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Illumination Models

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Images...

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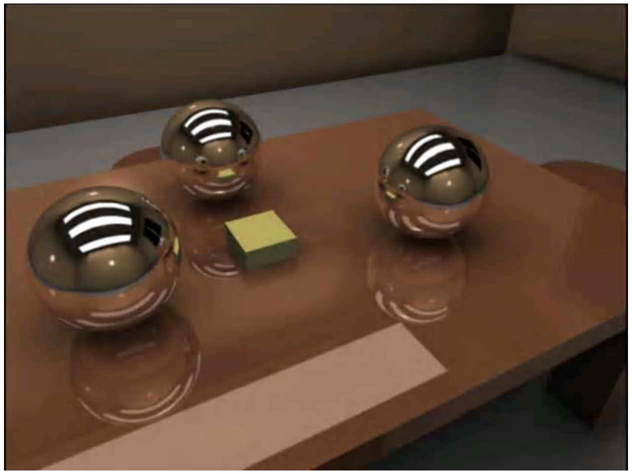

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Local Illumination

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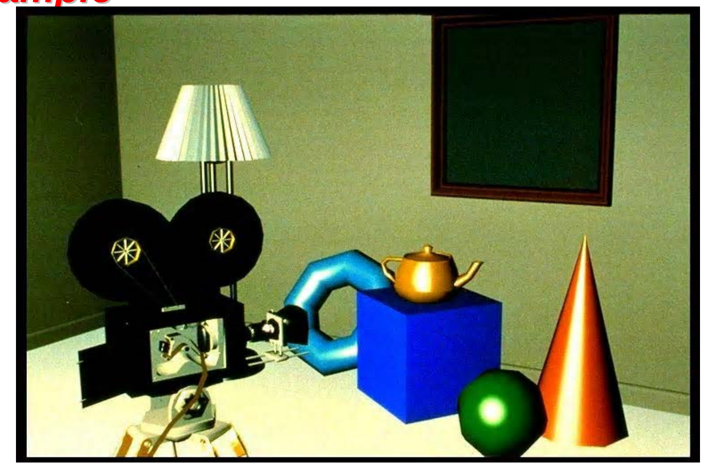
Example



Demo

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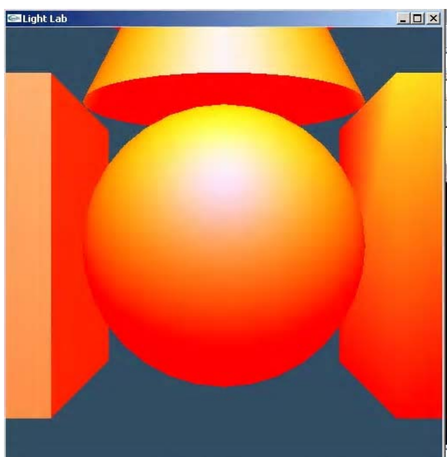

Local Illumination in the projective rendering pipeline

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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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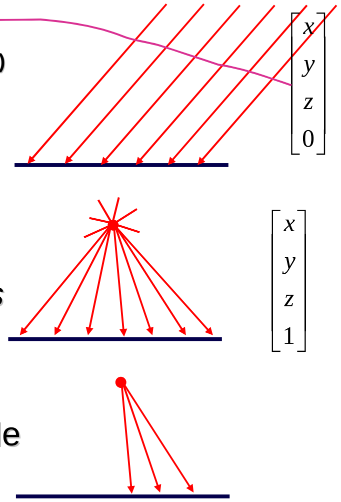
Types of light sources

- `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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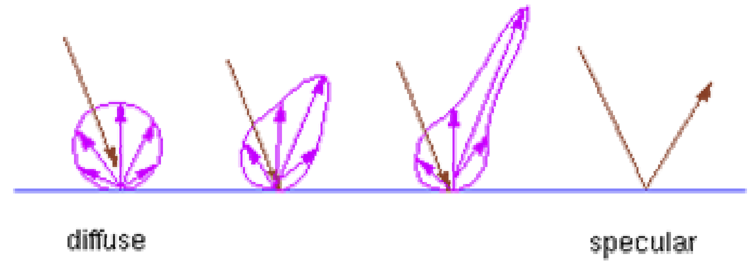

Commonly used model (simple, non-physical)

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Combine diffuse, specular, ambient

- E.g. OpenGL / graphics hardware:

L·N

$$I_{out}(\mathbf{x}) = \underbrace{k_a \cdot I_a}_{\text{ambient}} + \underbrace{k_d \cdot (\mathbf{l} \cdot \mathbf{n}) \cdot I_{diff}}_{\text{diffuse}} + \underbrace{k_s \cdot (\mathbf{h} \cdot \mathbf{n})^n \cdot I_{spec}}_{\text{specular}}$$

Blinn

$k_s (R \cdot V)^n I_{spec}$

Phong

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)

$k_a \in [0,1]$

$I_a \in [0,1]$

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

light source

material property

Diffuse component: Lambert's Law

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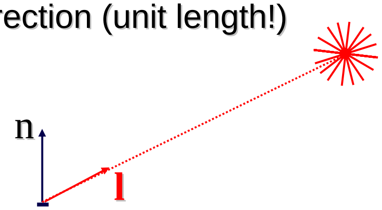
Johann Friedrich Lambert (1783):

- 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!)



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

Diffuse Component: a more detailed look

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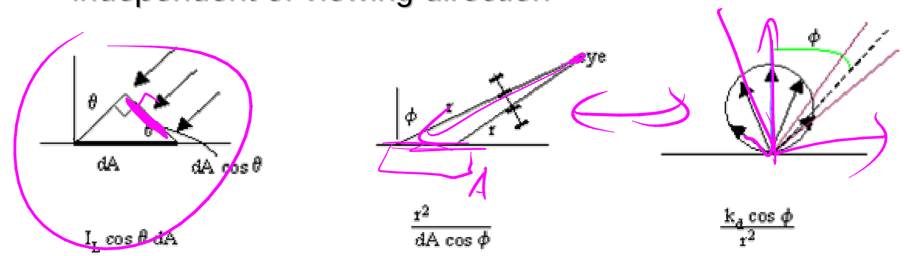
- independent of viewing direction



$I_p \propto$ 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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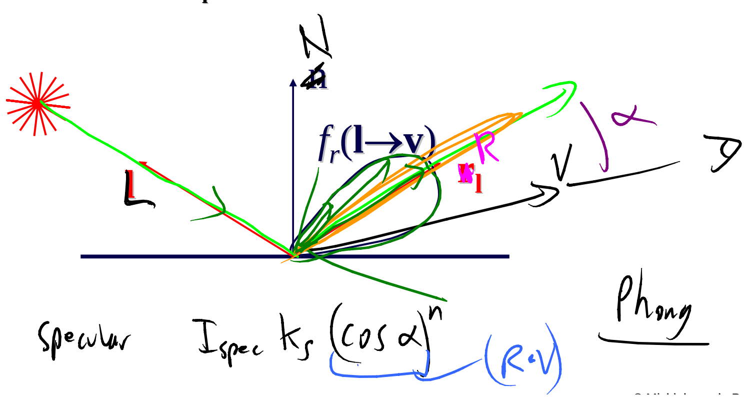
Specular/Glossy

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



Materials

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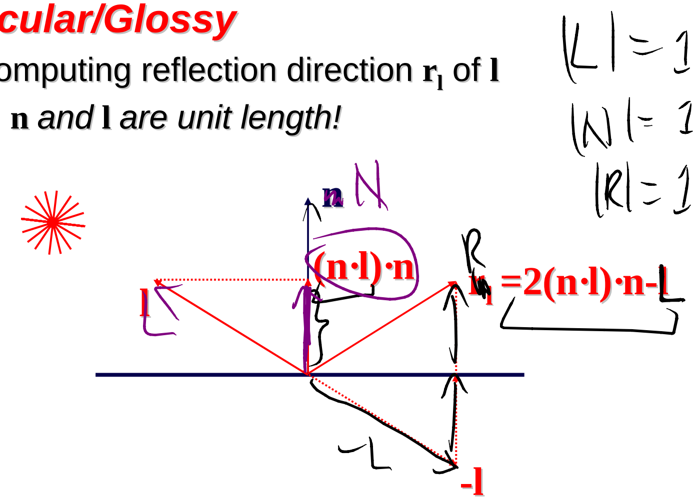
Specular/Glossy

- Computing reflection direction $\mathbf{r}_\mathbf{l}$ 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

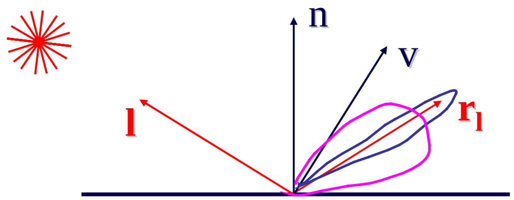
$$I_{spec}(\mathbf{x}) = k_s \cdot (\mathbf{v} \cdot \mathbf{r}_l)^n \cdot I_{in}(\mathbf{x})$$

V·R

n = 100 for highly specular surfaces

n = 10 for moderately specular

:



Materials

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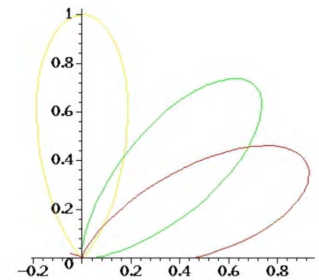
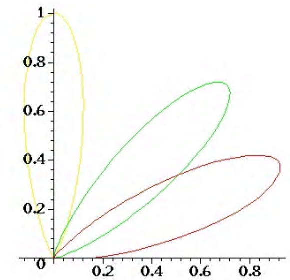
Phong model

- Polar plot



n=10



n=100

Materials

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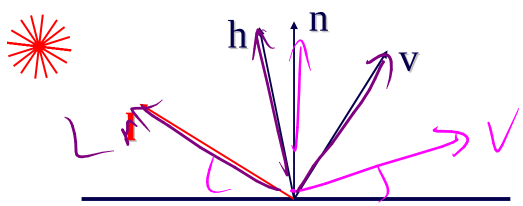
Blinn-Phong model (Jim Blinn, 1977)

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

(L+V)/2

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



Materials

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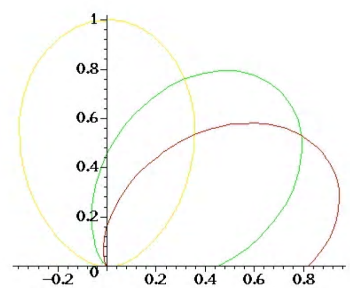
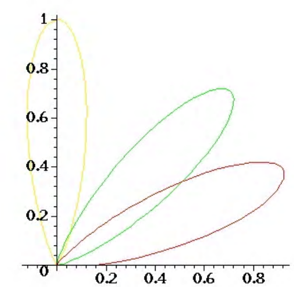
Blinn-Phong Model

- 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);

```
void setProperties(void)
{
   // Default values for material and light properties.
   GLfloat mat_ambient[] = { 0.2,0.2,0.2,1};
   GLfloat mat_diffuse[] = { 0.6, 0.6, 0.6, 1};
   GLfloat mat_specular[] = { 0.5, 0.5 ,0.5, 1.0 };

   GLfloat lightAmbient[] =  { 1,1,1,1};
   GLfloat lightDiffuse[] =  { 1,1,1,1};
   GLfloat lightSpecular[] = { 1,1,1,1};
   GLfloat lightZero[] =     {0,0,0,1};

   glShadeModel (GL_SMOOTH);

     // set material propreties
   glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient);  // material
   glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_diffuse);
   glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
   glMaterialfv(GL_FRONT, GL_SHININESS, &Shininess);

     // set light properties
   glLightModelfv( GL_LIGHT_MODEL_AMBIENT, lightZero);
   glLightfv(GL_LIGHT0, GL_AMBIENT, lightAmbient);
   glLightfv(GL_LIGHT0, GL_DIFFUSE, lightDiffuse);
   glLightfv(GL_LIGHT0, GL_SPECULAR, lightSpecular);

   glEnable(GL_LIGHTING);
   glEnable(GL_LIGHT0);
   glEnable(GL_DEPTH_TEST);
   glEnable(GL_NORMALIZE);
}
```

Flat Shading

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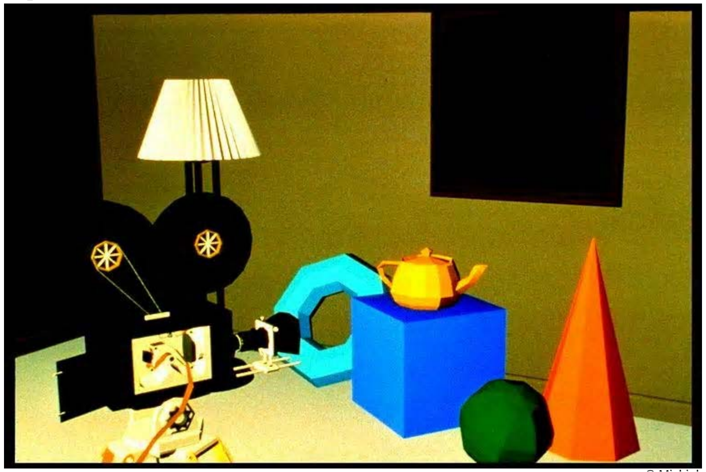
Example:



Gouraud Shading

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Example:

Materials

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Summary

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

Light Sources

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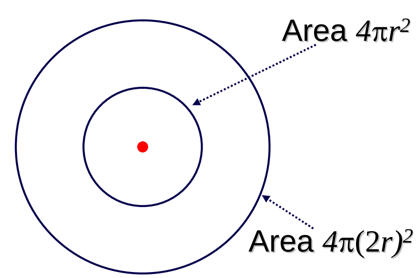
Quadratic falloff

- 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

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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

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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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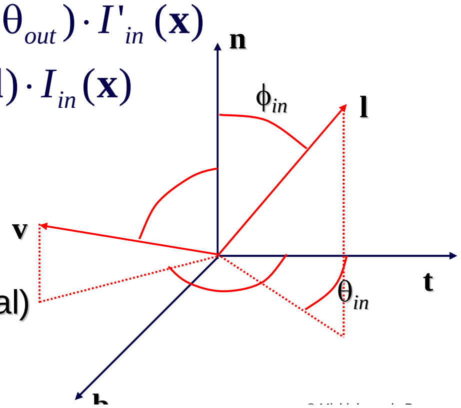
Bi-directional Reflectance Distribution Function (BRDF):

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

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



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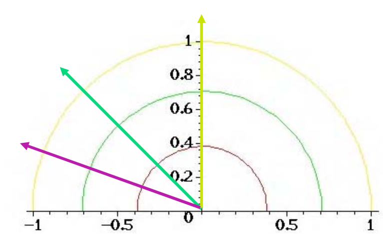
Polar plot of BRDF

- 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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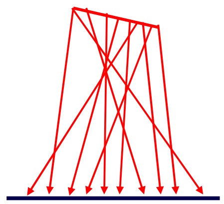
Area lights:

- 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