Advanced Rendering Concepts

Local phenomena

- Transparency - light can be transmitted through objects
- Shadows - light blocked by other objects
- Attenuation - light intensity reduces with the square of the distance

Global phenomena

- Reflection of objects on other objects
- Indirect diffuse light

Realistic surface detail

- Anisotropic reflection, microstructures (e.g. fibers)

Realistic light sources

- Sun, area light sources, monitors etc

Rendering Equation

Light arriving at p from p' and light leaving p must balance

$$b(p,p') = v(p,p')\left(\epsilon(p,p') + \int \rho(p,p',p'')b(p',p'')dp''\right)$$

- $b(p,p')$ is the flux of light (intensity for us) leaving *p*' and arriving at p.
- v visibility factor (0, or inverse function of distance)
- ϵ is emitting flux from p' in the direction of p
- ρ is the reflectance function at p'
- integral sums the contributions of every other point p'' sending light to p' that is reflected towards p

Rendering Equation

- Simple but difficult to solve
- High dimensionality
  - *b is a function of 6 parameters,*
  - *ρ is a function of 9 parameters*
  - *and we have not even used a variable for color (wavelength of light)*
- Solutions use sampling of illumination, for example photon mapping

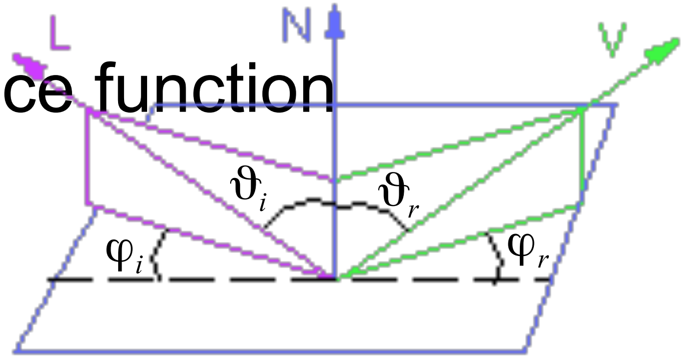
Realistic models

Light sources

- Physics-based illumination models
- Fluorescent etc

Materials

- BRDF: Bidirectional reflectance function



$$\rho(\vartheta_i, \varphi_i, \vartheta_r, \varphi_r, \lambda)$$

λ : light wavelength

Examples of a few simple diffuse BRDFs (wikipedia)

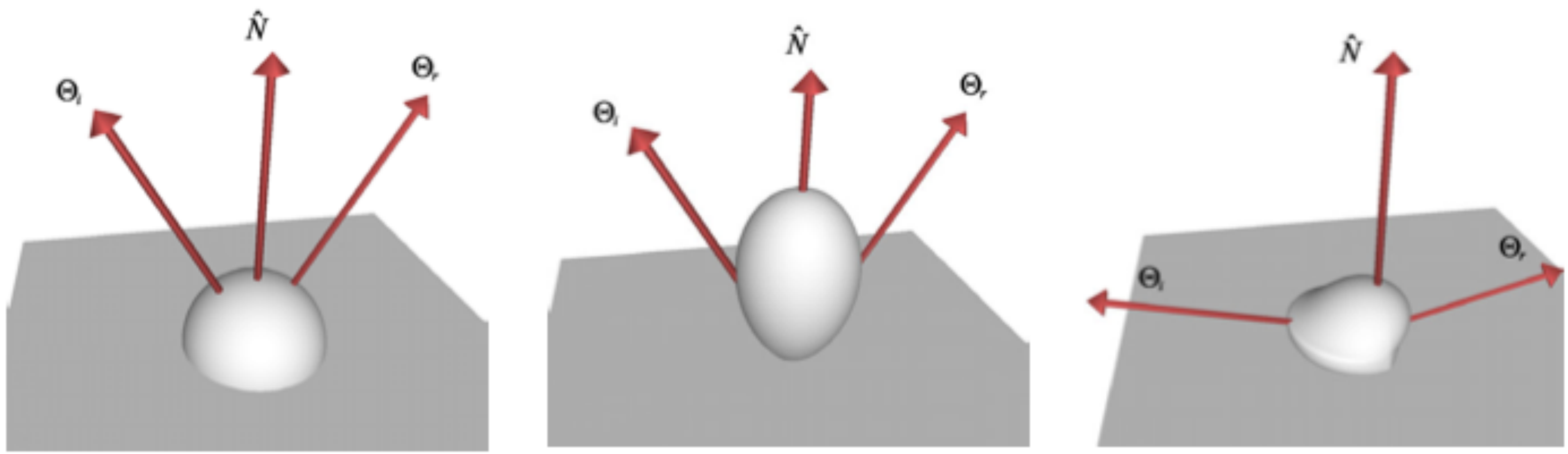


Fig. 2. Diffuse BRDF models: Lambert, Minnaert and Oren-Nayar.

Interesting Phenomena

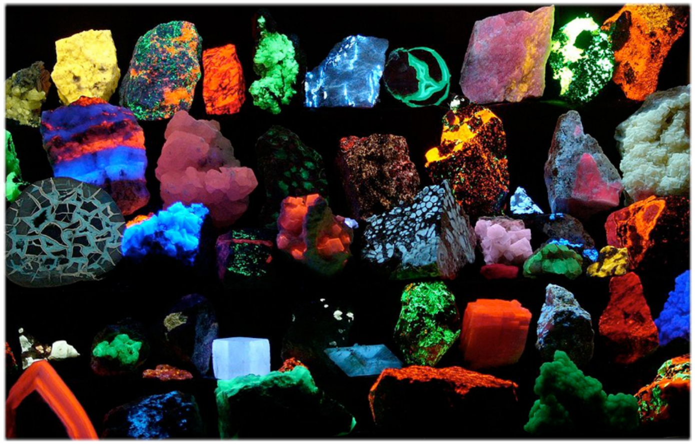
Fluorescence

Fluorescence

- Material absorbs electromagnetic radiation and emits light, usually of longer wavelength (lower frequency)
- Typical example: Material absorbs ultraviolet radiation and emits visible light

Courtesy of Beo Beyond at Wikipedia

Courtesy of Hannes Grobe at Wikipedia



Phosphorescence

Phosphorescence

- Material absorbs electromagnetic radiation and emits it as light at a later time (some times several hours later)
- Examples: glow in the dark toys, clock dials that glow
- It lead to the discovery of radioactivity in 1896
- Ironically White Phosphorus is not phosphorescent it is chemiluminescent (light emitted as a result of chemical reaction)

Iridescence

Iridescence

- Material appears to change colour as the angle of view or the angle of illumination changes

Courtesy of Wikipedia user Tagishsimon

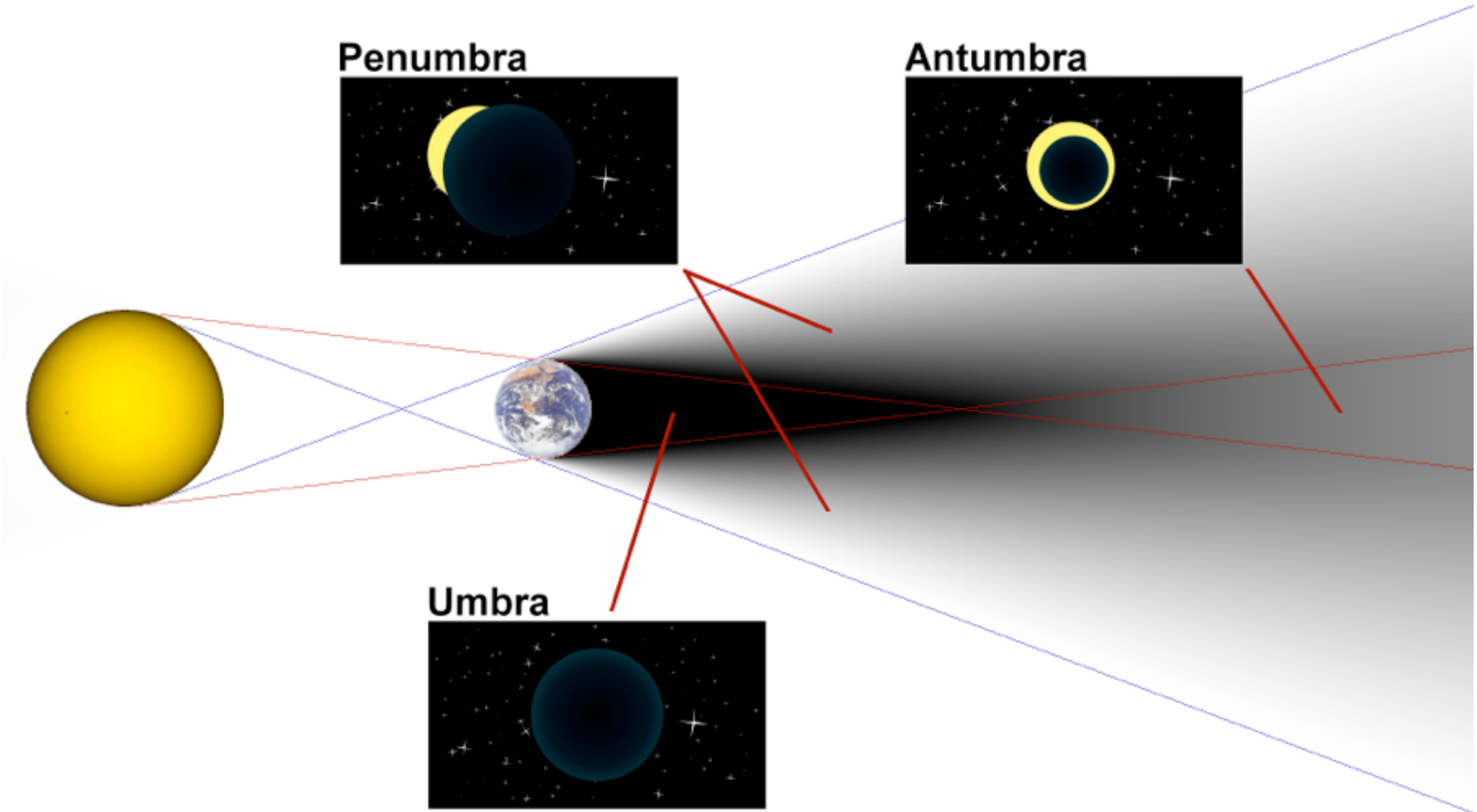
Courtesy of Didier Descouens, Wikipedia

Iridescence

- Material appears to change colour as the angle of view or the angle or illumination changes

Courtesy of Rocky Bloniarz and his family

Soft shadows (wikipedia)



Global Illumination Solutions

Computing light interface between all surfaces

Radiosity

Ray tracing

Courtesy of Henrik Wann Jensen

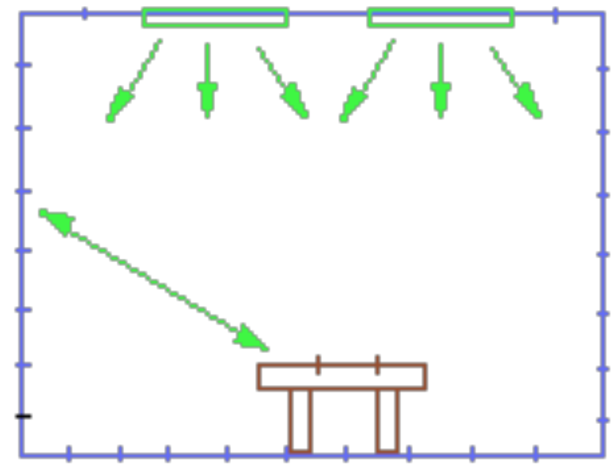
Radiosity

Physics-based (heat transfer and illumination engineering)

Suited for Diffuse reflection

Infinite reflections

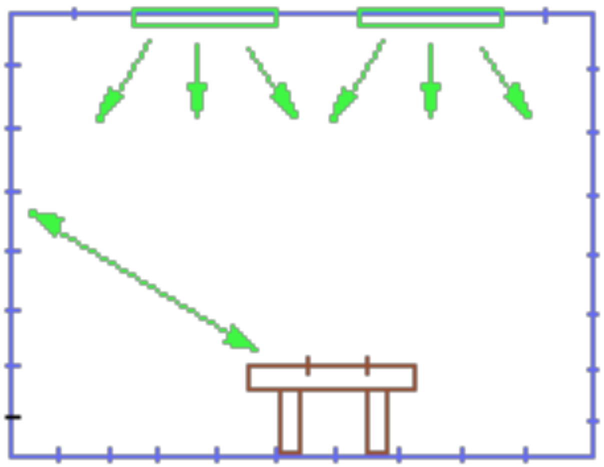
Soft shadows



Radiosity algorithm

Break scene into small patches, Ai

Assume uniform reflection and emission per patch



Energy balance for all patches:

Light leaving surface = emitted light + reflected light

Example

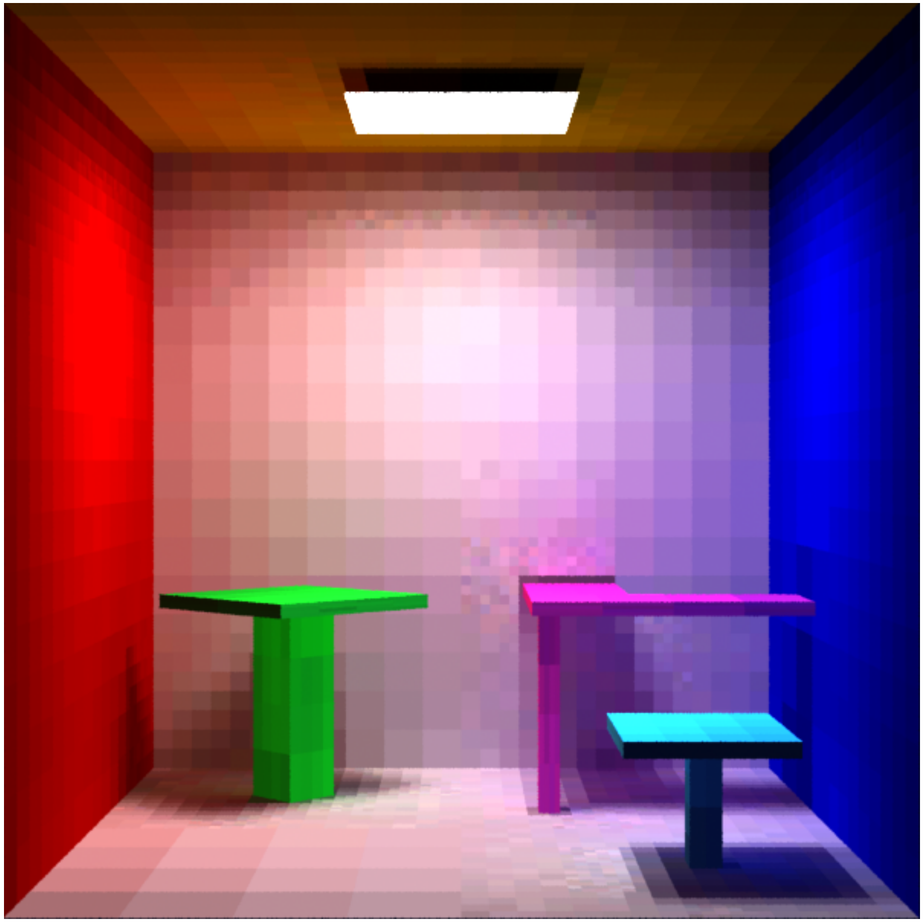


Image from

- https://www.cg.tuwien.ac.at/research/rendering/rays-radio/

Notation

- Flux: energy per unit time (W)
- Radiosity B: exiting flux density (W/m^2)
- E: exiting flux density for light sources
- Reflectivity R: fraction of incoming light reflected (unitless)
- Form factor F_{ij}: fraction of energy leaving A_i and arriving at A_j determined by the geometry of polygons i and j

Energy balance on surface patches

Light leaving patch = emitted light + reflected light

$$B_i A_i = E_i A_i + R_i \sum_j F_{ji}(B_j A_j) \rightarrow$$

$$B_i A_i = E_i A_i + R_i \sum_j B_j F_{ji} A_j \rightarrow$$

$$B_i = E_i + R_i \sum_j B_j F_{ji} \frac{A_j}{A_i}$$

Form factor reciprocity:

$$F_{ji} A_j = F_{ij} A_i \rightarrow F_{ij} = F_{ji} \frac{A_j}{A_i}$$

Final linear system:

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

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

Linear system for *n* patches

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

Matrix O(n^2)

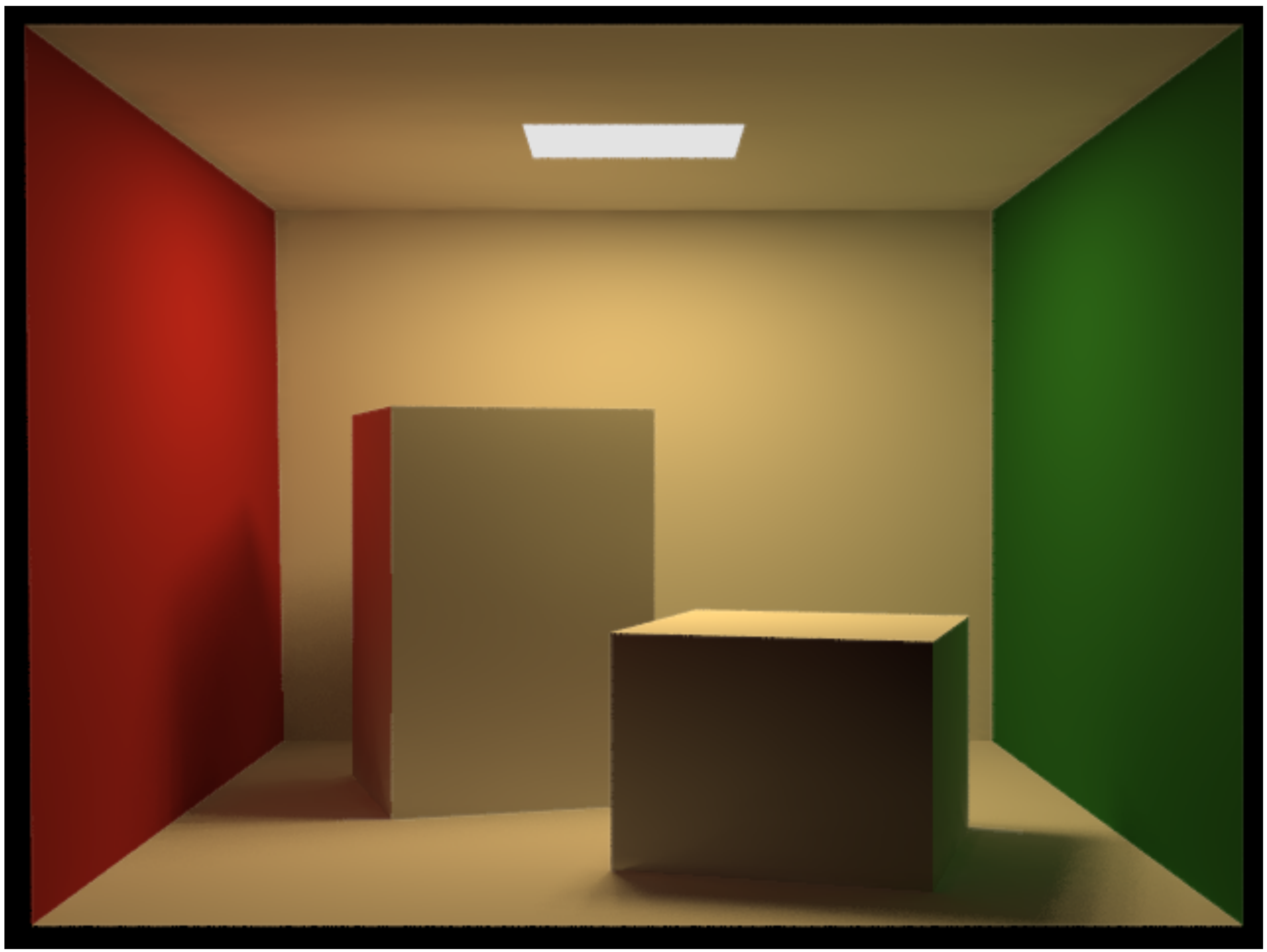
Computing Form-factors

- This is where all the difficulty lies

Main assumption

- Diffuse patches

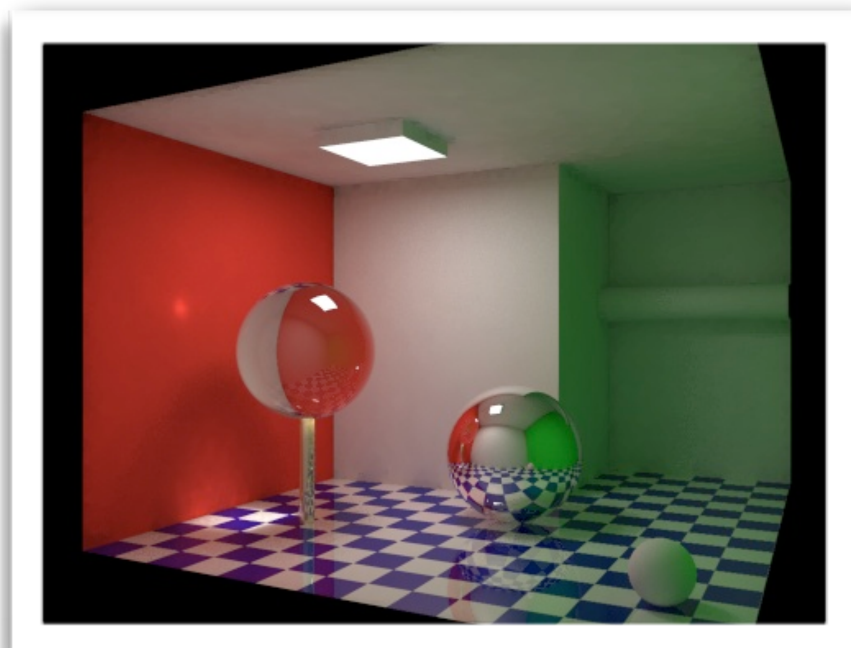
Example: The Cornell scene



Comparison (from wikipedia)

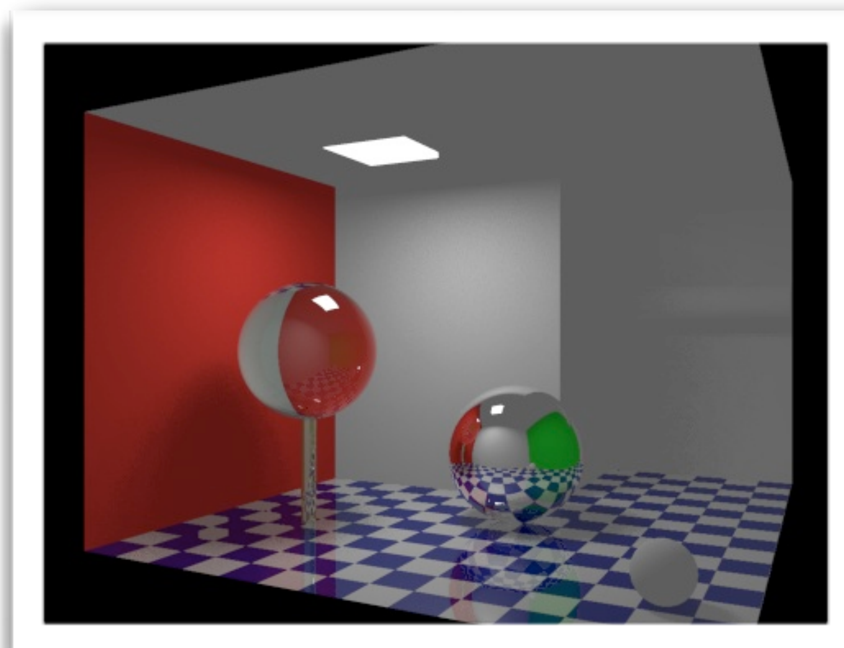
With

Rendering with global illumination. Light is reflected by surfaces, and colored light transfers from one surface to another. Notice how color from the red wall and green wall (not visible) reflects onto other surfaces in the scene. Also notable is the caustic projected onto the red wall from light passing through the glass sphere.



Without

Rendering without global illumination. Areas that lie outside of the ceiling lamp's direct light lack definition. For example, the lamp's housing appears completely uniform. Without the ambient light added into the render, it would appear uniformly black.



Radiosity summary

Object space algorithm

- Algorithm operates on patches of objects in world space

Suited for diffuse reflections

- Patches are assumed to be diffuse only

Nice soft-shadows

- Objects and lights subdivided into small patches