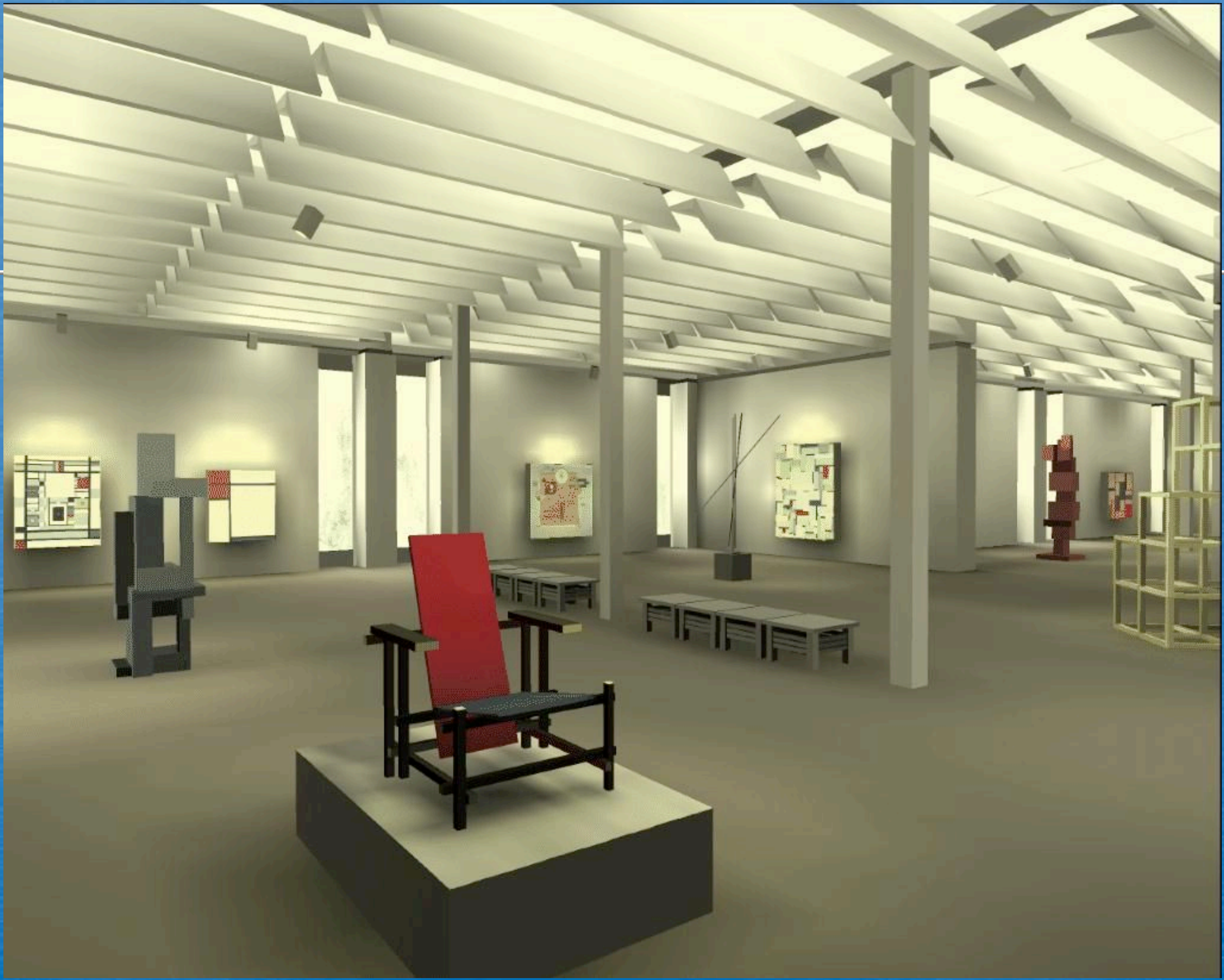


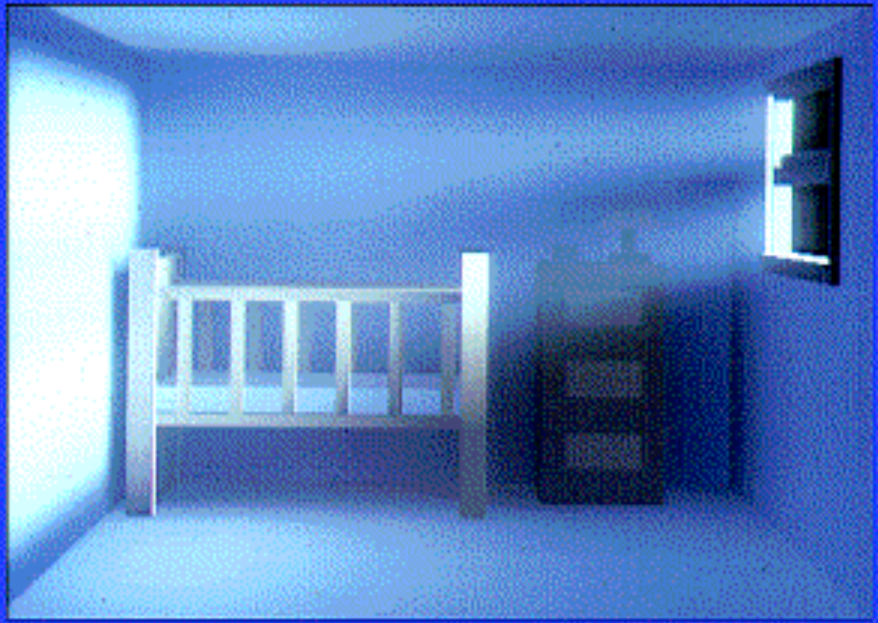
- Cohen, Chen, Wallace, and Greenberg '88

More Radiosity Topics

- Participating Media
  - Rushmeier and Torrance‘87
- Specular Reflections
  - Immel, Cohen, and Greenberg ‘86
  - Wallace, Cohen, and Greenberg ‘87
  - Sillion ‘89
- Discontinuity Meshing
  - Baum, Mann, Smith, and Winget ‘91
  - Lischinski, Tampieri, Greenberg ‘92

LIGHT AND A PARTICIPATING MEDIUM

Smoke, dust or water vapor in the air can emit, absorb, or scatter light causing these "participating media" to become visible in the scene. The "Zonal Method" is used to extend the calculation of the form factors to include volumes so that a participating medium can be included in the radiosity equation.

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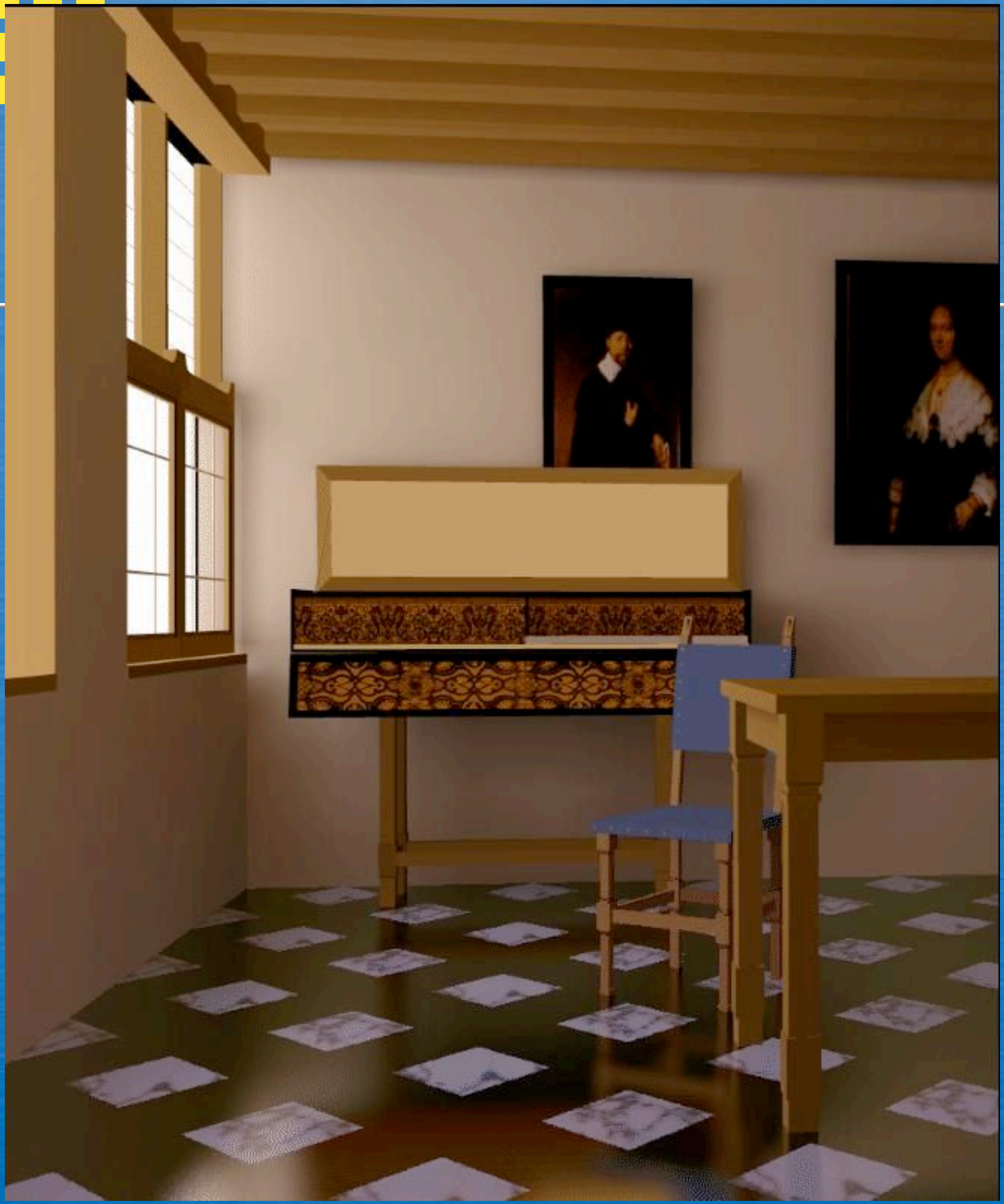

- Wallace, Cohen, and Greenberg ‘87


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- Lischinski, Tampieri, Greenberg ‘92

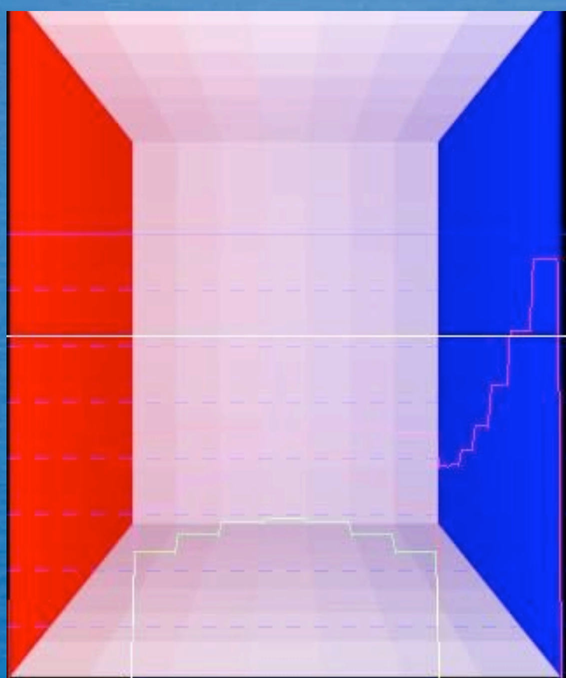
More Global Illumination Topics

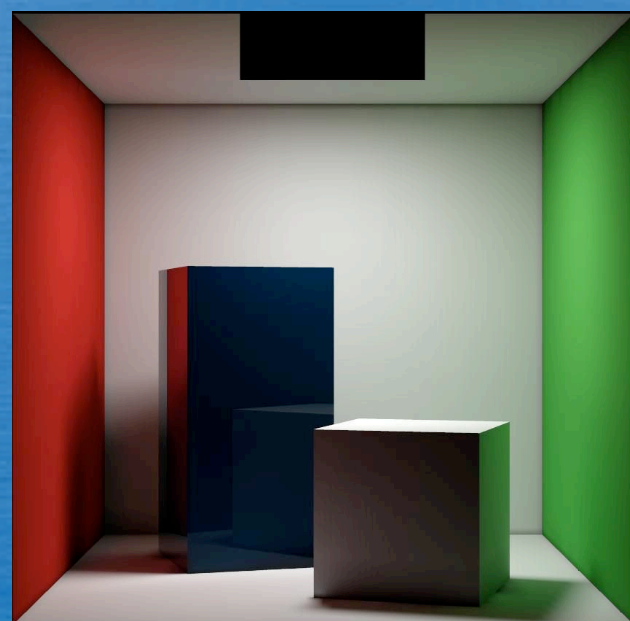
- Monte Carlo Methods
  - Lafortune and Willems ‘93
  - Veach and Guibas ‘97
- Error Estimates
  - Arvo, Torrance, and Smits ‘94
  - Lischinski, Smits, and Greenberg ‘94


Bidirectional Path Tracing


Metropolis Light Transport

The Cornell Box





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