Note Title 01/03/2006

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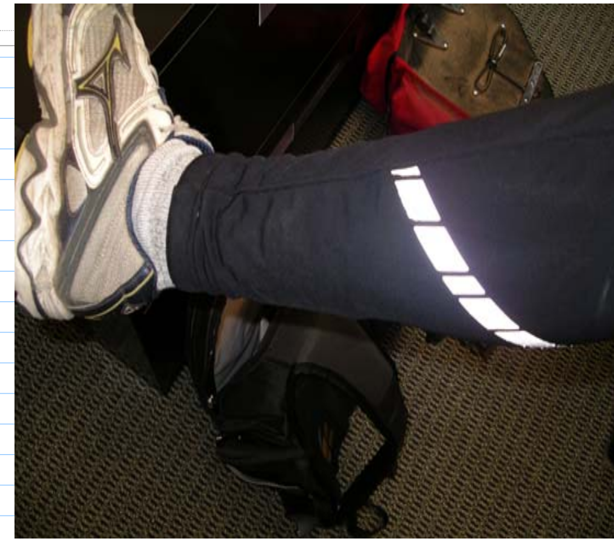

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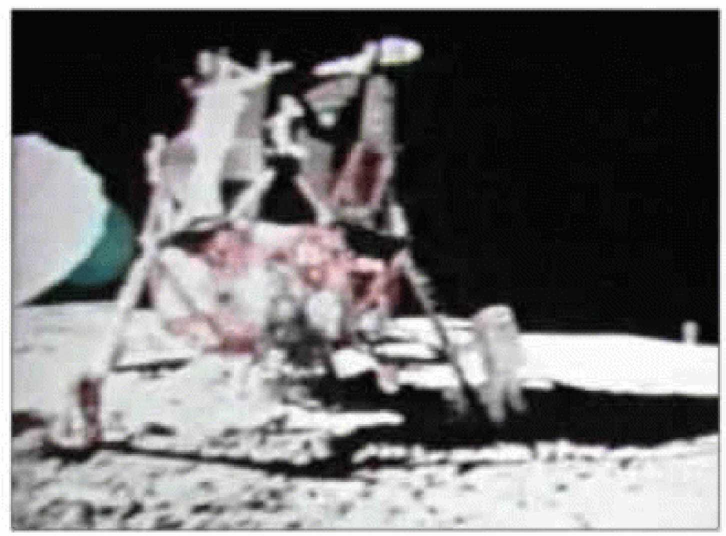
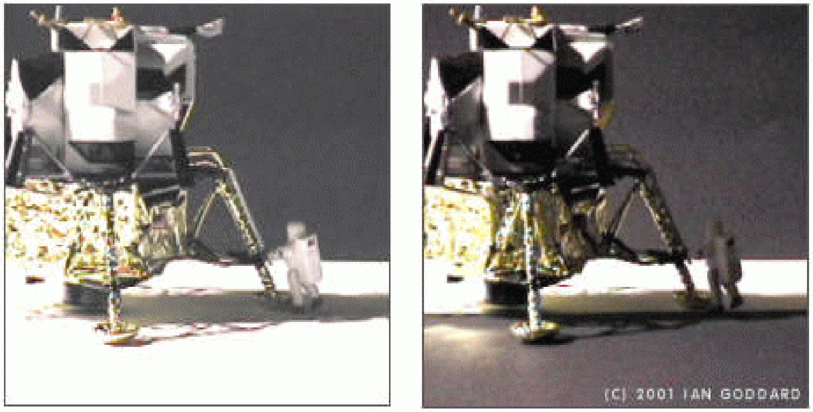
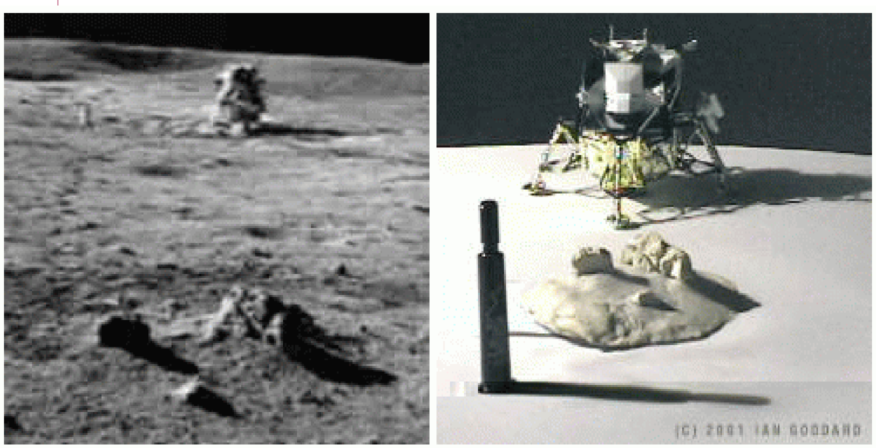


Question: *why is the astronaut in the shadow illuminated?*

Answer: *surface reflection of light:*



Test: *surface reflection illuminates toy astronaut in shadow.*
In second image, foreground reflection is reduced with black paper.



Test: *slanted surface alters shadow direction on Moon-rock model under one light. Identical ground slant can be detected in Moon photo on left.*

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Illumination Models

[electricimage.com]

Images...

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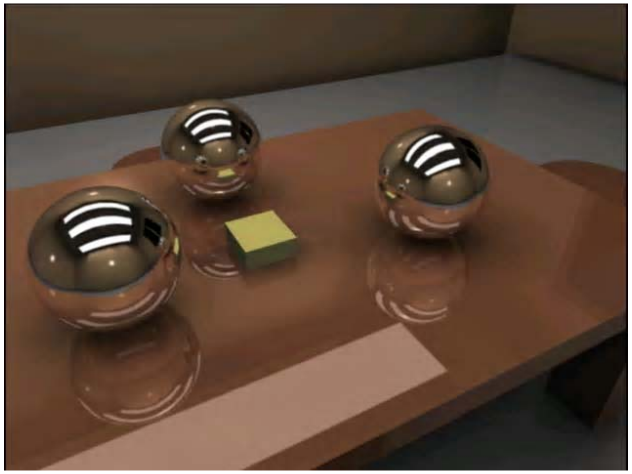

[electricimage.com]

Local Illumination

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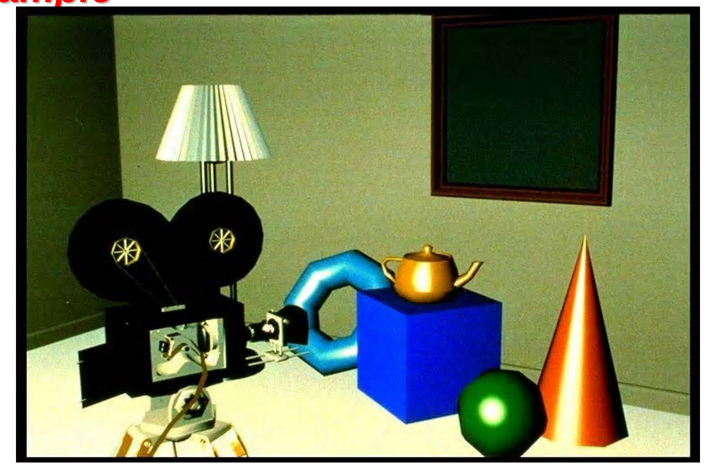
Example



Demo

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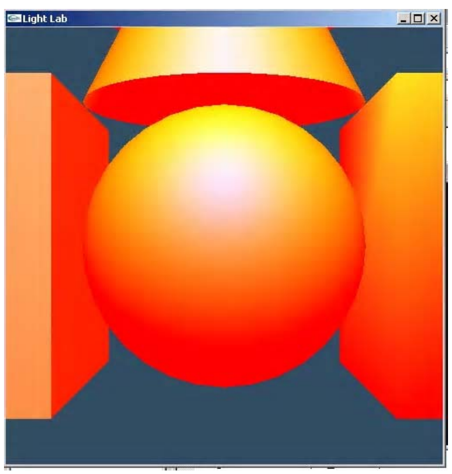

Local Illumination in the projective rendering pipeline

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Local Illumination

- only models light arriving directly from light source
- interreflections and shadows
  - *added through tricks, multiple rendering passes*

Types of Models

- Simple, non-physical reflection models (Phong, Blinn)
- physically-based reflection models
  - *BRDFs: Bidirectional Reflection Distribution Functions*

Light Sources

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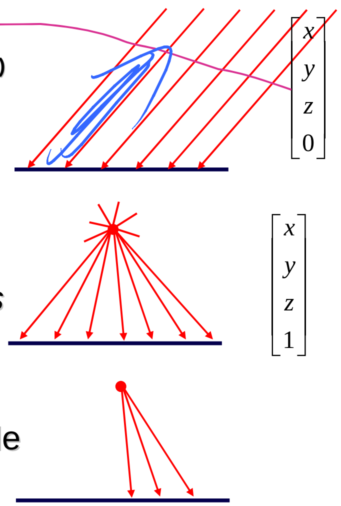
Types of light sources

- `glLightfv(GL_LIGHT0,GL_POSITION,light[])`
- Directional/parallel lights
  - *E.g.sun*
  - *Homogeneous vector*
- (Homogeneous) point lights
  - *Same intensity in all directions*
- Spot lights
  - *Limited set of directions:*
    - Point+direction+cutoff angle



Local Illumination

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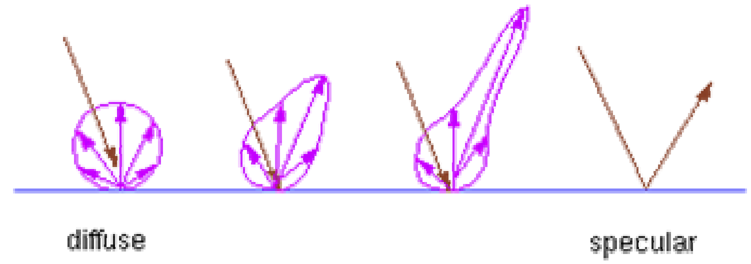

Commonly used model (simple, non-physical)

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Combine diffuse, specular, ambient

- E.g. OpenGL / graphics hardware:

$$I_{out}(\mathbf{x}) = k_a \cdot I_a + k_d \cdot (\mathbf{l} \cdot \mathbf{n}) \cdot I_{diff} + k_s \cdot (\mathbf{h} \cdot \mathbf{n})^n \cdot I_{spec}$$

ambient — diffuse — specular

k_a, k_d, k_s surface params

I_a, I_d, I_s light params

Materials

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Ambient Light

- Incoming light component that is identical everywhere in the scene
- No direction
- Hack for replacing true global illumination (light bouncing off from other objects)

$$I_{out}(\mathbf{x}) = k_a \cdot I_a$$

Diffuse component: Lambert's Law

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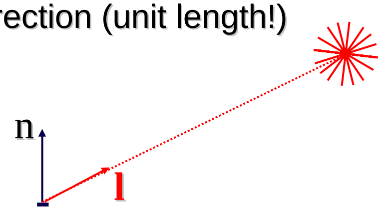
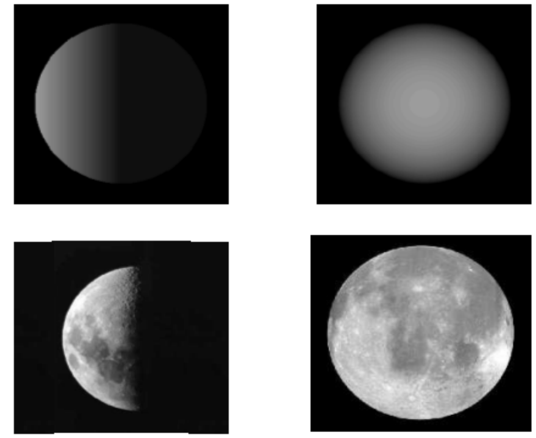
Johann Friedrich Lambert (1783):

- Power per unit area arriving at some object point $\mathbf{x}$ also depends on the angle of the surface to the light direction
  - dA: *differential surface area* surrounding $\mathbf{x}$
  - $\mathbf{l}$: light direction (unit length!)



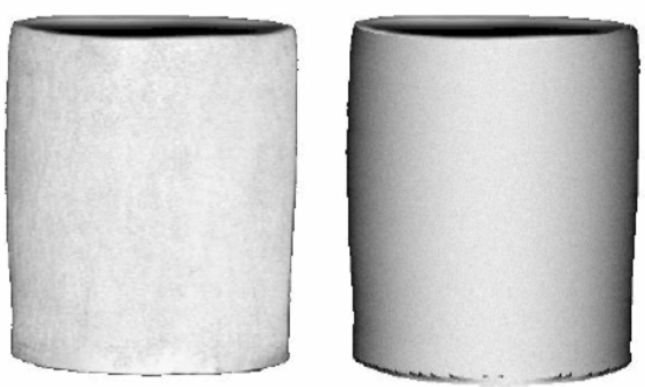
$$I'_{in}(\mathbf{x}) = \cos(\angle(\mathbf{n},\mathbf{l})) \cdot I_{in}(\mathbf{x}) = (\mathbf{n}\cdot\mathbf{l}) \cdot I_{in}(\mathbf{x})$$

Why does the Full Moon have a flat appearance?



Lambertian Spheres and Moon Photos illuminated similarly

Surface Roughness Causes Flat Appearance



Actual Vase | Lambertian Vase

Diffuse Component: a more detailed look

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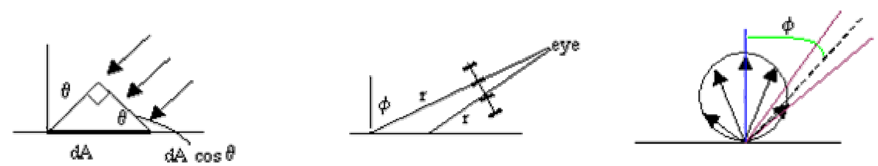
- independent of viewing direction



$I_L \cos\theta\, dA$ | $\frac{r^2}{dA \cos\phi}$ | $\frac{k_d \cos\phi}{r^2}$

$I_p \propto$ incoming energy per unit surface area
x amount of surface area visible through pixel
x fraction of energy sent in the direction of the pixel

$= I_L \cos\theta\, dA$
x $r^2 / (dA \cos\phi)$
x $k_d \cos\phi / r^2$

Materials

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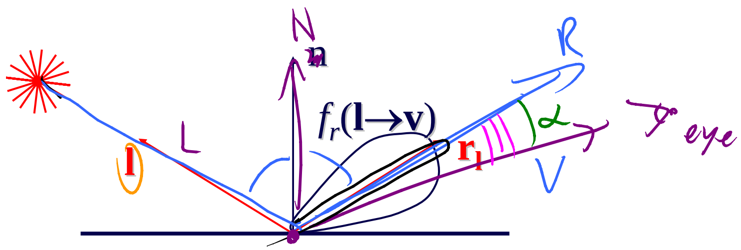
Specular/Glossy

- Light is mostly reflected into the directions around the mirror direction $\mathbf{r_l}$ of $\mathbf{l}$



Materials

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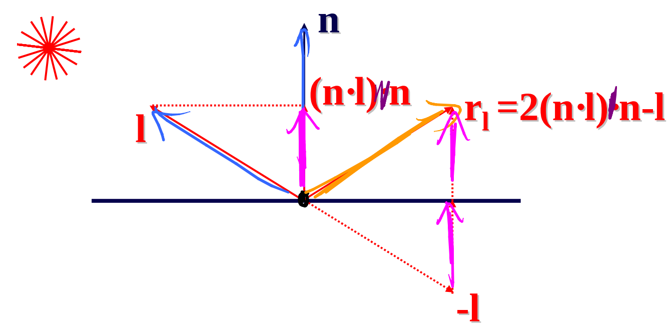
Specular/Glossy

- Computing reflection direction $\mathbf{r_l}$ of $\mathbf{l}$
  - $\mathbf{n}$ *and* $\mathbf{l}$ *are unit length!*



Materials

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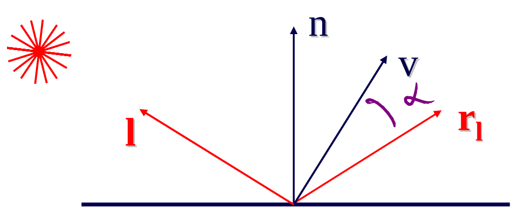
Phong Model (Phong Bui-Tuong, 1975)

- Use cosine power as heuristic

$$I_{spec}(x) = k_s \cdot (\mathbf{v}\cdot\mathbf{r_l})^n \cdot I_{in}(x)$$

"shininess"
n = 50–200 "shiny"
=10 large hilights
cos α

:



Materials

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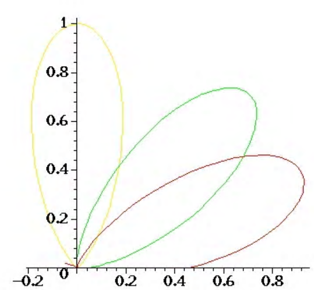
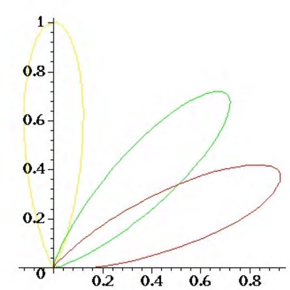
Phong model

- Polar plot



n=10



n=100

Materials

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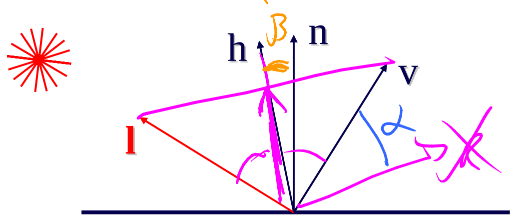
Blinn-Phong model (Jim Blinn, 1977)

- Variation with better physical interpretation
  - **h**: *halfway vector;* n:*shininess*

$$I_{out}(\mathbf{x}) = k_s \cdot (\mathbf{h} \cdot \mathbf{n})^n \cdot I_{in}(\mathbf{x}); \text{with } \mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$



Materials

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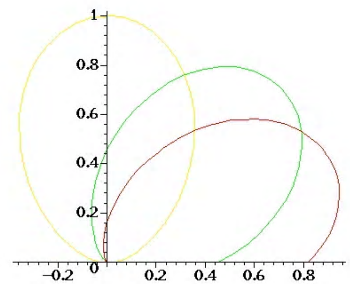
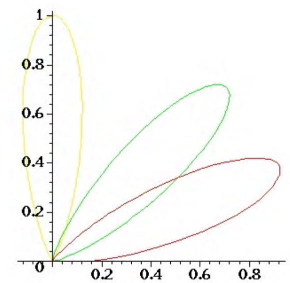
Blinn-Phong Model

- Polar plot



r=0.1



r=0.01

Commonly used model (simple, non-physical)

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Combine diffuse, specular, ambient

- E.g. OpenGL / graphics hardware:

$$I_{out}(\mathbf{x}) = k_a \cdot I_a + k_d \cdot (\mathbf{l} \cdot \mathbf{n}) \cdot I_{diff} + k_s \cdot (\mathbf{h} \cdot \mathbf{n})^n \cdot I_{spec}$$

ambient — diffuse — specular

Lighting in OpenGL

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- Light source: amount of RGB light emitted
  - *value represents percentage of full intensity, e.g., (1.0,0.5,0.5)*
  - *every light source emits ambient, diffuse, and specular light*
- Materials: amount of RGB light reflected
  - *value represents percentage reflected e.g., (0.0,1.0,0.5)*

Lighting in OpenGL

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```
glLightfv(GL_LIGHT0, GL_AMBIENT, amb_light_rgba );
glLightfv(GL_LIGHT0, GL_DIFFUSE, dif_light_rgba );
glLightfv(GL_LIGHT0, GL_SPECULAR, spec_light_rgba );
glLightfv(GL_LIGHT0, GL_POSITION, position);
glEnable(GL_LIGHT0);

glMaterialfv( GL_FRONT, GL_AMBIENT, ambient_rgba );
glMaterialfv( GL_FRONT, GL_DIFFUSE, diffuse_rgba );
glMaterialfv( GL_FRONT, GL_SPECULAR, specular_rgba );
glMaterialfv( GL_FRONT, GL_SHININESS, n );
```

Flat Shading

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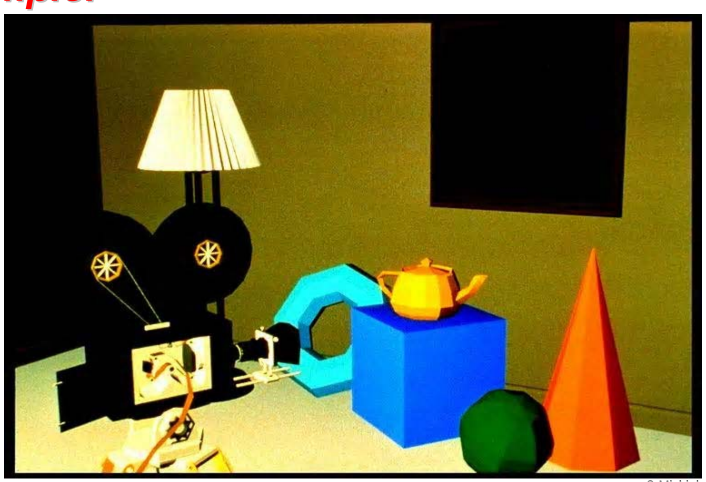
Example:



Gouraud Shading

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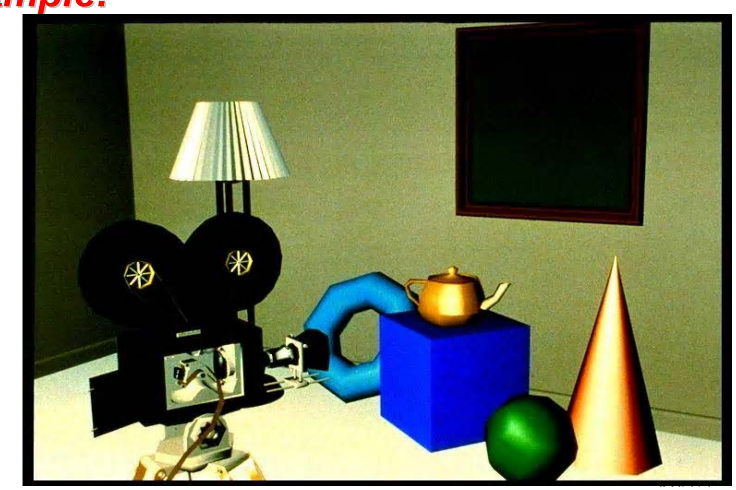
Example:



Materials

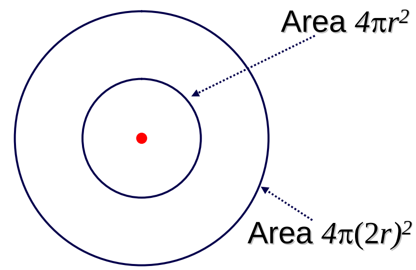
Summary

- Very simple reflection models
- Fast (dot products & exponentiation)
- No physical justification
- Not very good for modeling real world

Light Sources

Quadratic falloff

- Brightness of objects depends on power per unit area that hits the object
- The power per unit area for a point or spot light decreases quadratically with distance



Light Sources

Non-quadratic falloff:

- Many systems allow for other falloffs
- Allows for faking of the effect of area light sources
- OpenGL / graphics hardware:
  - *I_o: intensity of light source*
  - *$\mathbf{x}$: object point*
  - *r: distance of light from $\mathbf{x}$*

$$I_{in}(\mathbf{x}) = \frac{1}{ar^2 + br + c} \cdot I_0$$

Materials

Bi-directional Reflectance Distribution Function (BRDF):

- Describes fraction of light reflected for all combinations of incoming (light) and outgoing (viewing) directions
- Color channels (R, G, B) are treated separately
  - *Actually: wavelengths (see later in course)*

Materials

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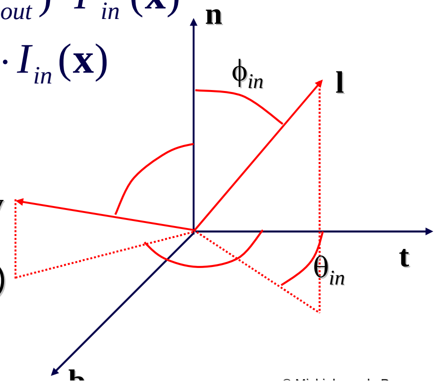
Bi-directional Reflectance Distribution Function (BRDF):

$$I_{out}(\mathbf{x}) = f_r(\phi_{in}, \theta_{in}, \phi_{out}, \theta_{out}) \cdot I'_{in}(\mathbf{x})$$
$$= f_r(\mathbf{l} \rightarrow \mathbf{v}) \cdot (\mathbf{n} \cdot \mathbf{l}) \cdot I_{in}(\mathbf{x})$$

- $f_r(\mathbf{l} \rightarrow \mathbf{v})$ is called *BRDF*
- $(\mathbf{t},\mathbf{n},\mathbf{b})$ is *local coordinate frame* (normal, tangent, binormal)



Materials

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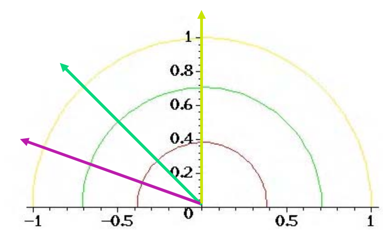
Polar plot of BRDF

- Fix incoming light direction $\mathbf{l}$
- Plot $f_r(\mathbf{l} \rightarrow \mathbf{v}) \cdot \mathbf{v}$ for all viewing directions $\mathbf{v}$
- Works for 2D and 3D plots
- Example: 2D polar plot for diffuse BRDF



Light Sources

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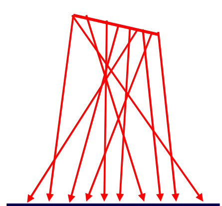
Area lights:

- light sources with a finite area
- more realistic model of many light sources
- Not available with projective rendering pipeline, (i.e., not available with OpenGL)



Gouraud Shading

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Mach Bands:

- Eye enhances discontinuity in first derivative
- Very disturbing, especially for highlights