# Rendering

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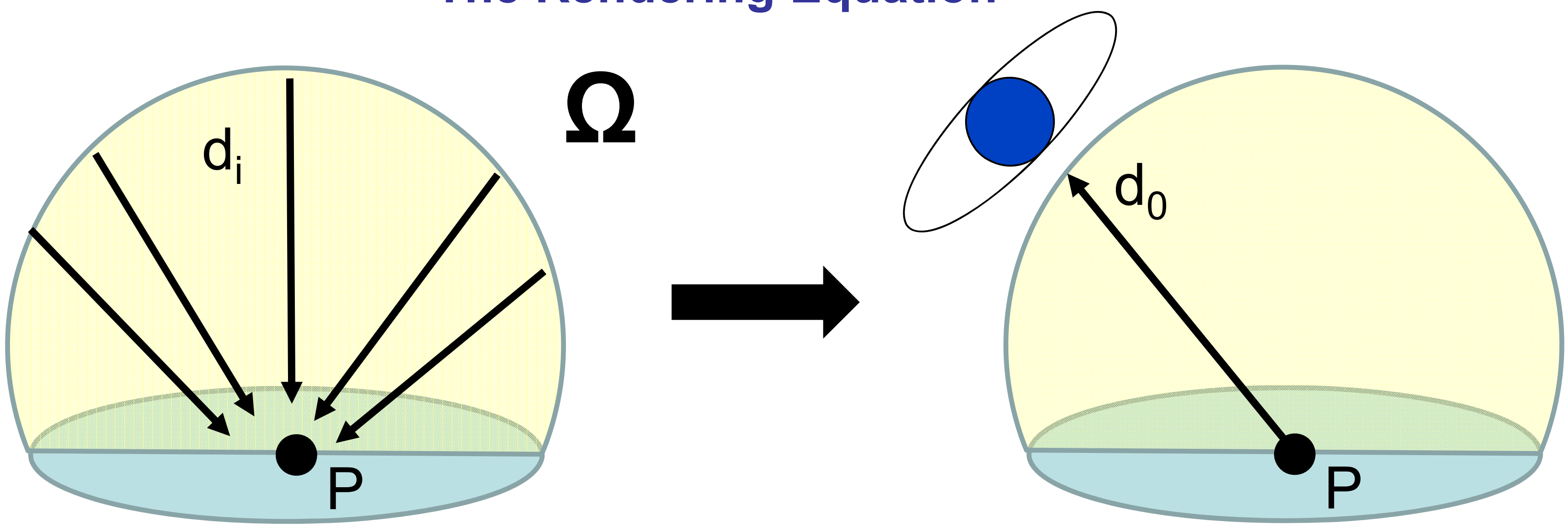
# The Rendering Equation




$$B(P, d_0, \lambda) = E(P, d_0, \lambda) + \int_\Omega B(P, d_i, \lambda) f(\lambda, d_i, d_0)(d_i \cdot \hat{n})\, d\Omega$$

This is the true rendering situation.  Essentially, it is an energy balance:

Light Shining from a point =
  Light emitted by that point +
  Σ(Light arriving from all other points) * Reflectivity

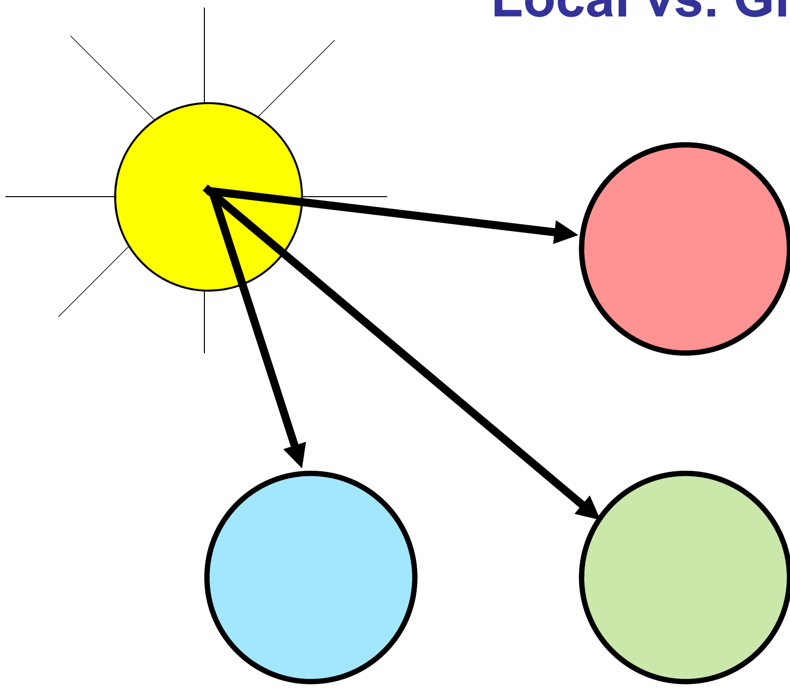
But, this is time-consuming to solve “exactly”.
So, we need to know **how much of an approximation do we need?**

# Rendering

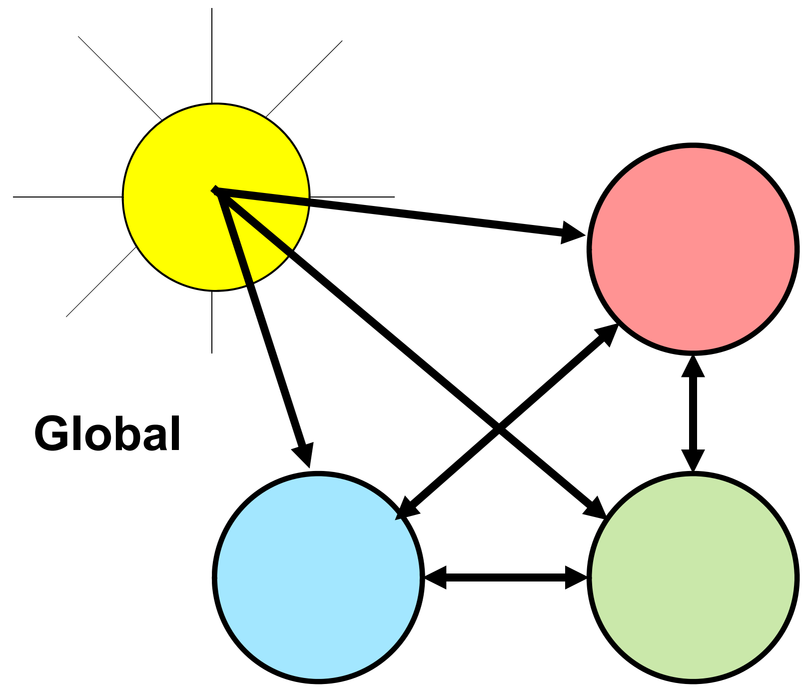
Rendering is the process of creating an image of a geometric model. There are questions you need to ask:

- For what purpose am I doing this?
- How realistic do I need this image to be?
- How much compute time do I have to create this image?
- Do I need to take lighting into account?
- Does the illumination need to be global or will local do?
- Do I need to create shadows?
- Do I need to create reflections and refractions?
- How good do the reflections and refractions need to be?

# Local vs. Global Illumination

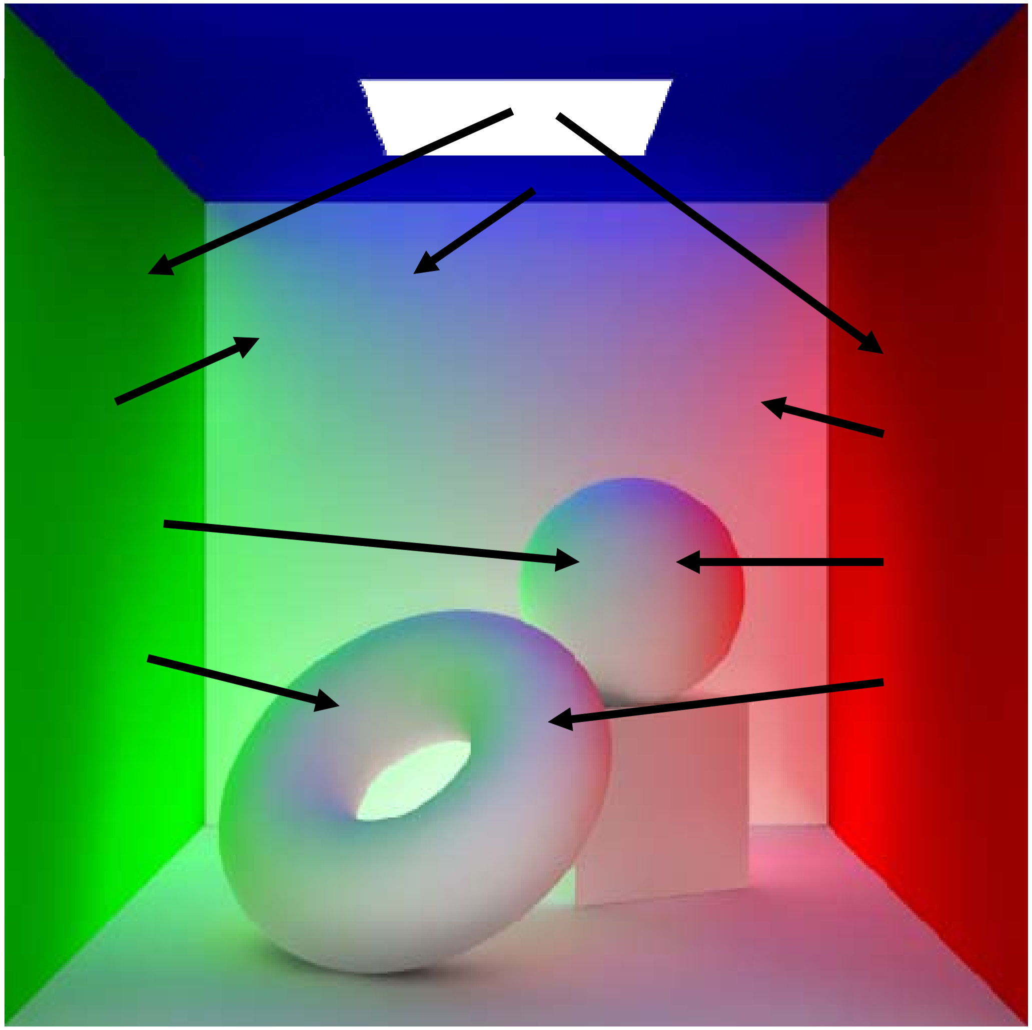


Local



Global

# Global Illumination at Work



http://www.swardson.com/unm/tutorials/mentalRay3/

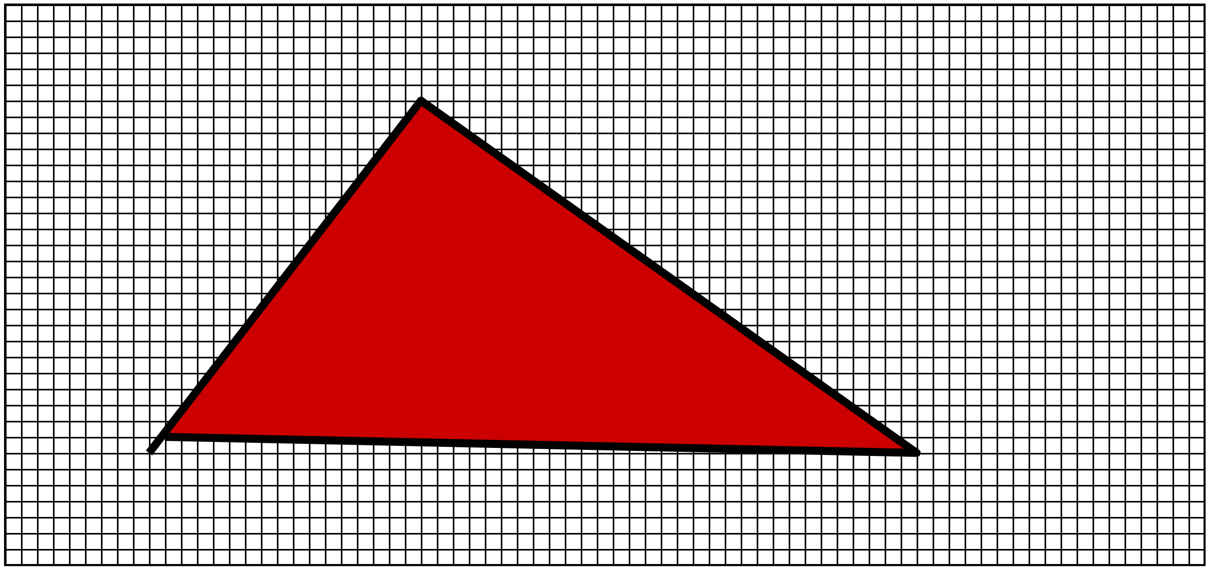
# Two Directions for the Rendering to Happen

1. Starts at the object, works towards the eye

2. Starts at the eye, works towards the object

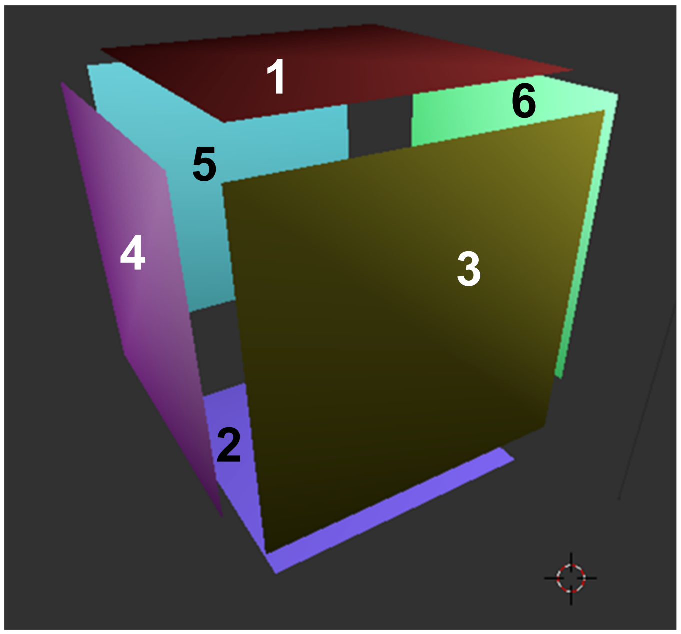
# Starts at the Object, Works Towards the Eye

This is the typical kind of rendering you get on a graphics card.
You have been doing this all along.
Start with the geometry and project it onto the pixels.



# How do things in front look like they are *really* in front?

Your application might draw this cube's polygons in 1-2-3-4-5-6 order, but 1, 3, and 4 still need to look like they were drawn last:



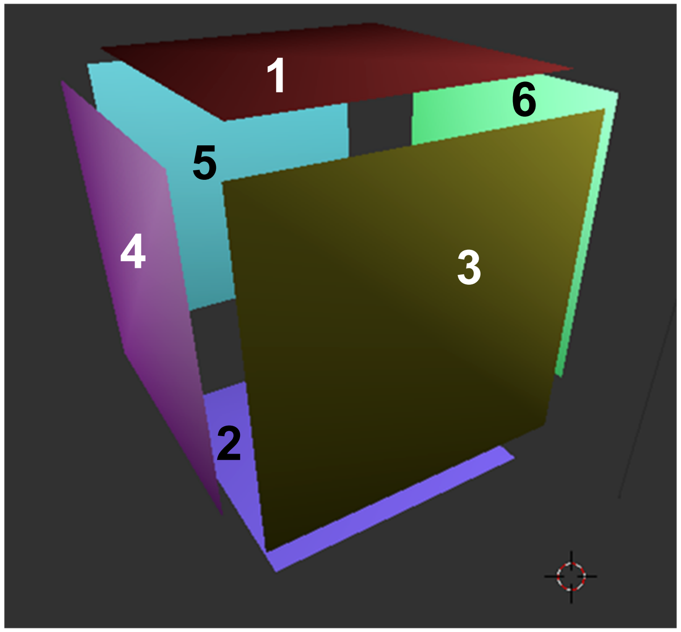

**Solution #1**: Sort your polygons in 3D by depth and draw them back-to-front.

In this case 1-2-3-4-5-6 becomes 5-6-2-4-1-3.

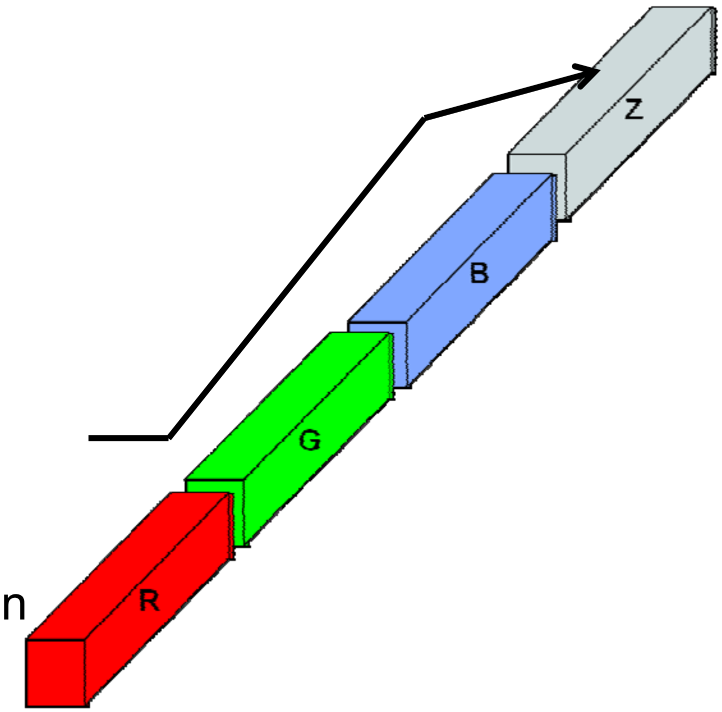
This is called the **Painter's Algorithm**. It sucked to have to do things this way.

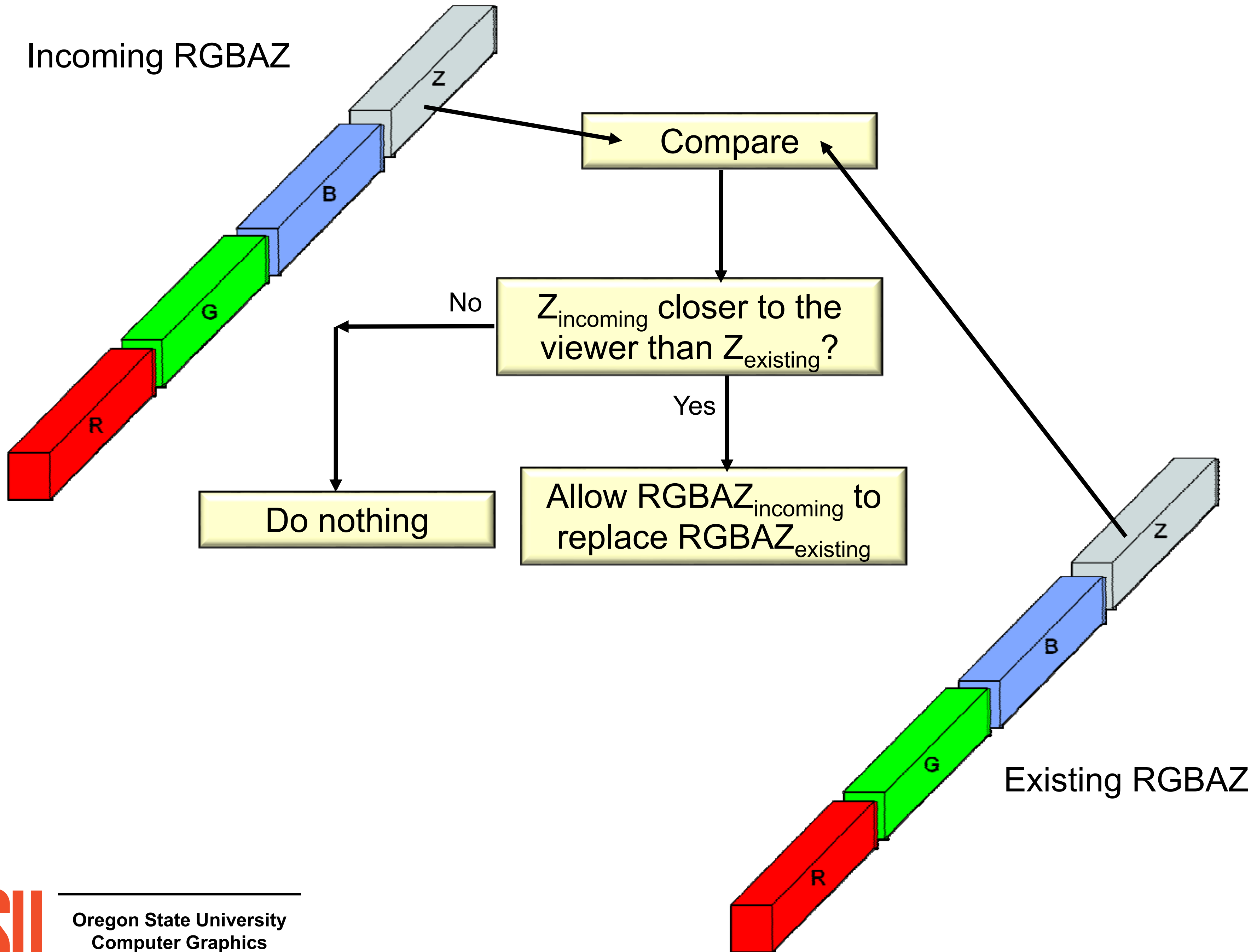
# How do things in front look like they are *really* in front?

Your application might draw this cube's polygons in 1-2-3-4-5-6 order, but 1, 3, and 4 still need to look like they were drawn last:

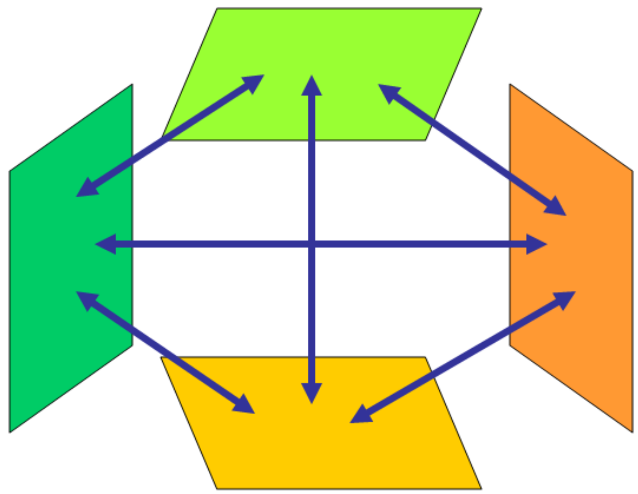



**Solution #2:** Add an extension to the framebuffer to store the depth of each pixel. This is called a **Depth-buffer** or **Z-buffer.** Only allow pixel stores when the depth of the incoming pixel is closer to the viewer than the pixel that is already there.




Incoming RGBAZ
Z
B
G
R
Compare
No
Zincoming closer to the viewer than Zexisting?
Yes
Do nothing
Allow RGBAZincoming to replace RGBAZexisting
Z
B
G
R
Existing RGBAZ

# Another From-the-Object Method -- Radiosity



Based on the idea that all surfaces gather light intensity from all other surfaces

The fundamental radiosity equation is an energy balance that says:

"The light energy leaving surface *i* equals the amount of light energy generated by surface *i* plus surface *i*'s reflectivity times the amount of light energy arriving from all other surfaces"

$$B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \to i}$$

This is a very good approximation to the Rendering Equation

# The Radiosity Equation

$$B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j\to i}$$

$B_i$ is the light energy intensity shining from surface element *i*

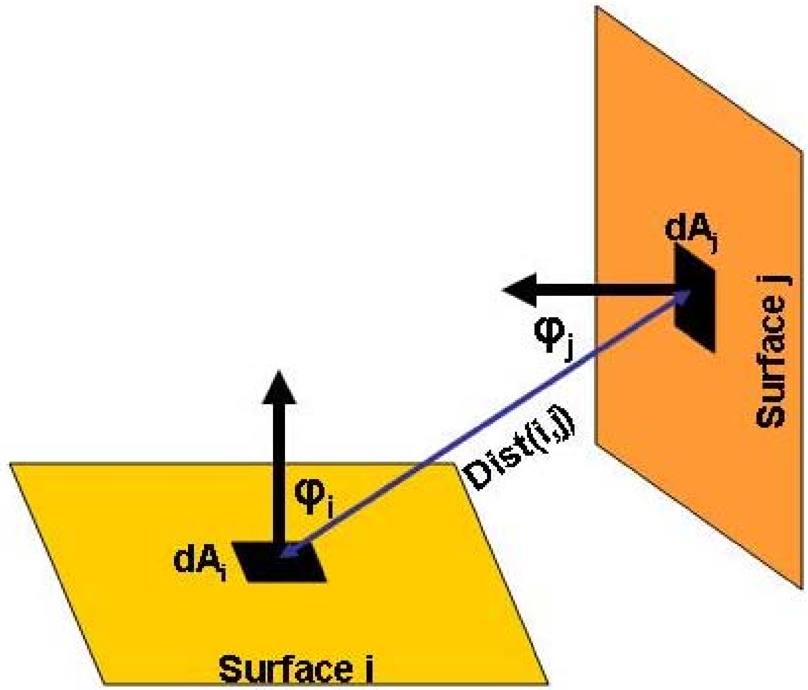
$A_i$ is the area of surface element *i*

$E_i$ is the internally-generated light energy intensity for surface element *i*

$\rho_i$ is surface element *i*'s reflectivity

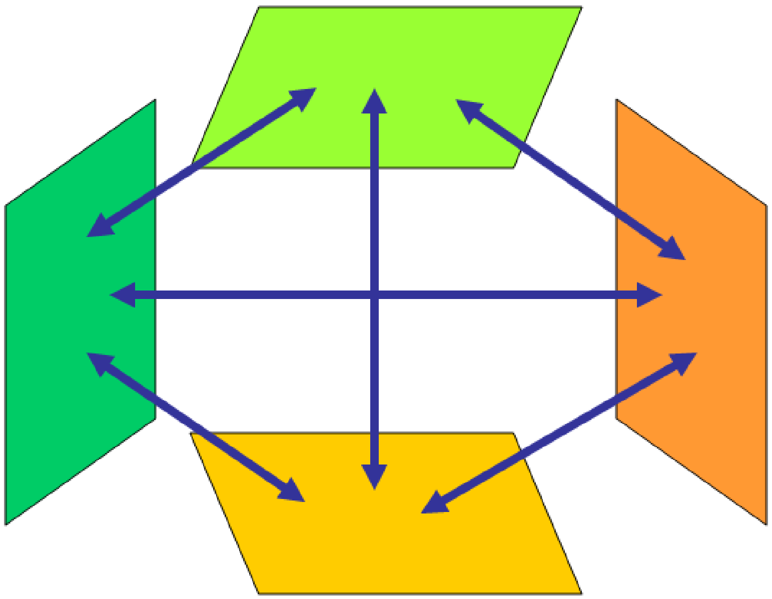
$F_{j\to i}$ is referred to as the Form Factor, or Shape Factor, and describes what percent of the energy leaving surface element *j* that arrives at surface element *i*

# The Radiosity Shape Factor




$$F_{j \to i} = \int_{Ai} \int_{A_j} visibility(di, dj) \frac{\cos \Theta_i \cos \Theta_j}{\pi Dist(di, dj)^2} dA_j dA_i$$

## Does it seem to you that the light just keeps propagating and you never get an answer?



To many people, radiosity seems like this:

$$y = 3x + 5$$

$$x = y - 7$$

"x produces y, then y produces x, then x produces y, then …"

Not really – it is simply N equations, N unknowns – you solve for the unique solution

$$-3x + y = 5$$

$$x - y = -7$$

$x = 1$
$y = 8$

# The Radiosity Matrix Equation

Expand $B_i A_i = E_i A_i + \rho_i \sum_j B_j A_j F_{j \to i}$

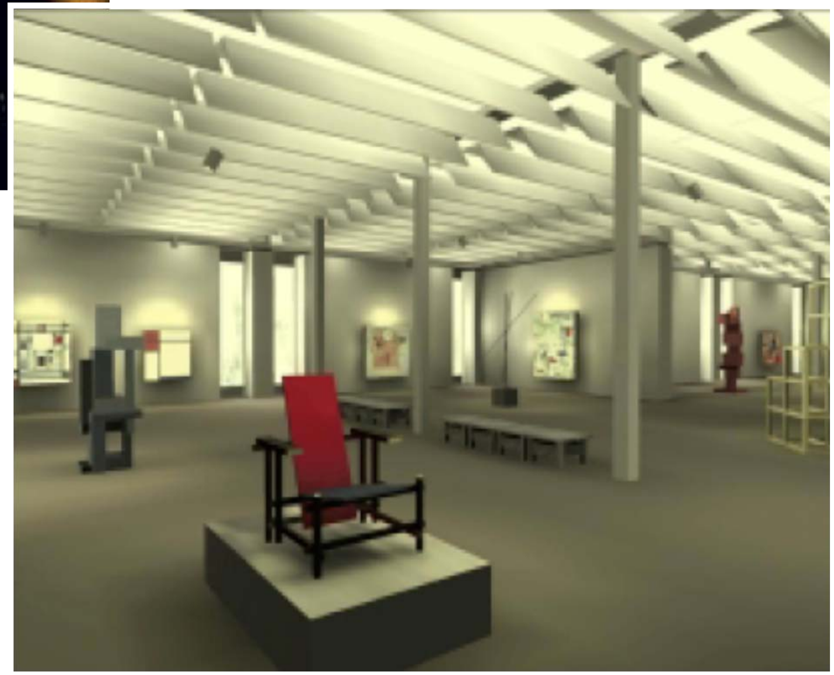
For each surface element, and re-arrange to
**solve for the surface intensities, the *B*'s**:

$$\begin{bmatrix} 1-\rho_1 F_{1\to 1} & -\rho_1 F_{1\to 2} & \bullet\bullet\bullet & -\rho_1 F_{1\to N} \\ -\rho_2 F_{2\to 1} & 1-\rho_2 F_{2\to 2} & \bullet\bullet\bullet & -\rho_2 F_{2\to N} \\ \bullet\bullet\bullet & \bullet\bullet\bullet & \bullet\bullet\bullet & \bullet\bullet\bullet \\ -\rho_N F_{N\to 1} & -\rho_N F_{N\to 2} & \bullet\bullet\bullet & 1-\rho_N F_{N\to N} \end{bmatrix} \begin{Bmatrix} B_1 \\ B_2 \\ \bullet\bullet\bullet \\ B_N \end{Bmatrix} = \begin{Bmatrix} E_1 \\ E_2 \\ \bullet\bullet\bullet \\ E_N \end{Bmatrix}$$

This is a lot of equations!

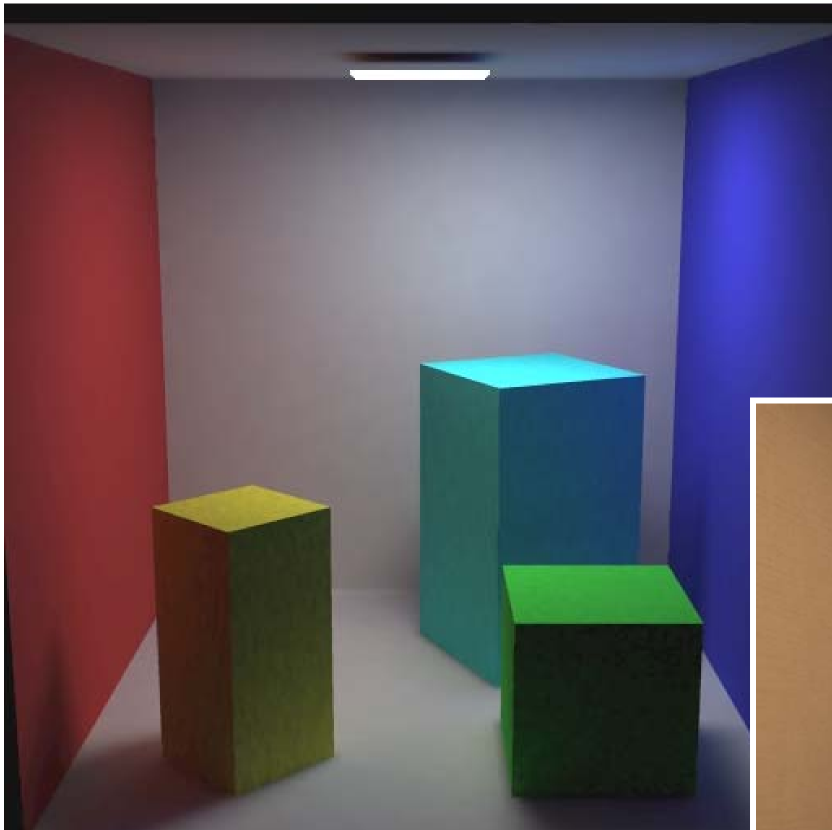
# Radiosity Examples

Cornell University



Cornell University

# Radiosity Examples

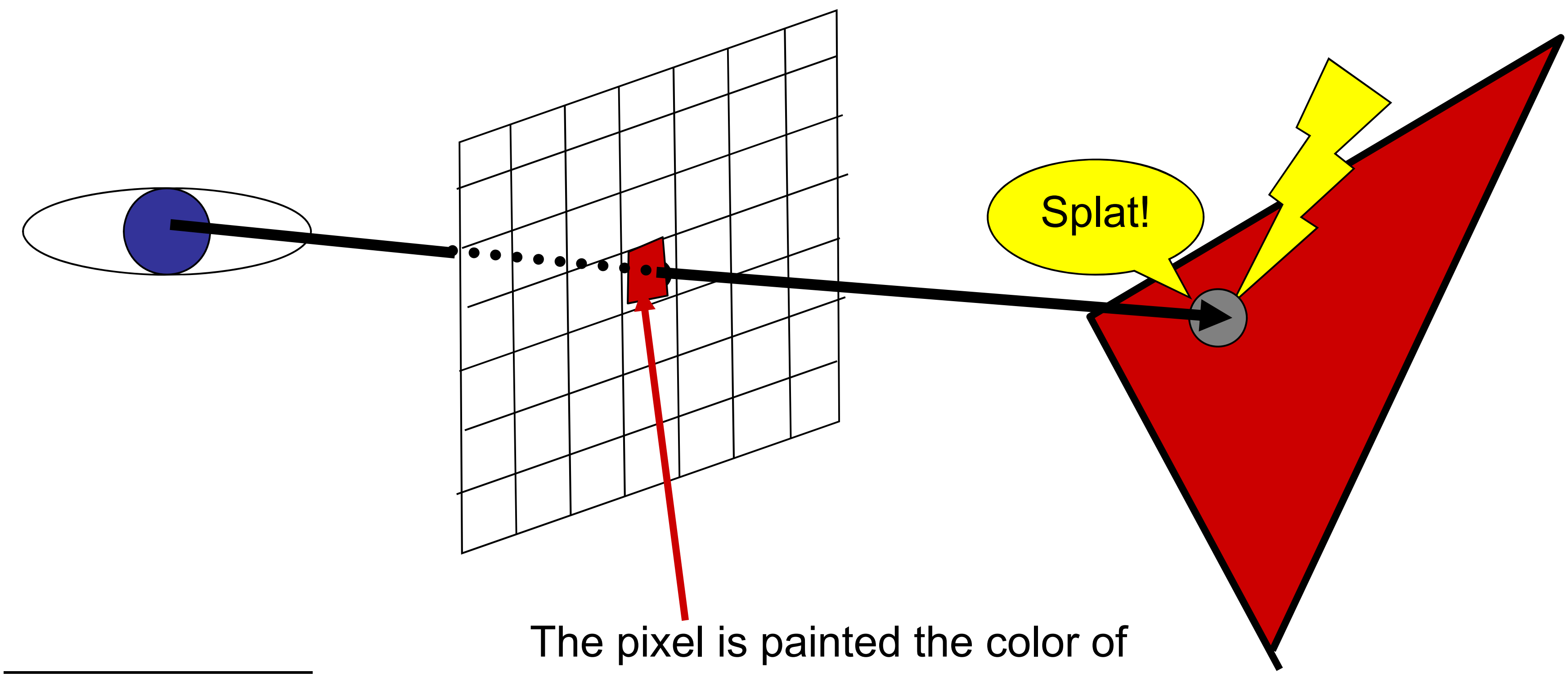


AR Toolkit

Autodesk

# Starts at the Eye, Works Towards the Objects

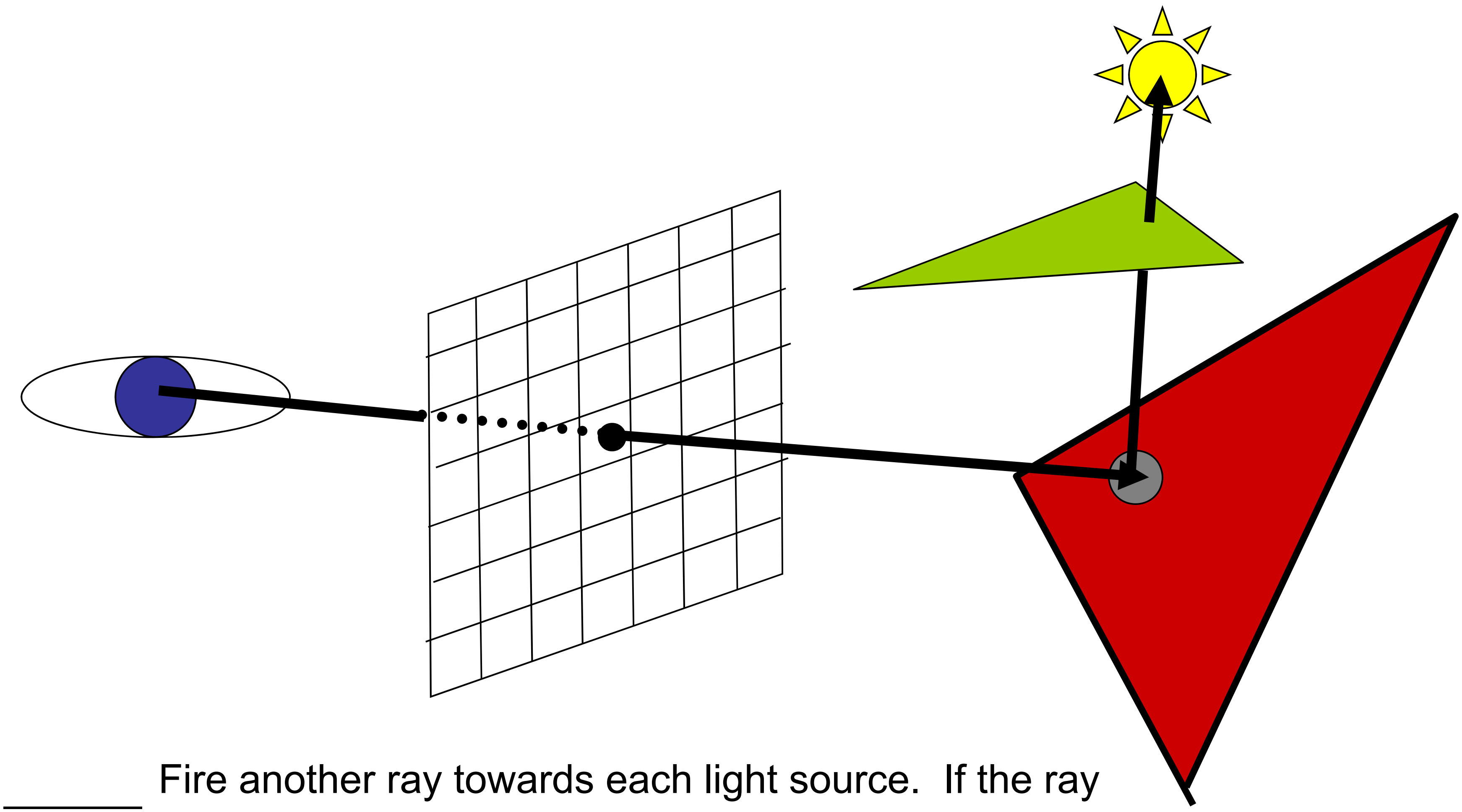
The most common approach in this category is **ray-tracing**:




The pixel is painted the color of the nearest object that is hit.

# Starts at the Eye

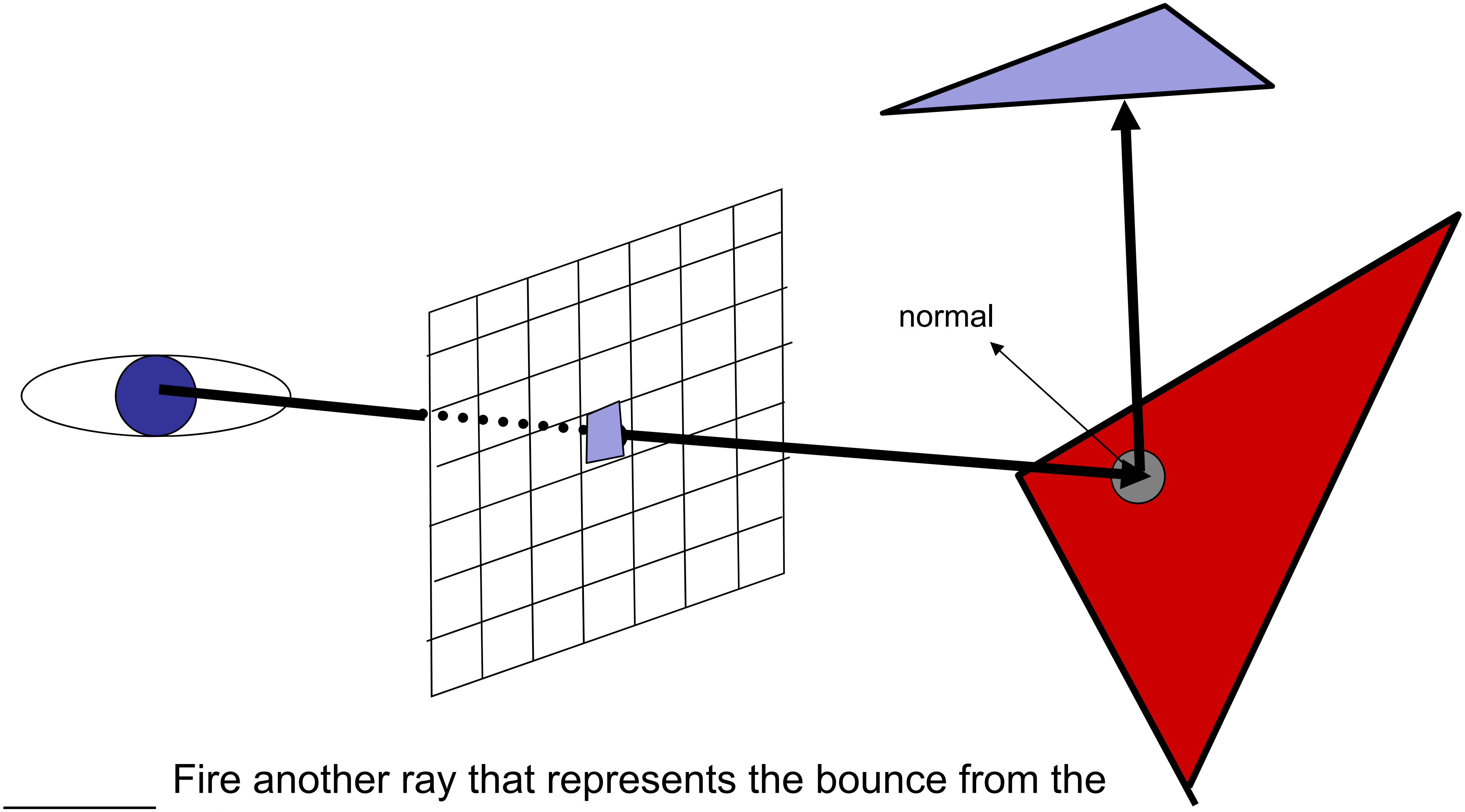
It's also easy to see if this point lies in a shadow:



Fire another ray towards each light source. If the ray hits anything, then the point does not receive that light.

# Starts at the Eye

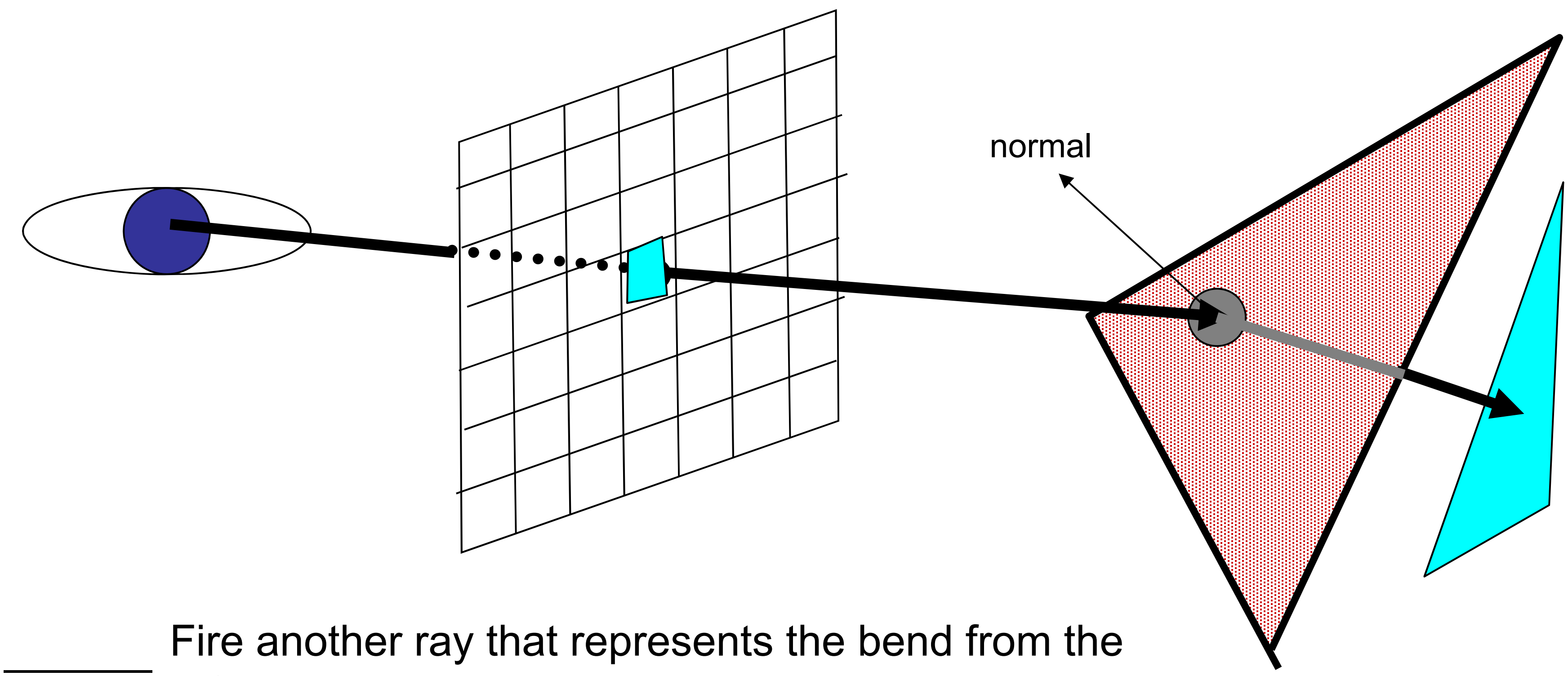
It's also easy to handle reflection




Fire another ray that represents the bounce from the reflection.  Paint the pixel the color that this ray sees.

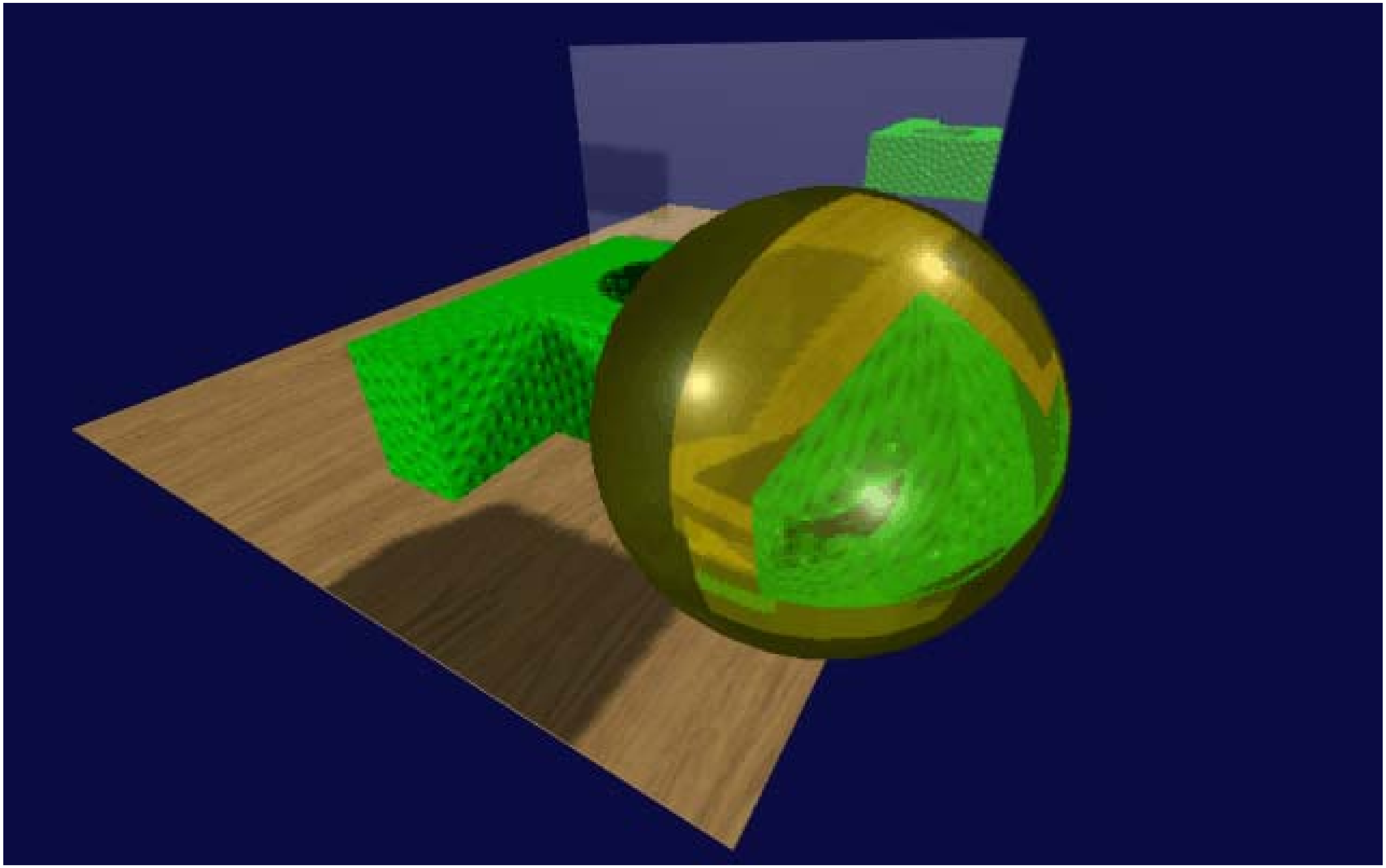
# Starts at the Eye

It's also easy to handle refraction

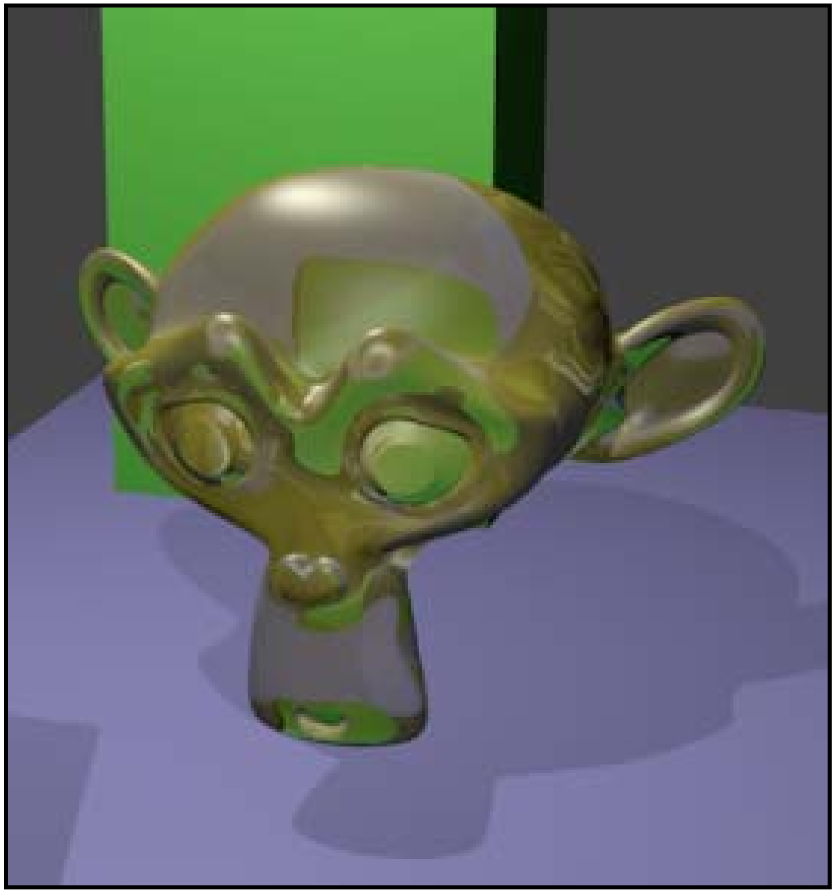



Fire another ray that represents the bend from the refraction. Paint the pixel the color that this ray sees.

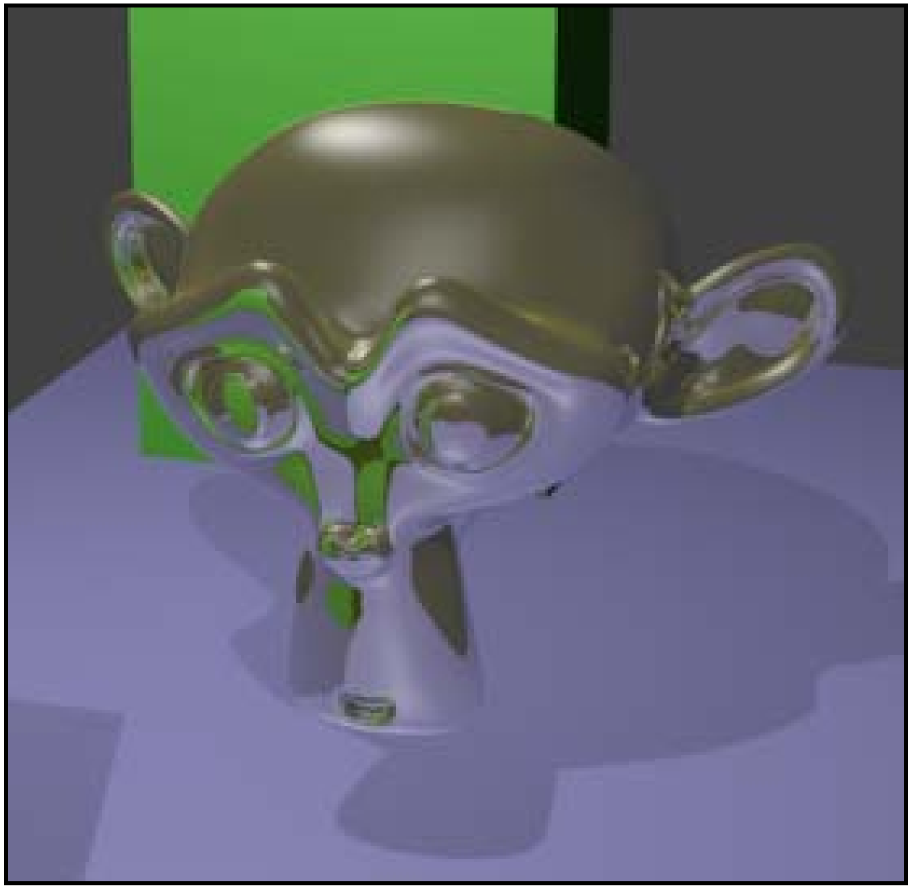
# IronCAD Ray-tracing Example



# Blender Ray-tracing Example

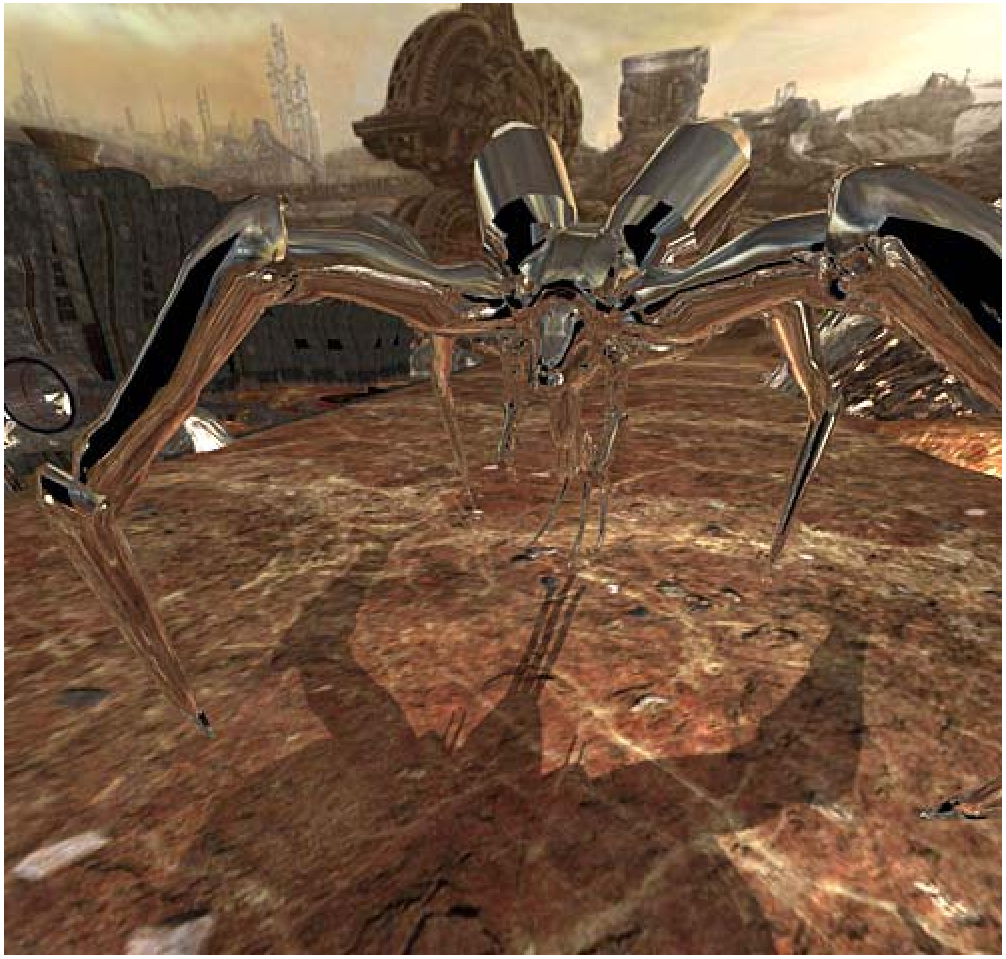


Refraction



Reflection

# More Ray-tracing Examples



**Quake 4 Ray-Tracing Project**

# More Ray-tracing Examples

IBM's Cell Interactive Ray-tracer

# More Ray-tracing Examples

Bunkspeed

# Subsurface Scattering

Models light bouncing around within an object before coming back out.
This is a good way to render skin, wax, milk, etc.

Original rendering

Subsurface scattering