Fundamentals of Computer Graphics

Lecture 11. Radiosity

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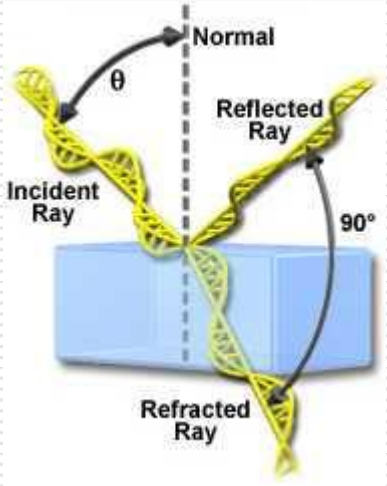
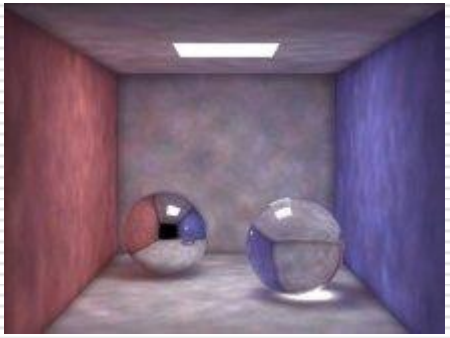
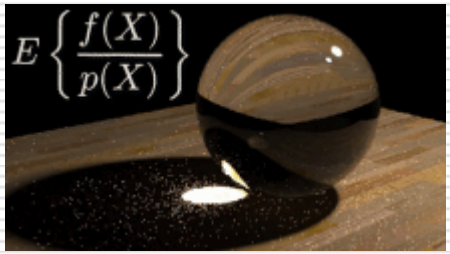
Trade-off: speed vs. accuracy







Simple lighting
heuristic rules

Global
illumination

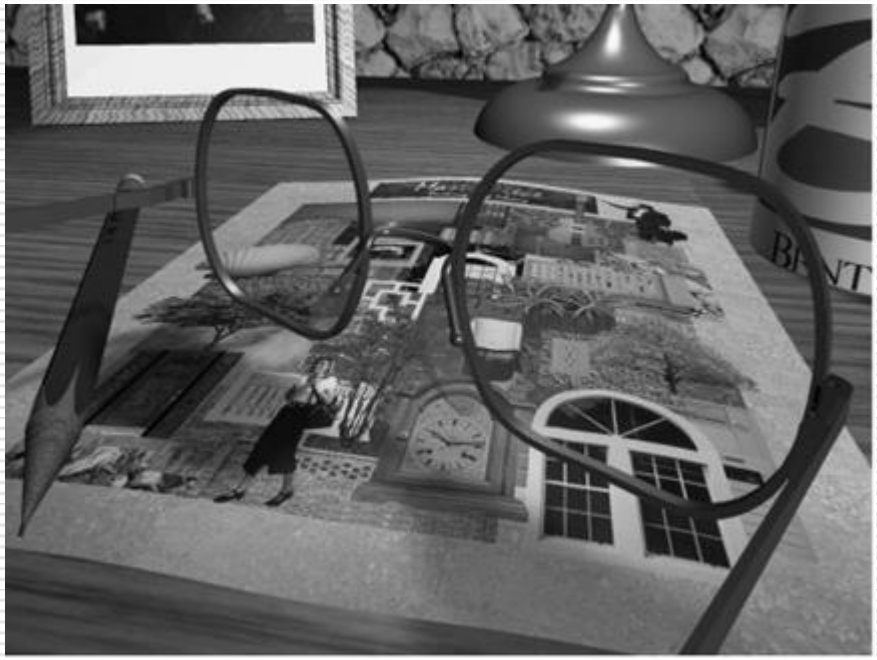
Physics
Optics

Computer
Science

Realistic(Accurate)
Very time consuming

Fast
Real time

Local vs Global Illuminations

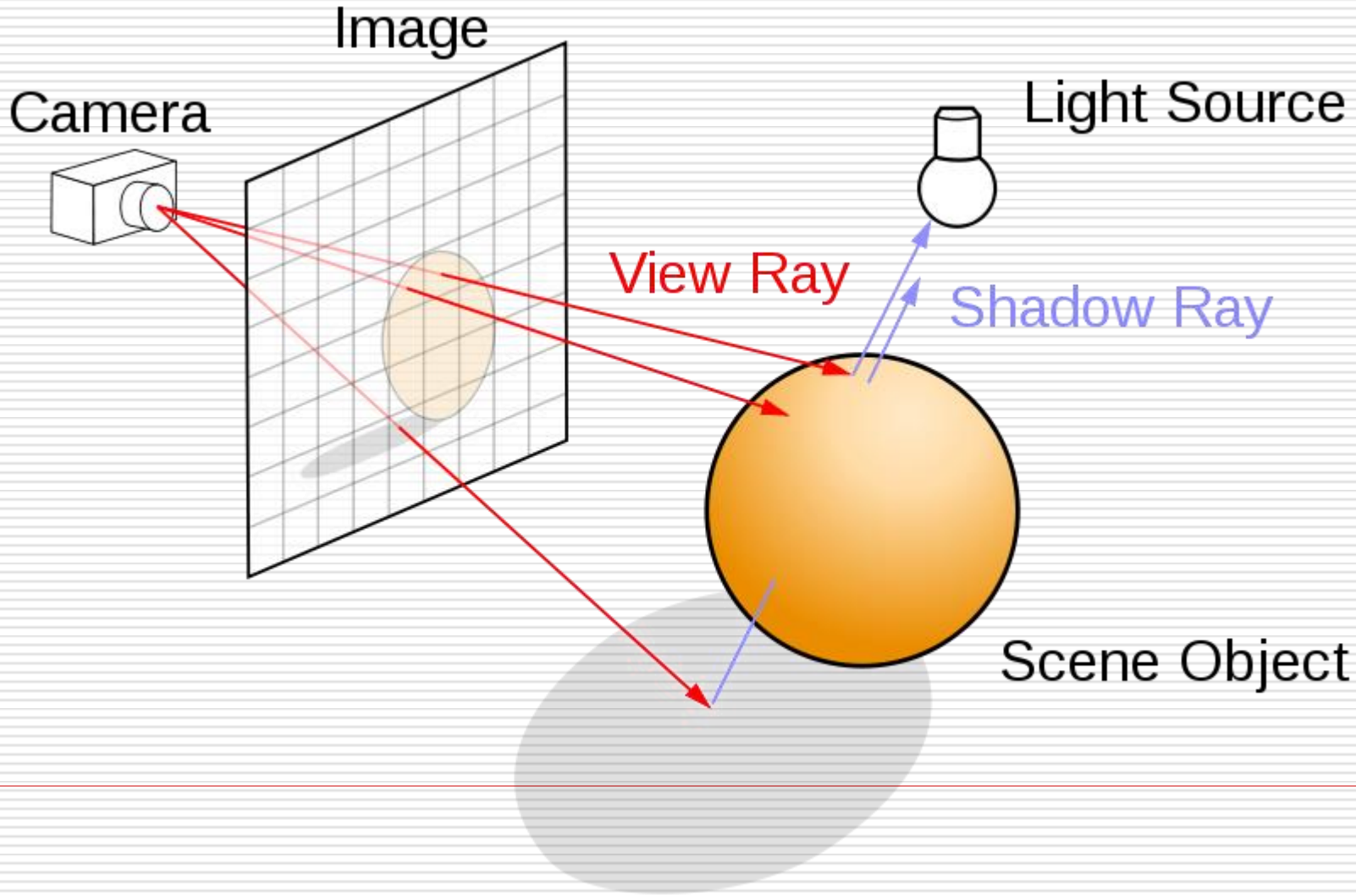


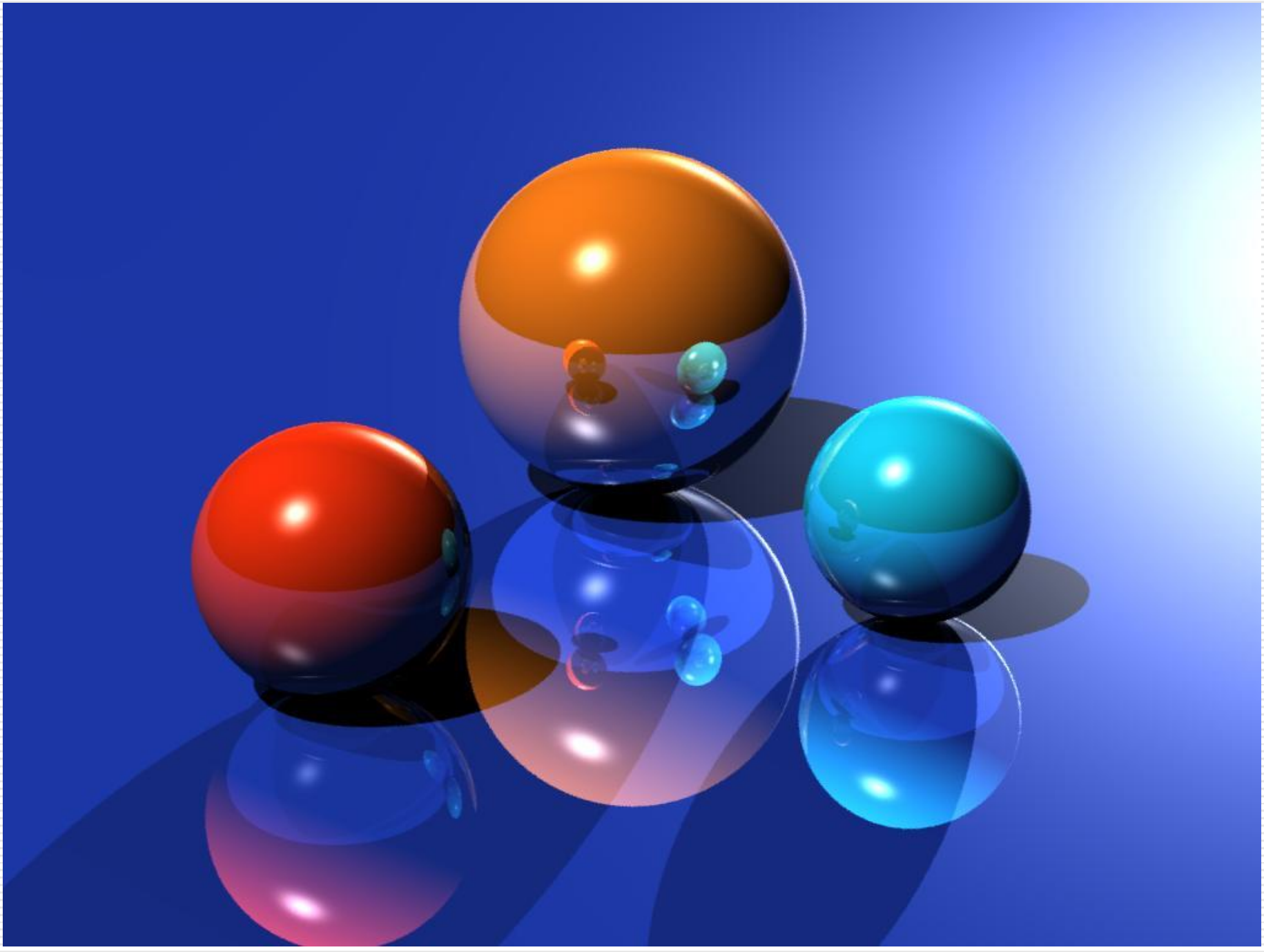
OpenGL model

Ray tracing

Specular, reflective and transparent components

Ray Tracing





Outline

Global illumination

- Improved Image Quality:
  Indirect light, soft shadows, and color bleeding between surfaces produce images of natural realism
- More Intuitive Lighting
  Instead of specifying lighting intensity with arbitrary values, light intensity can now be specified using photometric units (lumens, candelas, and so on).

Outline

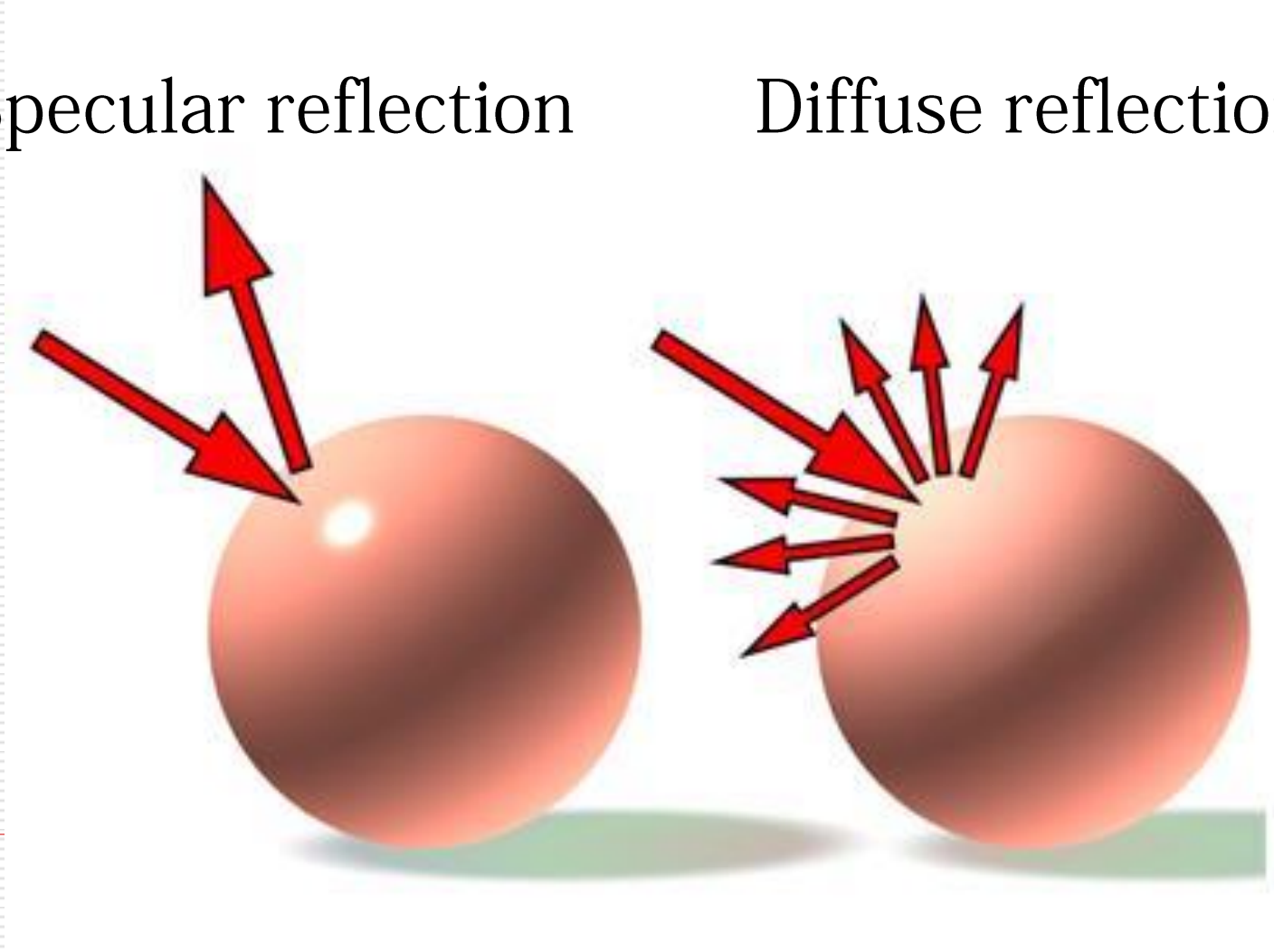
3DS MAX offers two global illumination algorithms as an integral part of its production rendering system:

- Ray-tracing
- Radiosity

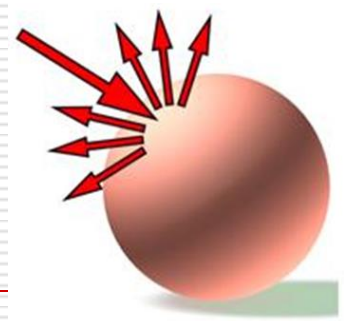
Why *ray-tracing* vs. *radiosity*

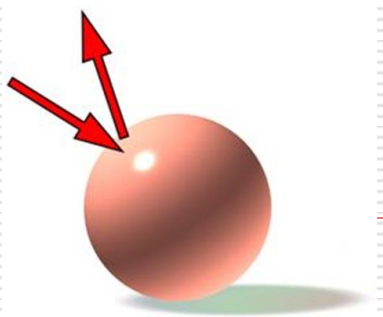
Specular reflection

Diffuse reflection



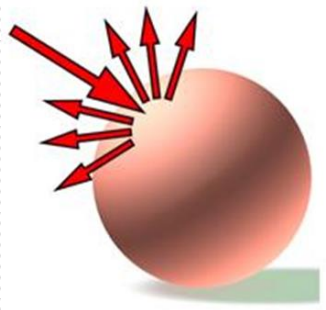
Ray Tracing

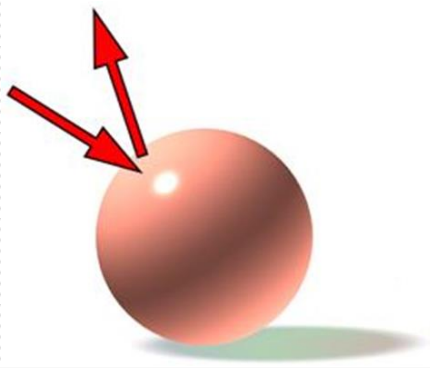


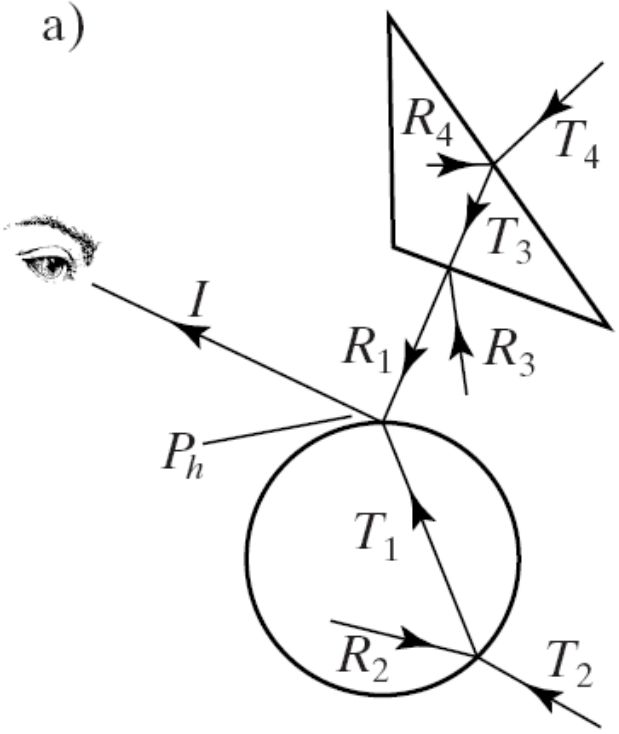


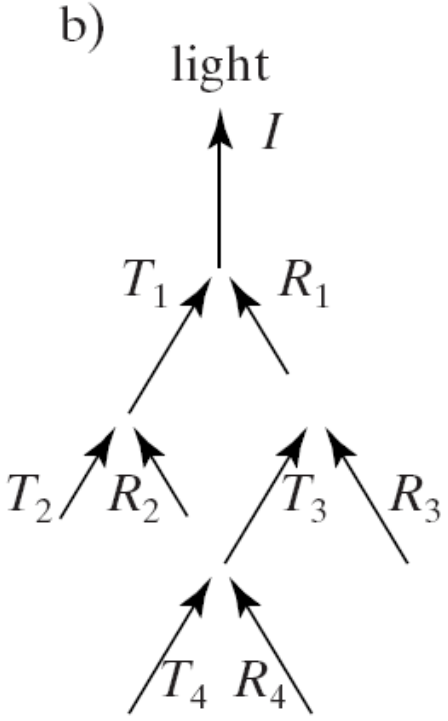
Reflections and Transparency

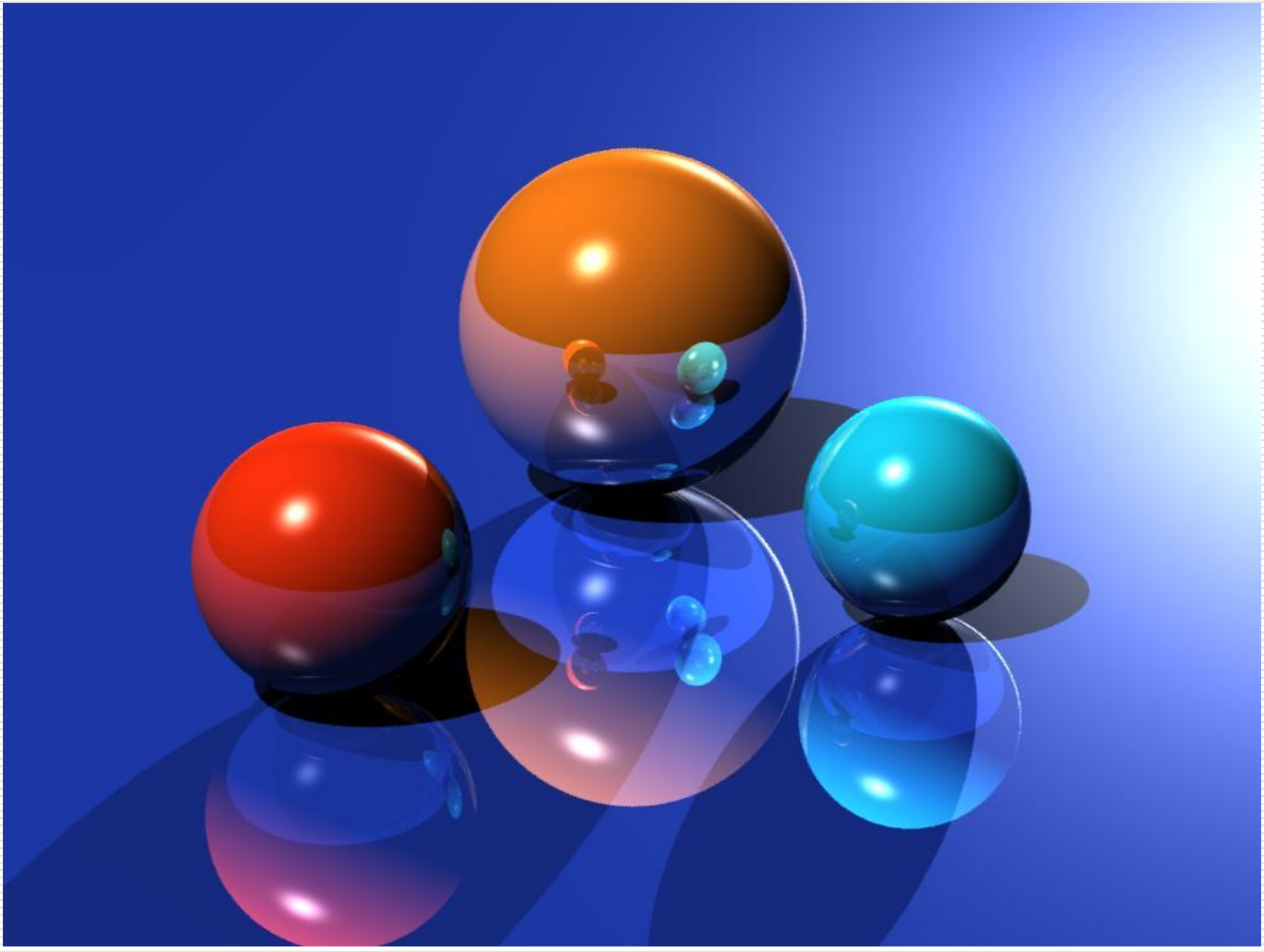
- The tree of light rays; local components are not shown





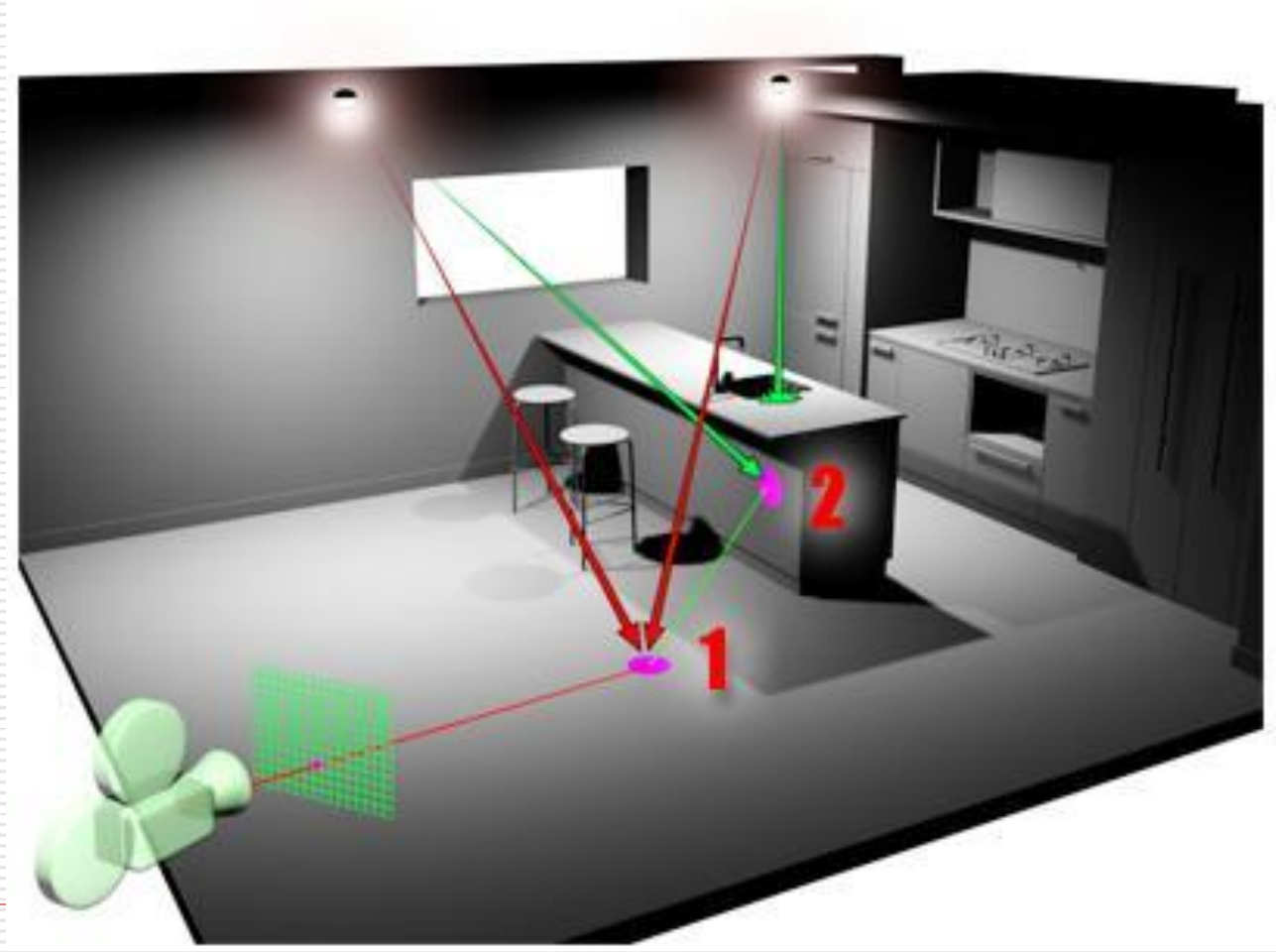


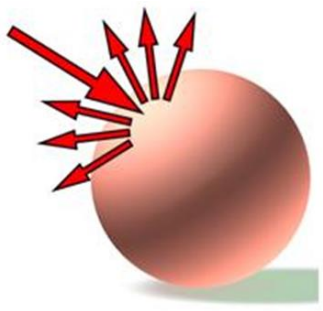




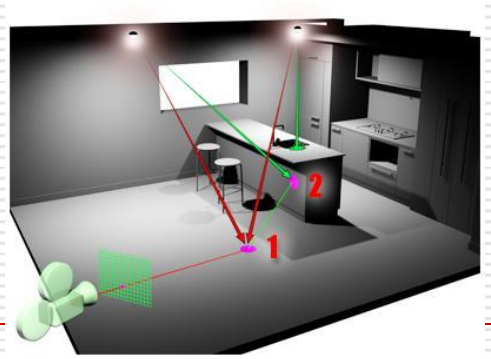
Ray tracing:

Rays are traced from the camera through a pixel, to the geometry, then back to their light sources

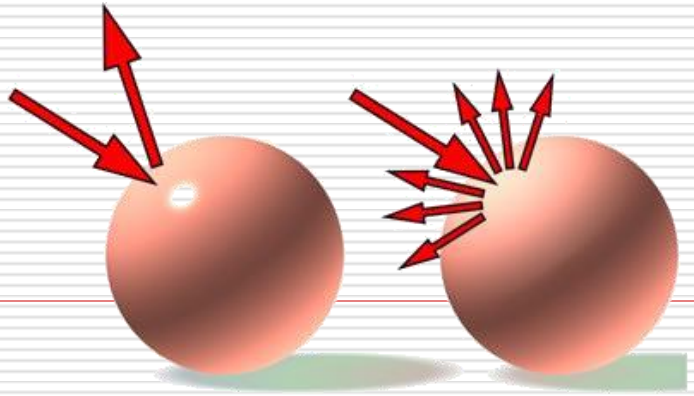




Ray tracing



- Accurately account for the global illumination characteristics of direct illumination, shadows, **specular reflections** (for example, mirrors), and refraction through transparent materials
- Very slow for environments of even moderate complexity
- Do not account for **diffuse inter-reflections**



Radiosity

Global illumination

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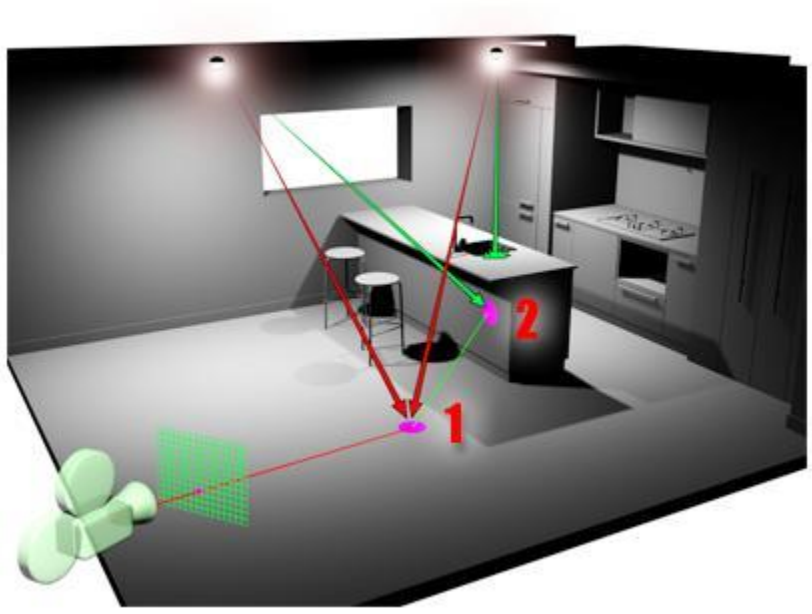
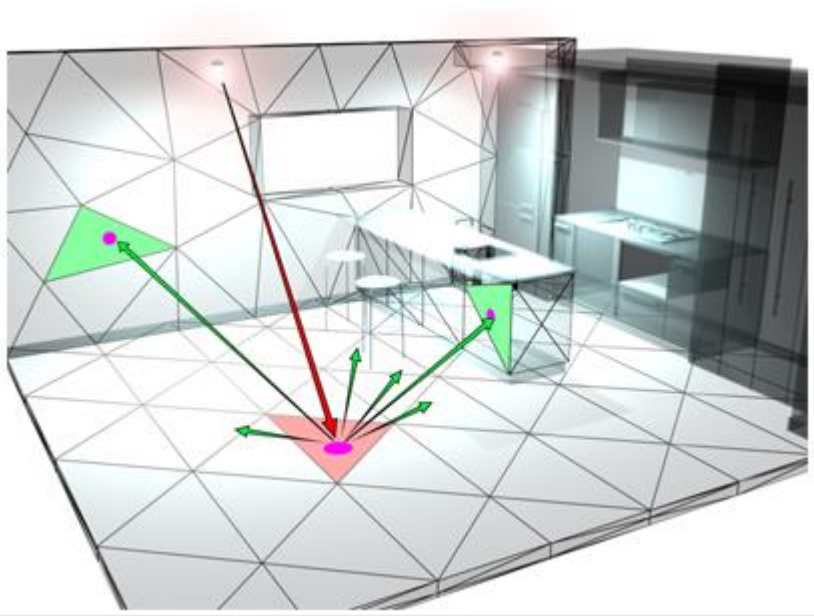
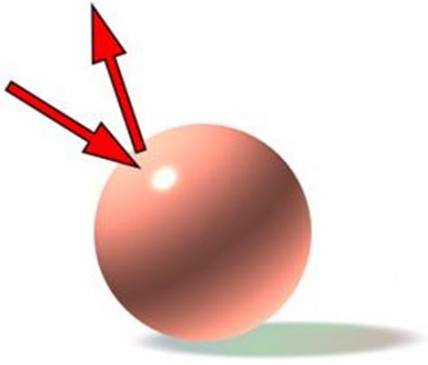
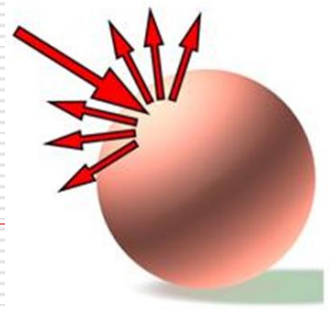
Ray tracing

Radiosity









Radiosity

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Radiosity: More Intuitive Lighting

In conjunction with radiosity techniques, 3ds Max also provides a real-world lighting interface. Instead of specifying lighting intensity with arbitrary values, light intensity is specified using photometric units (lumens, candelas, and so on). In addition, the characteristics of real-world lighting fixtures can be defined using industry-standard Luminous Intensity Distribution files (such as IES, CIBSE, and LTLI), which are obtainable from most lighting manufacturers. By being able to work with a real-world lighting interface, you can intuitively set up the lighting in your scenes. You can focus more on your design exploration than on the computer graphic techniques required to visualize them accurately.

Application scenarios

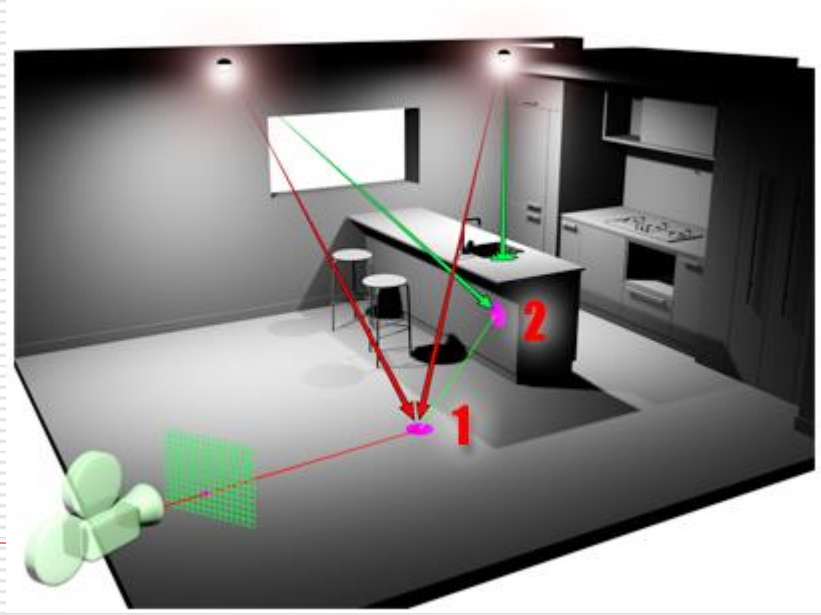
This kitchen right has two light sources. One theory of light considers the light in terms of discrete particles called photons, that travel from the light source until they encounter some surface in the kitchen. Depending on the surface material, some of these photons are absorbed and others are scattered back out into the environment. The fact that photons traveling at a particular wavelength are absorbed while others are not is what determines the color of the surface.

Application scenarios

Surfaces that are very smooth reflect the photons in one direction, at an angle equal to the angle at which they arrive at the surface, the angle of incidence. These surfaces are known as specular surfaces, and this type of reflection is known as specular reflection.

A mirror is an example of a perfectly specular surface.

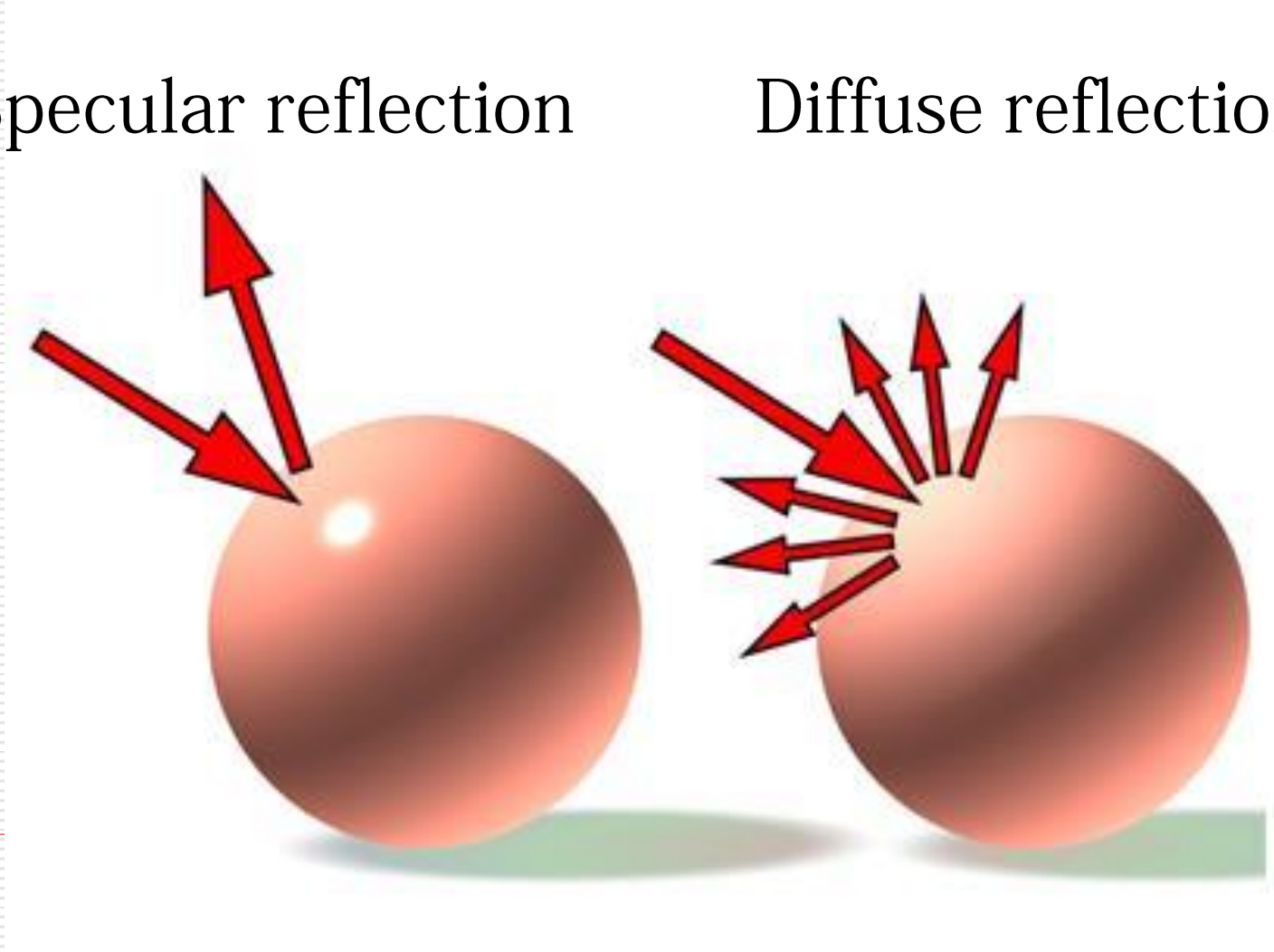
Of course, many materials display some degree of both specular and diffuse reflection.



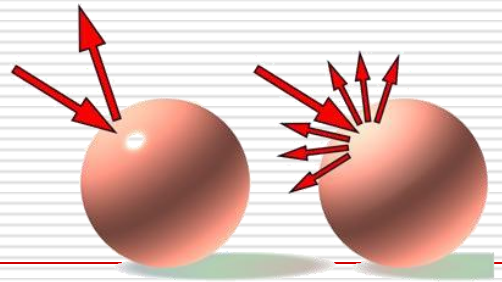
Why *ray-tracing* vs. *radiosity*

Specular reflection

Diffuse reflection



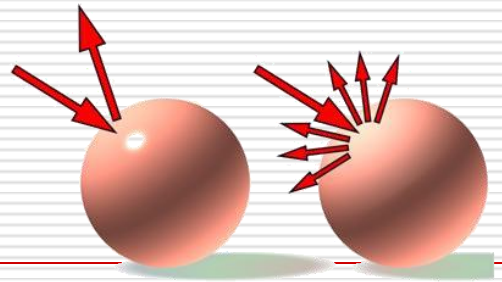
Ray tracing



- Not good for diffuse components

Ray tracing displays only specular highlights

Radiosity

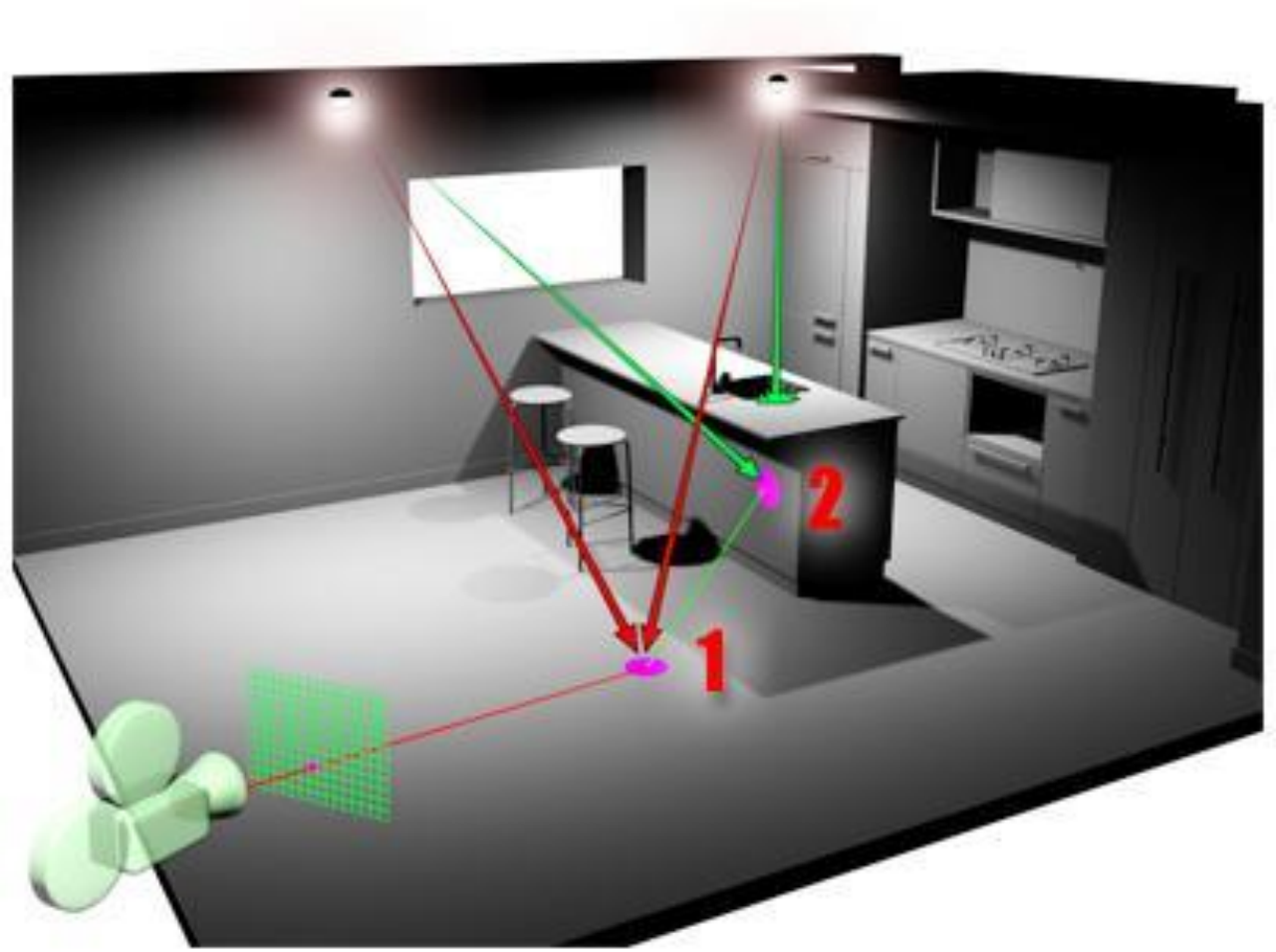


- Very good for diffuse components

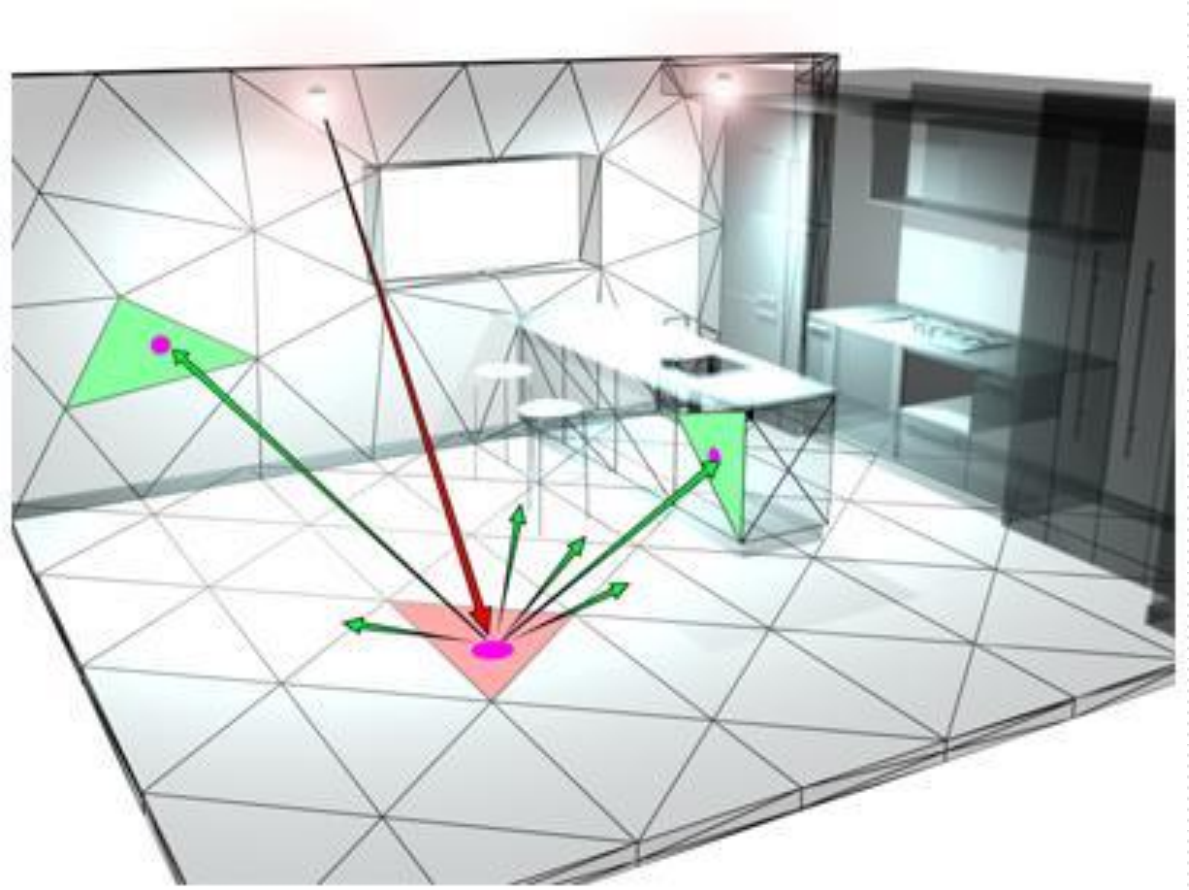
Notice that the walls are more naturally illuminated by reflected as well as direct light. Notice in particular, the circle of light on the left wall above the table. This is caused by light reflecting from the silver tray (with decanter and glasses) on the table.

Ray tracing:

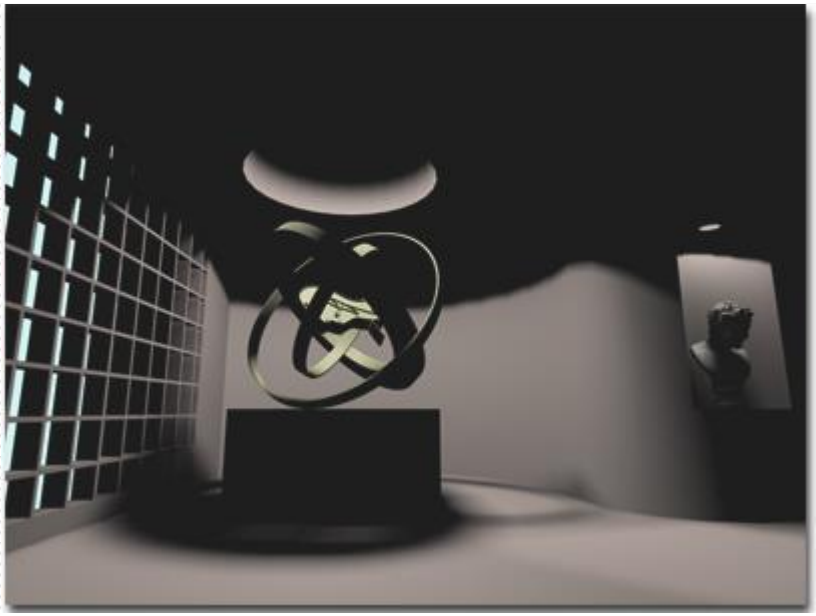
Rays are traced from the camera through a pixel, to the geometry, then back to their light sources

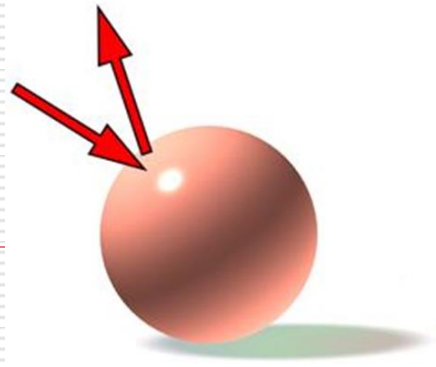


Radiosity

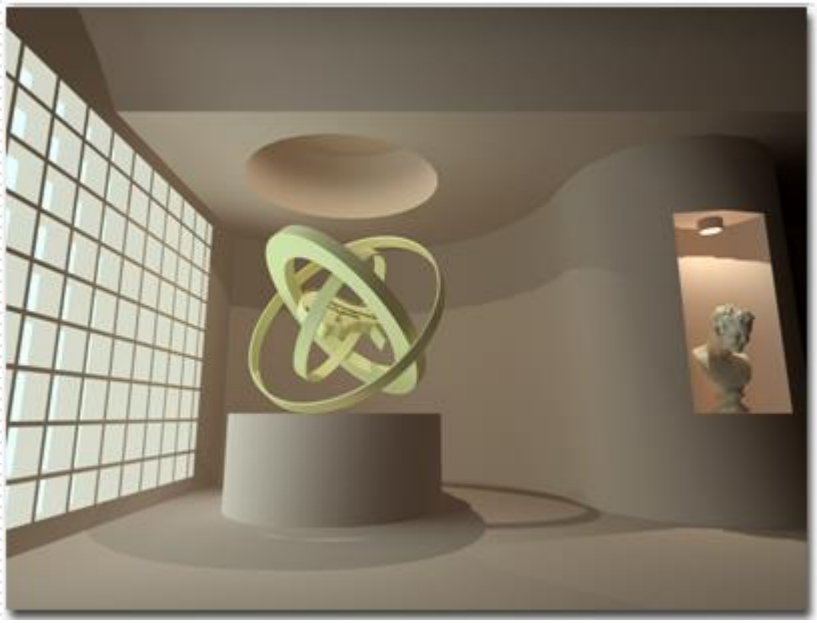


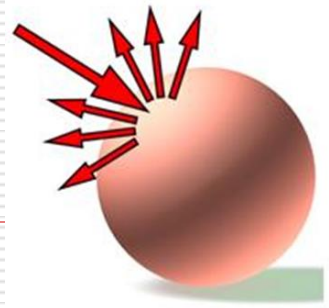
Ray tracing





Radiosity



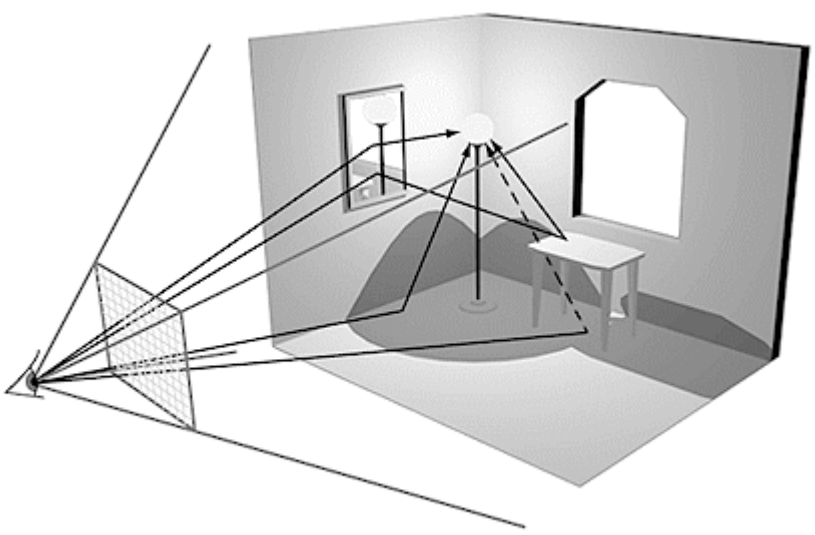


Summary

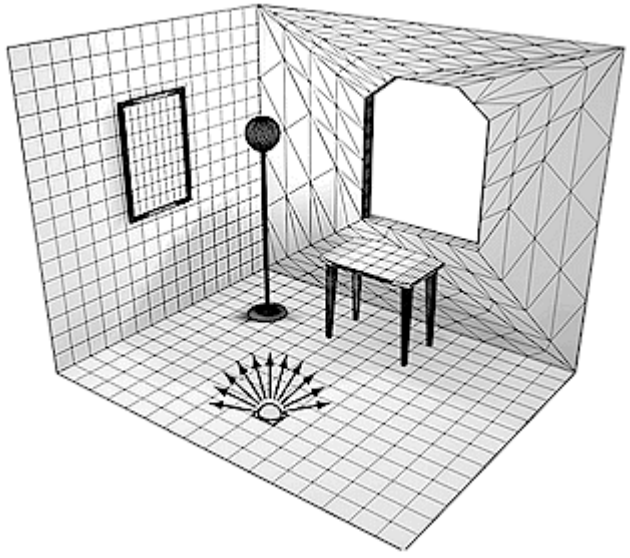
- Ray tracing has a visual signature
  - Only models perfect specular reflection and transmission
- Interaction between diffusely reflecting surfaces
  - Interiors, matte surfaces, indirect lighting

Basic idea (Radiosity)

- Divide surfaces into discrete patches
  - Object space algorithm
- Treat every polygon as light source



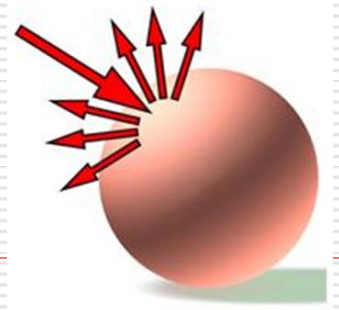
Ray tracing

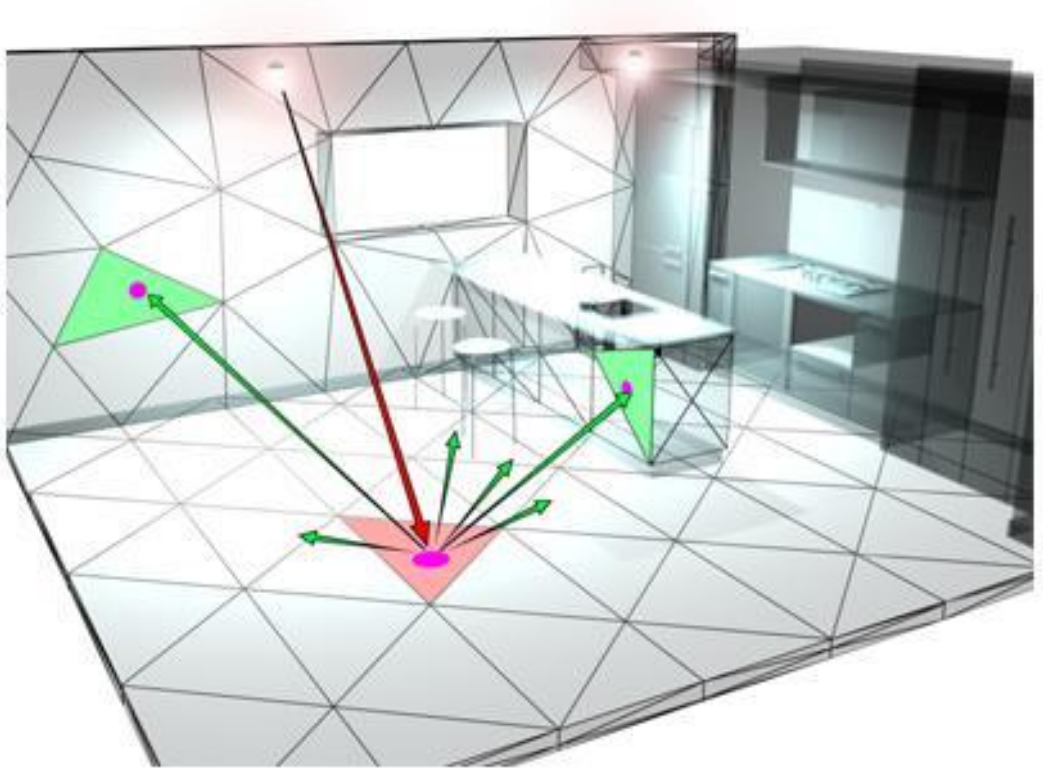


Radiosity

Basic idea (Radiosity)

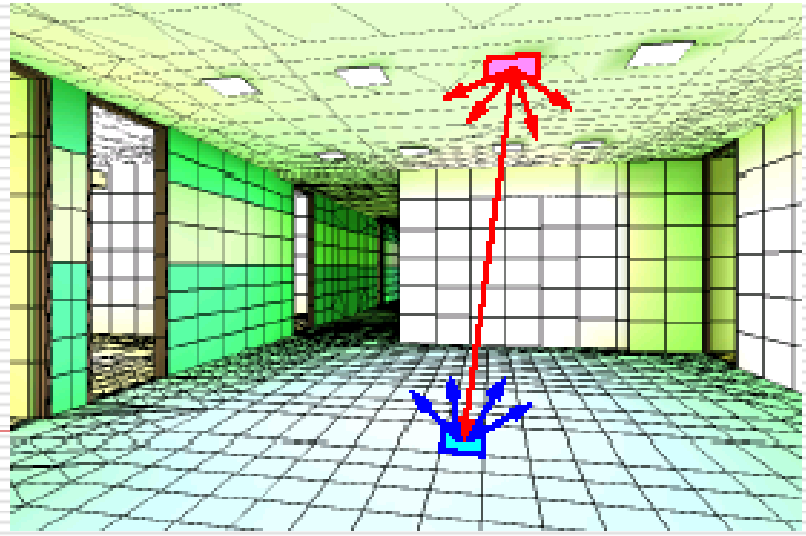
- Divide surfaces into discrete patches
- Treat every polygon as light source





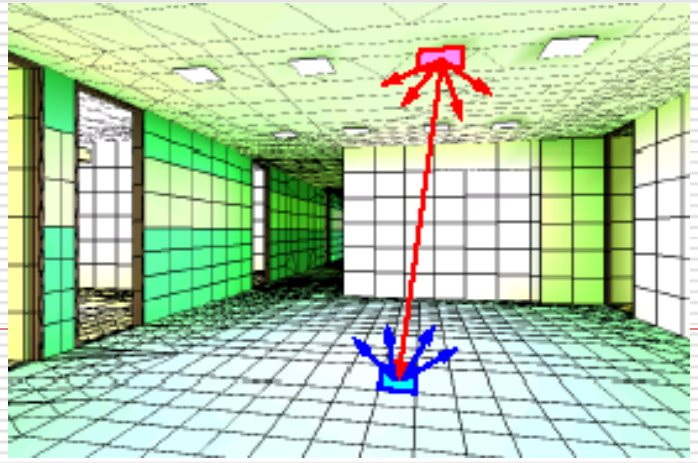
Basic idea (Radiosity)

- Divide surfaces into discrete patches
  - Object space algorithm
- Treat every polygon as light source
- Model light transfer between patches as system of linear equations



Basic idea (Radiosity)

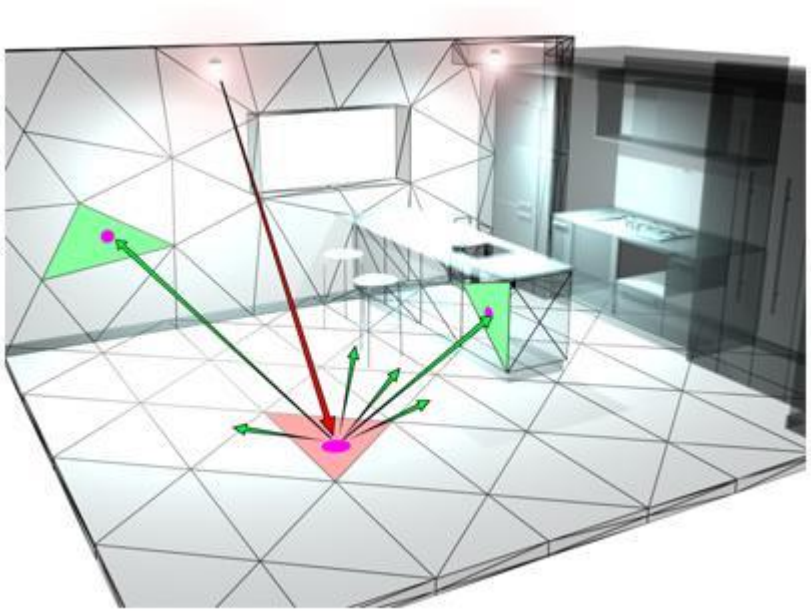
- Divide surfaces into discrete patches
- Treat every polygon as light source
- Model light transfer between patches as system of linear equations
- Solve matrix equation for radiosity of each patch
  - Do it for R,G,B



Basic idea (Radiosity)

- Divide surfaces into discrete patches
- Treat every polygon as light source
- Model light transfer between patches as system of linear equations
- Solve matrix equation for radiosity of each patch
- Render patches as colored polygons

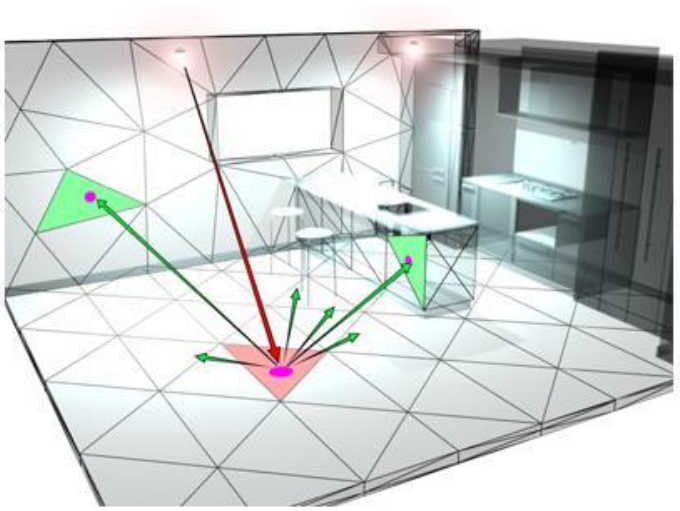
Basic idea (Radiosity)



Basic Radiosity Model

- Radiosity Equation

$$B_k = E_k + \rho_k \sum_{j=1}^{n} B_i F_{jk}$$



- B_k : Radiosity of patch k
- E_k : Emission of patch k
- ρ_k : Reflectivity of patch k
- F_{jk} : Form Factor between patch j and k

Basic Radiosity Model

$$\begin{bmatrix} 1-P1F1,1 & -P1F1,2 & \cdots\cdots & -P1Fi,n \\ -P2F2,1 & 1-P2F2,2 & \cdots\cdots & -P2F2,n \\ & \cdots\cdots & & \\ & \cdots\cdots & & \\ -PnFn,1 & -PnFn,2 & \cdots\cdots & 1-PnFn,n \end{bmatrix} \begin{bmatrix} b1 \\ b2 \\ \\ \\ bn \end{bmatrix} = \begin{bmatrix} e1 \\ e2 \\ \\ \\ en \end{bmatrix}$$

Basic Radiosity Model

- Since form factor is only dependent on geometry, the above matrix is only needed to be computed once providing the geometry is not changed. Algorithms using this approach are called **Full Matrix** or **FM** algorithms

Basic Radiosity Model

Background

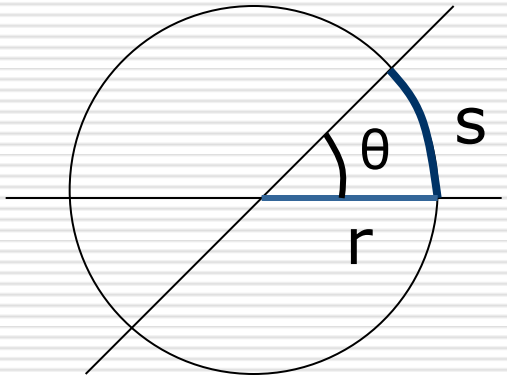
- Radian

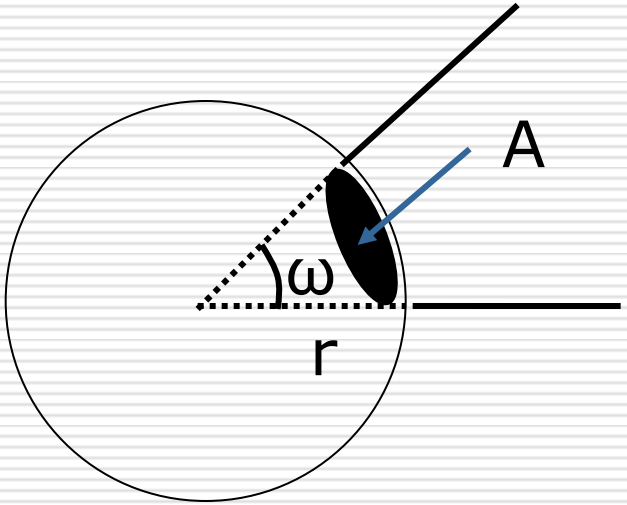
  $\theta = s/r$

- Solid angle

  $\omega = A/r^2$

  ω : steradian

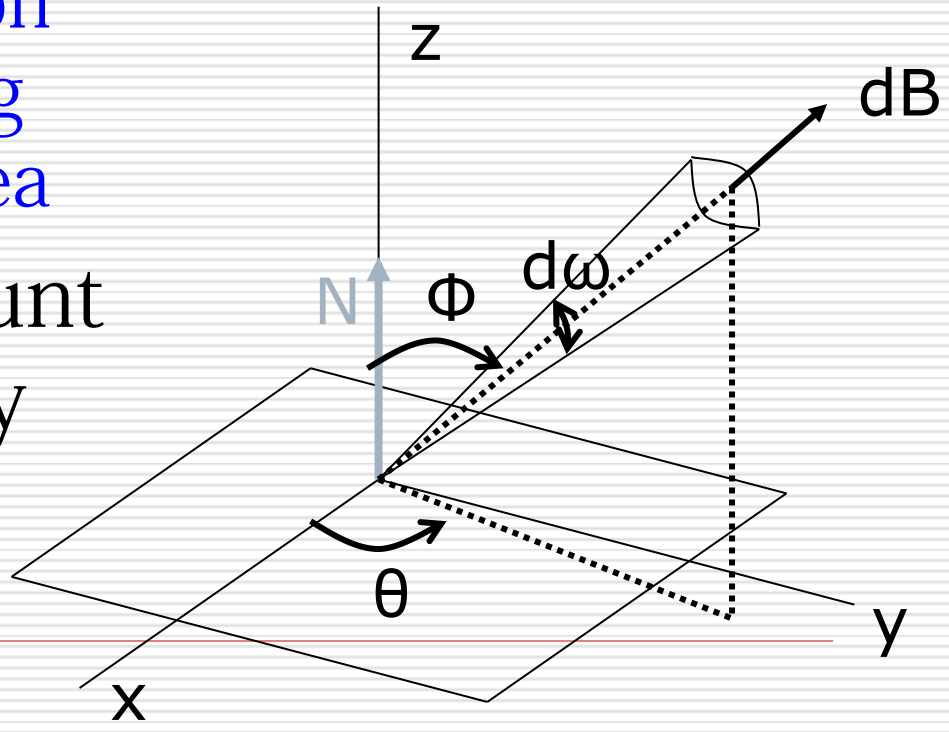




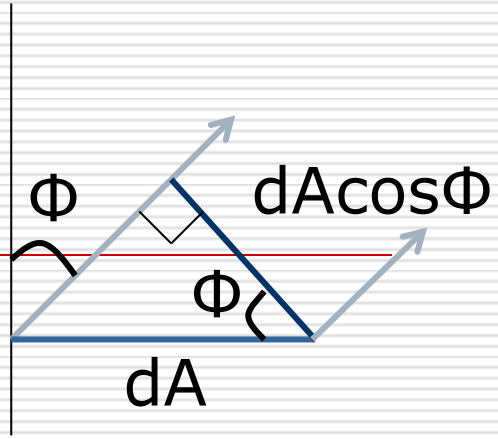
Basic Radiosity Model

Radiosity of patch: B

- B_k : Radiosity of patch k
  - Total diffuse reflection rate of energy leaving surface k per unit area
- dB : differential amount of radiant energy
  - joules/sec•meter2, watts/meter2



Basic Radiosity Model



- I : Intensity or luminance
  - radiant energy per unit time
  - per unit projected area per unit solid angle (watts/meter^2•steradians)

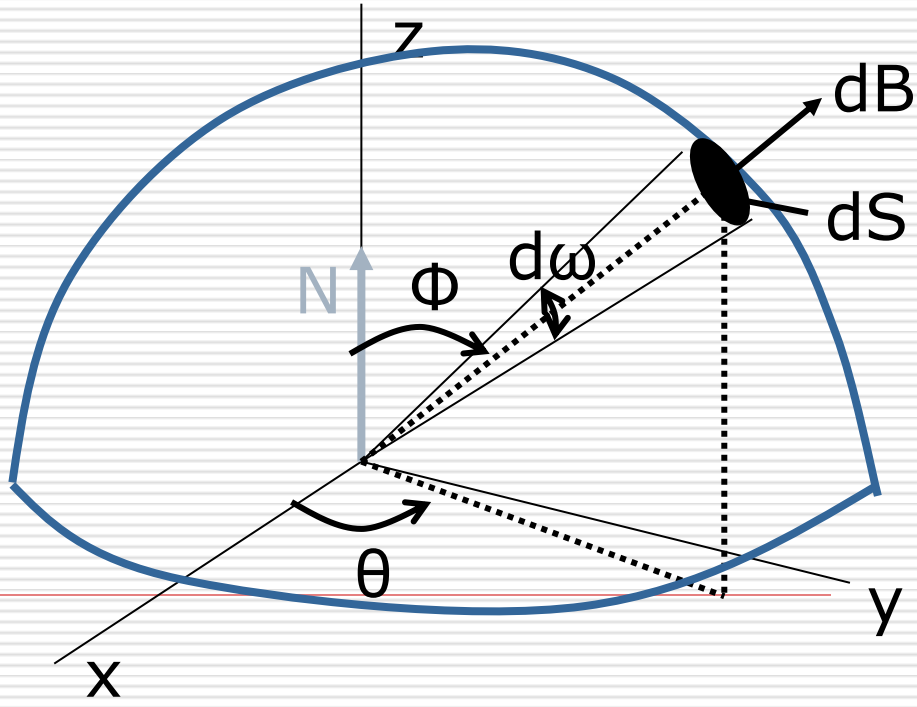
$$I = dB / d\omega \cos\Phi$$

  - assuming the surface is ideal diffuse reflector, I = constant

$$B = \int_{hemi} dB \qquad B = I \int_{hemi} \cos\Phi d\omega$$

Basic Radiosity Model

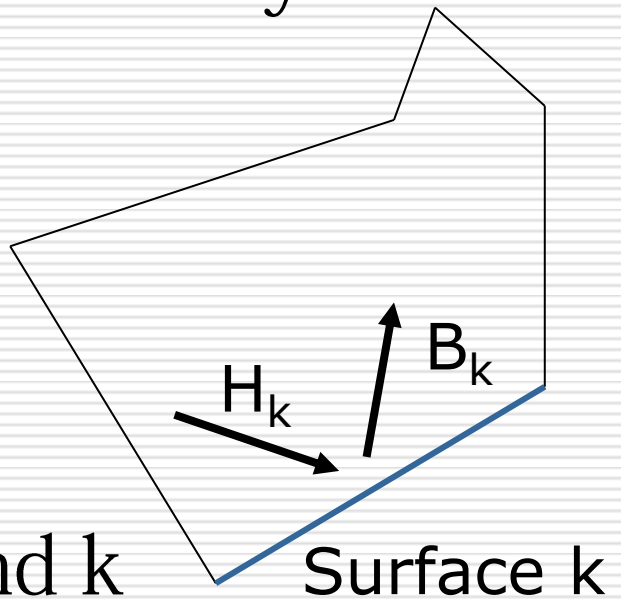
- $d\omega = dS / r^2 = \sin\Phi d\Phi d\theta$
- $B = I \int_o \int_o \cos\Phi \sin\Phi d\Phi d\theta$
  $= I\pi$



Basic Radiosity Model

- Enclose of surfaces for the radiosity model

$$H_k = \sum_j B_j F_{jk}$$



H_k : Insident energy

F_{jk} : Form factor for surfaces j and k

(fractional amount of surfaces j ⇨ k)

Basic Radiosity Model

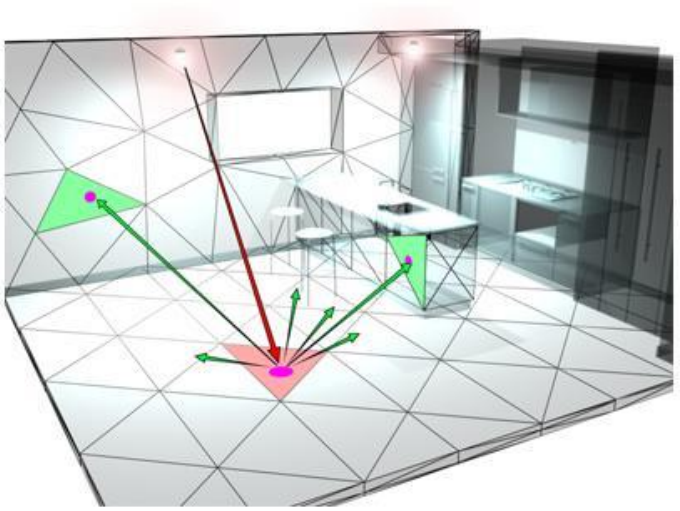
- $B_k = E_k + \boldsymbol{\rho}_k H_k$

$$\Rightarrow \quad B_k = E_k + \rho_k \sum_{j=1}^{n} B_j F_{jk}$$

Basic Radiosity Model

- Radiosity Equation

$$B_k = E_k + \rho_k \sum_{j=1}^{n} B_i F_{jk}$$



- B_k : Radiosity of patch k
- E_k : Emission of patch k
- ρ_k : Reflectivity of patch k
- F_{jk} : Form Factor between patch j and k

Basic Radiosity Model

$$\begin{bmatrix} 1-P1F1,1 & -P1F1,2 & \cdots\cdots & -P1Fi,n \\ -P2F2,1 & 1-P2F2,2 & \cdots\cdots & -P2F2,n \\ & \cdots\cdots & & \\ & \cdots\cdots & & \\ -PnFn,1 & -PnFn,2 & \cdots\cdots & 1-PnFn,n \end{bmatrix} \begin{bmatrix} b1 \\ b2 \\ \\ \\ bn \end{bmatrix} = \begin{bmatrix} e1 \\ e2 \\ \\ \\ en \end{bmatrix}$$

Basic Radiosity Model

- Emission of patch : E
  - if surface k is not a light source
    E = 0
  - Else
    rate of energy emitted from surface per unit area(watts/meter^2)
- Reflectivity factor of patch : ρ
  - percent of incident light reflected in all directions

Basic Radiosity Model

- Form factor : F
  - energy transfer from surface j to surface k

$dB_j dA_j = (I_j \cos\Phi_j d\omega) dA_j$

solid angle $d\omega$: the projection of area element dA_k perpendicular to the direction dB_j

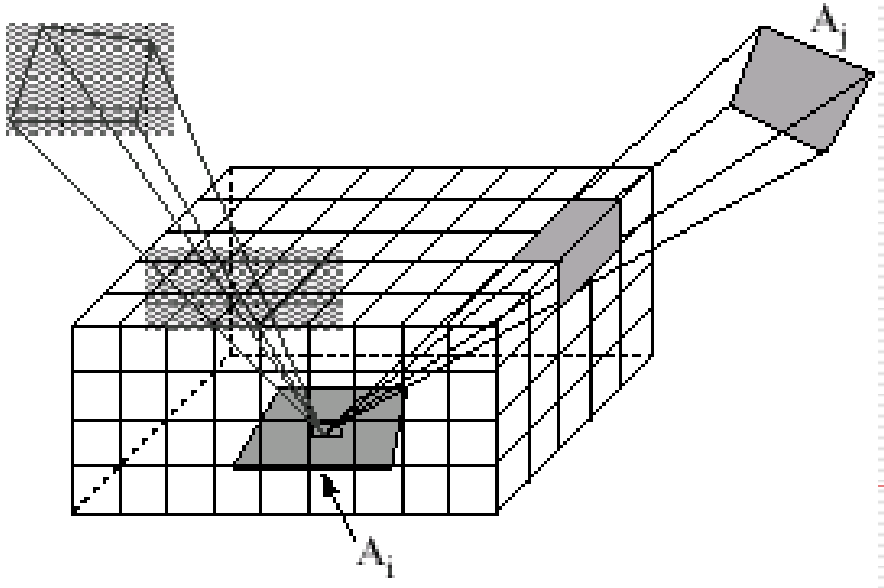
$d\omega = dA / r^2 = \cos\Phi_k dA_k / r^2$

Basic Radiosity Model

- Form factor

HemiSphere → HemiCube

(spherical surface) (linear(plane) surface)



Basic Radiosity Model

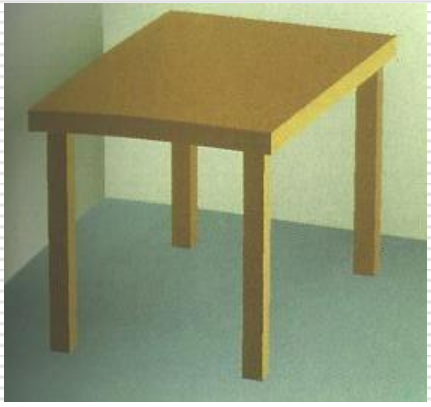
- HemiCube Method
  - project scene onto hemicube positioned at centroid of patch i
  - count pixel coverage to determine form factors F_i
  - can use H/W z-buffer
    → speed up
    → use Image precision, prone to aliasing

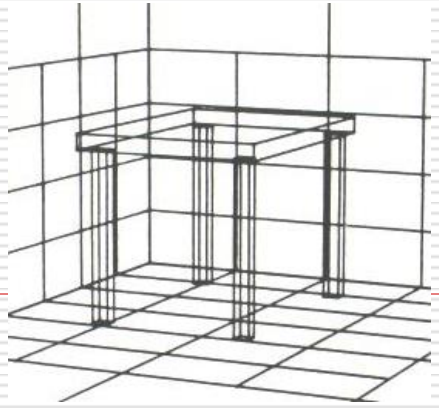
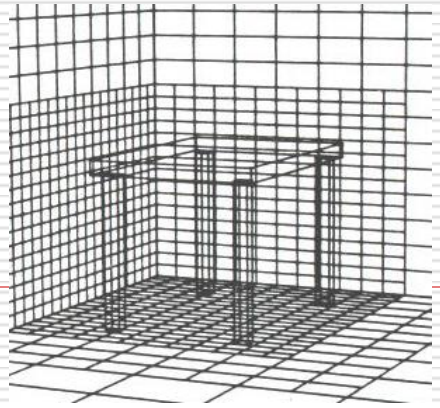
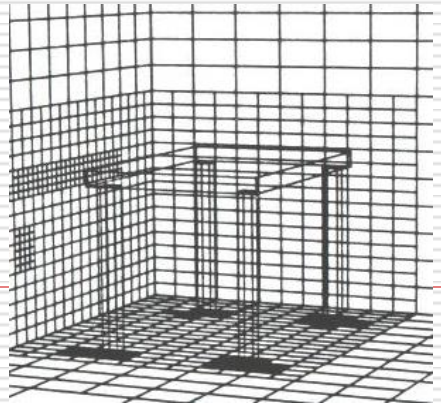
Basic Radiosity Model

- Since form factor is only dependent on geometry, the above matrix is only needed to be computed once providing the geometry is not changed. Algorithms using this approach are called **Full Matrix** or **FM** algorithms
- Progressive method

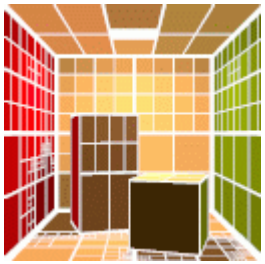
Substructure & Hierarchical

- Example : using hemicube to compute form factors

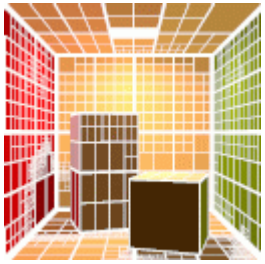


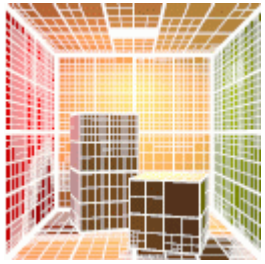
Energy Error: 0.000592 Path count: 381
Path generation/refinement: 3s Energy Propagation: 0.246s



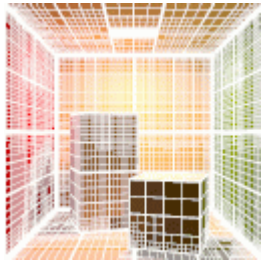
Energy Error: 0.000148 Path count: 1,440
Path generation/refinement: 20s Energy Propagation: 2s



Energy Error: 0.000037 Path count: 7,155
Path generation/refinement: 42s Energy Propagation: 13s



Energy Error: 0.000009 Path count: 24,501
Path generation/refinement: 4min 50sec
Energy Propagation: 33sec



Energy Error: 0.000002 Path count: 169,500
Path generation/refinement: 33min 50sec
Energy Propagation: 2min 8sec

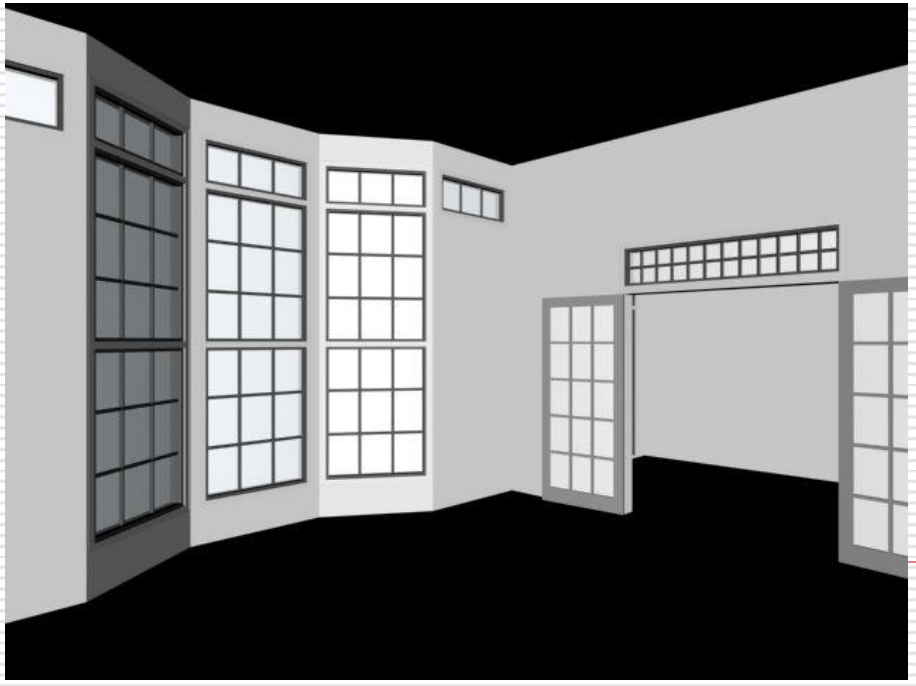
Outline

3DS MAX offers two global illumination algorithms as an integral part of its production rendering system:

- Ray-tracing
- Radiosity

3DMax tutorial

- A complete example of how to use 3DMax for modeling a scene in radiosity as follows: http://area.autodesk.com/tutorials/radiosity_the_things_your_mother_never_told_you



3DMax tutorial

Reference

Reference

These two images were rendered by Michael F. Cohen, Shenchang Eric Chen, John R. Wallace and Donald P. Greenberg for the 1988 paper ***A Progressive Refinement Approach to Fast Radiosity Image Generation***. The factory model contains 30,000 patches, and was the most complex radiosity solution computed at that time. The radiosity solution took approximately 5 hours for 2,000 shots, and the image generation required 190 hours; each on a VAX8700.

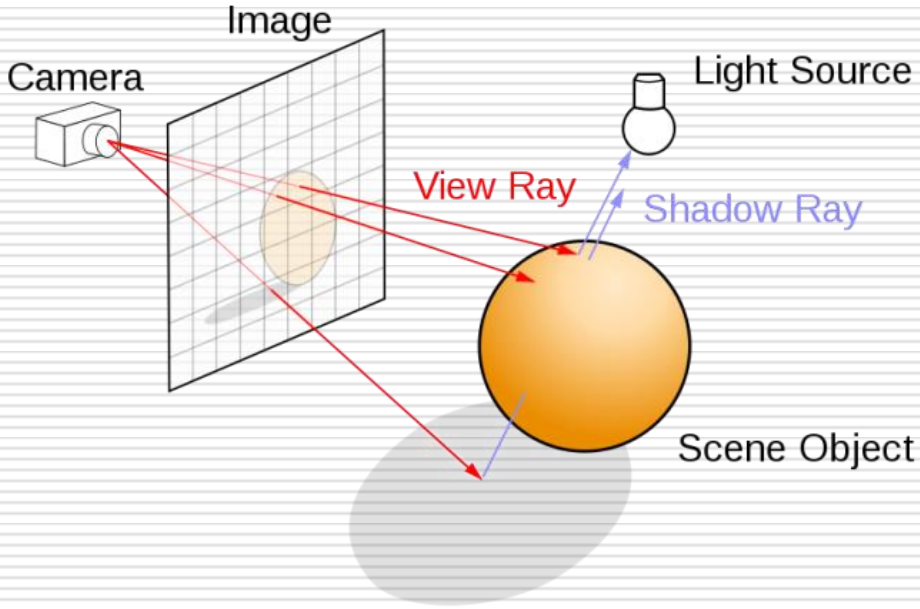
State-of-the-art radiosity I

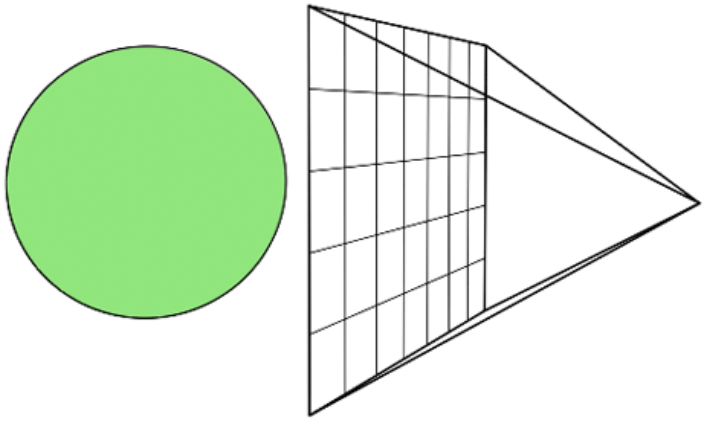
State-of-the-art radiosity II

State-of-the-art radiosity III

Summary: Ray-tracing

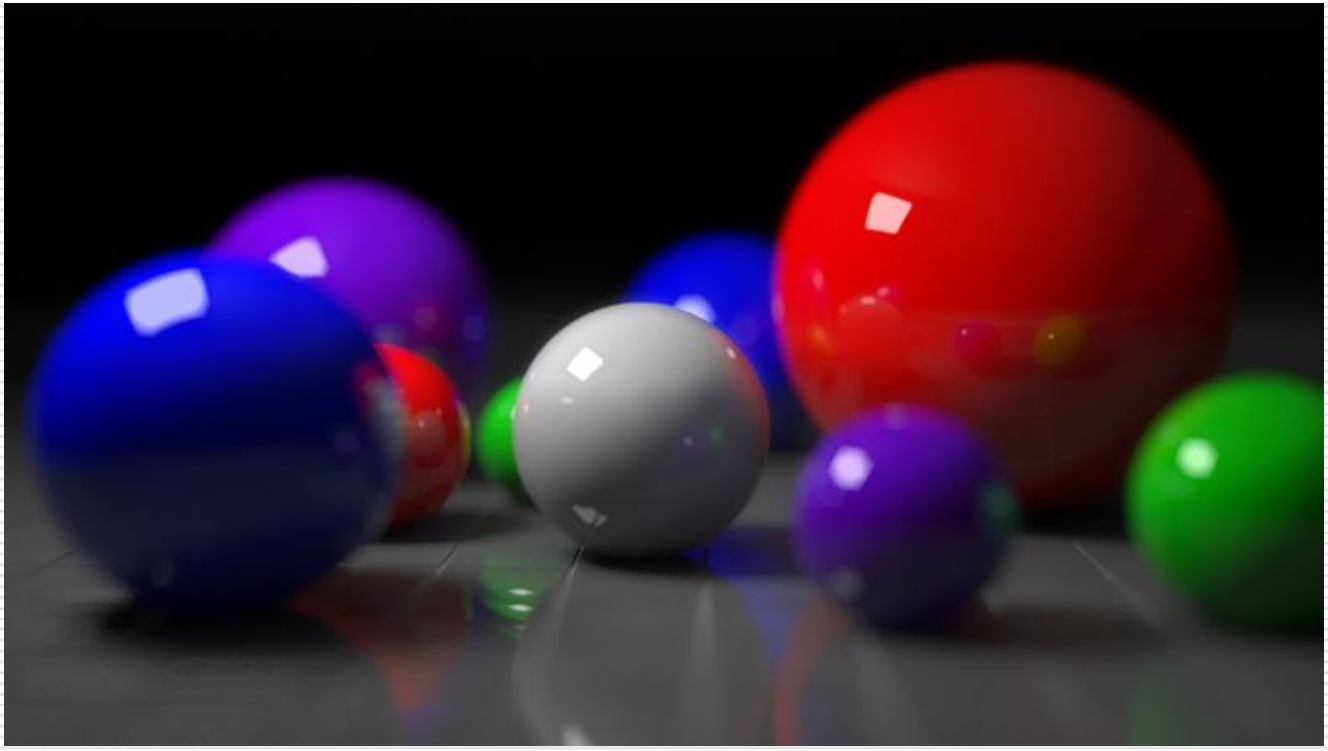
- Ray-tracing is a **direct** global illumination algorithm
- It is only concerned with simulating light reflecting once of each surface





View-dependent

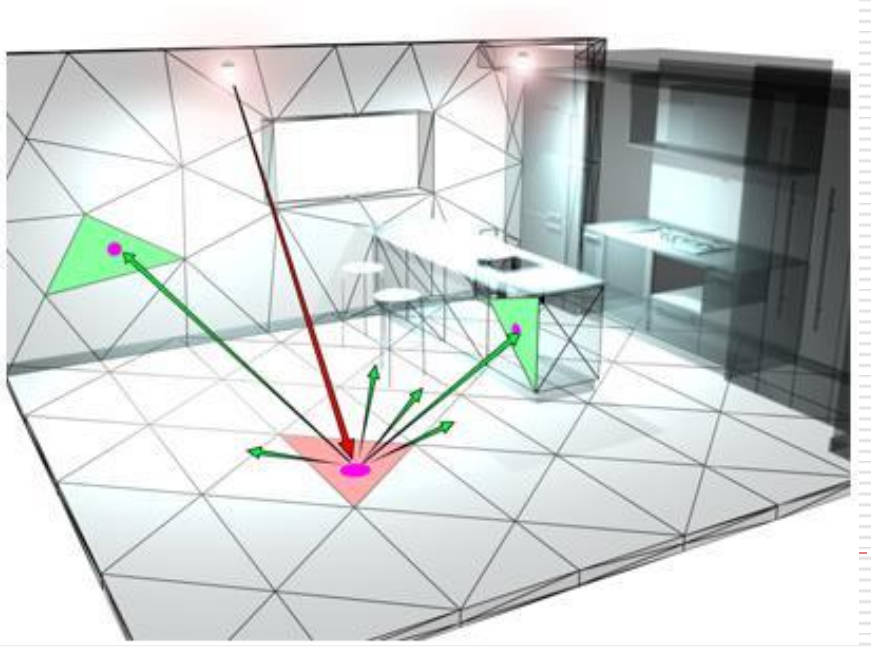
Ray-tracing



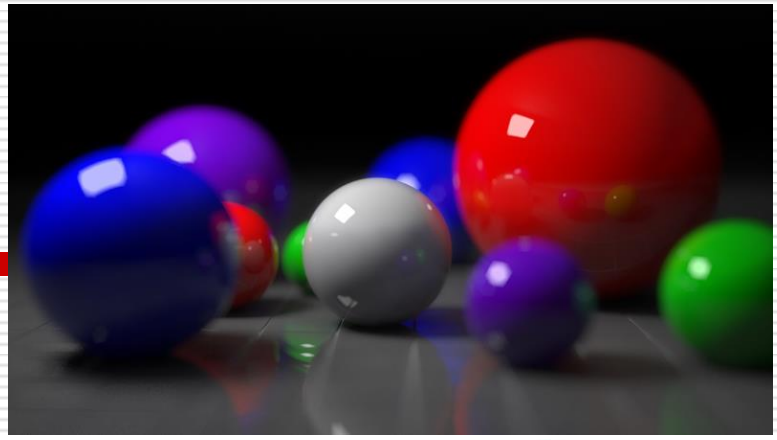
Summary: Radiosity

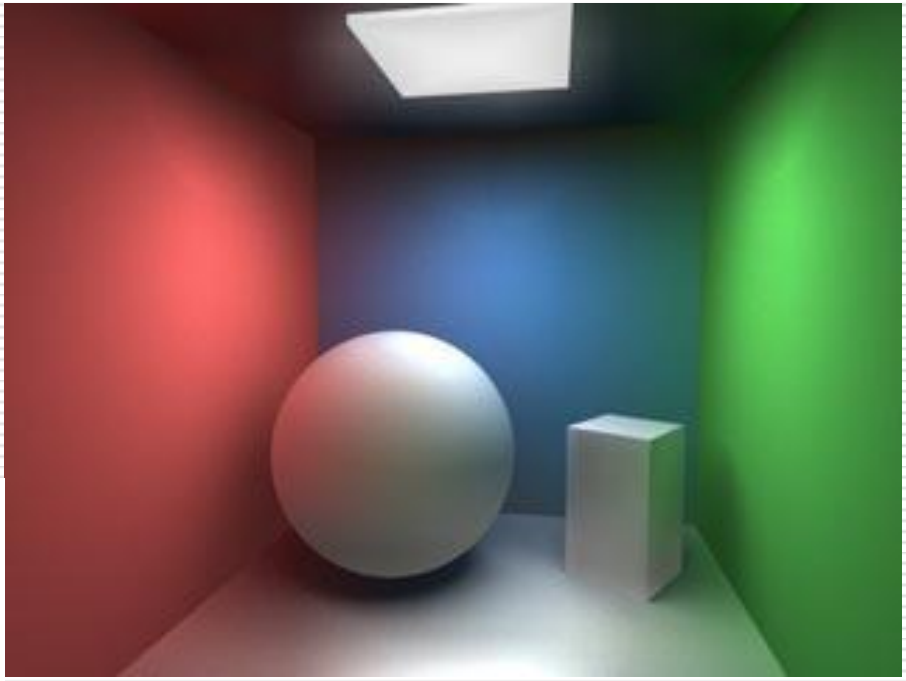
- It is an **indirect** global illumination algorithm
- Diffuse inter-reflectivity simulates many reflections of light around a scene
- The result is often **softer** more natural shadows

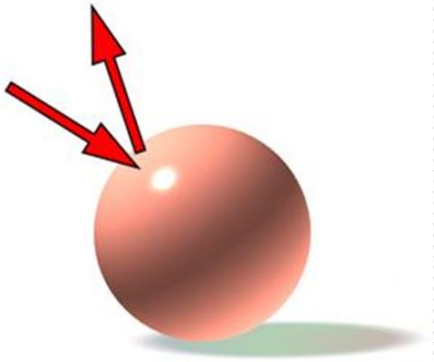
View-independent

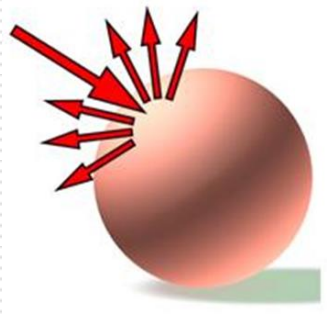


Radiosity



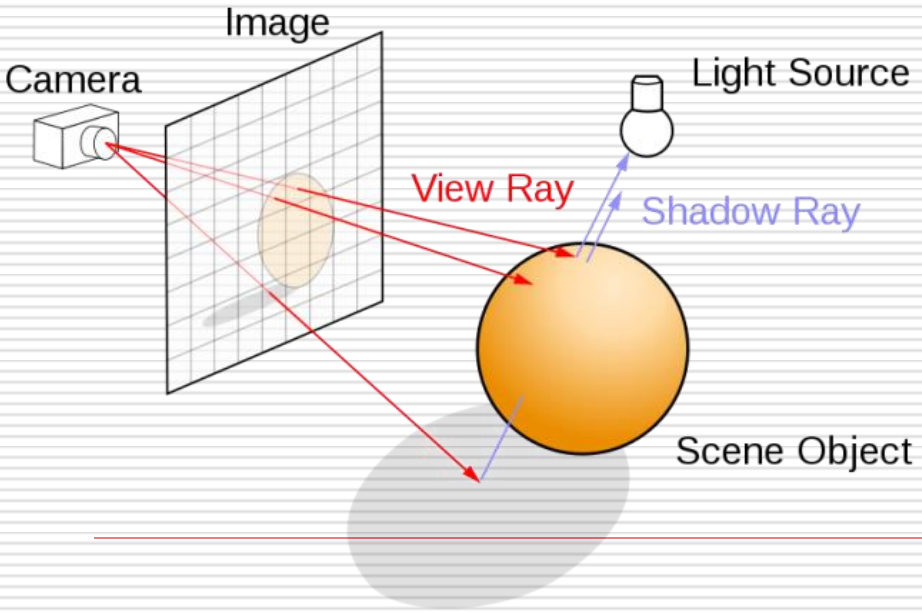


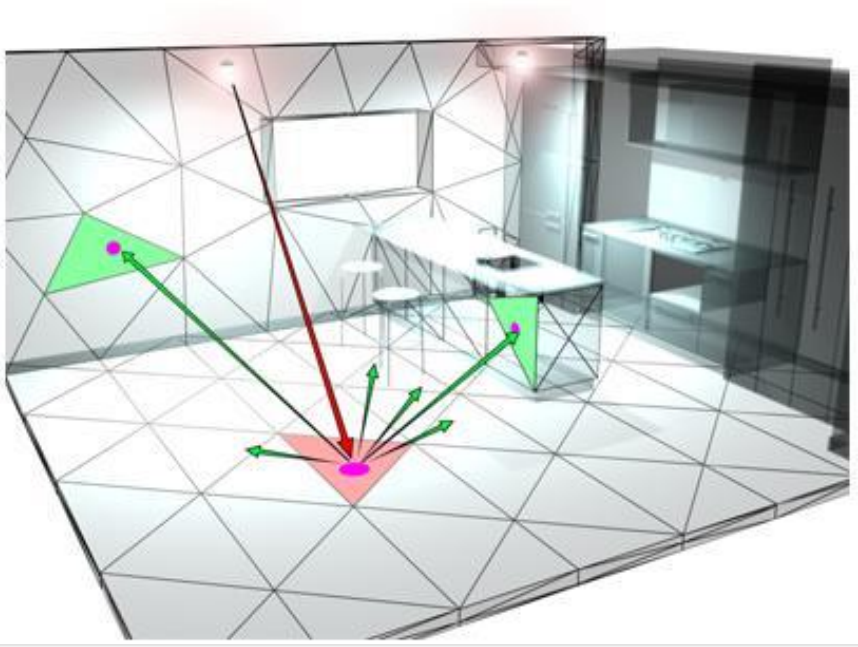




Summary:

- Although the ray-tracing and radiosity algorithms are very different, they are in many ways complementary. Each technique has advantages and disadvantages.





Summary:

Lighting Algorithm	Advantages	Disadvantages
Ray-Tracing	Accurately renders direct illumination, shadows, specular reflections, and transparency effects. Memory Efficient	Computationally expensive. The time required to produce an image is greatly affected by the number of light sources. Process must be repeated for each view (view dependent). Doesn't account for diffuse interreflections.
Radiosity	Calculates diffuse interreflections between surfaces. Provides view independent solutions for fast display of arbitrary views. Offers immediate visual results.	3D mesh requires more memory than the original surfaces. Surface sampling algorithm is more susceptible to imaging artifacts than ray-tracing. Doesn't account for specular reflections or transparency effects.

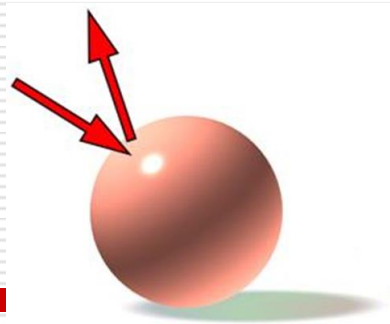
Summary:

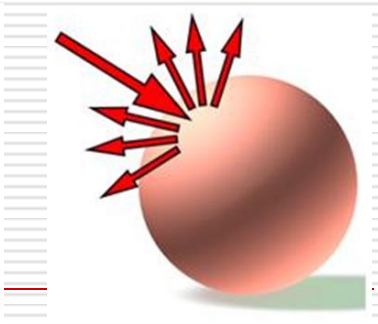
- Although the ray-tracing and radiosity algorithms are very different, they are in many ways complementary. Each technique has advantages and disadvantages.
- Neither radiosity nor ray-tracing offers a complete solution for simulating all global illumination effects.

Summary:

- By integrating ray-tracing and radiosity, 3ds Max offers a full range of visualization possibilities, from fast, interactive lighting studies to images of exceptional quality and realism.
- By integrating both techniques with a production quality scanline rendering system, 3ds Max offers the best of both worlds. After you create a radiosity solution, you can render a two-dimensional view of it. In your 3ds Max scene, ray-tracing adds effects in addition to those that radiosity provides: lights can provide ray-traced shadows, and materials can provide ray-traced reflections and refractions. The rendered scene combines both techniques, and appears more realistic than either technique alone could provide.

Summary:





- By integrating ray-tracing and radiosity, 3ds Max offers a full range of visualization possibilities, from fast, interactive lighting studies to images of exceptional quality and realism.

End.
Thanks