CS 354
Lighting

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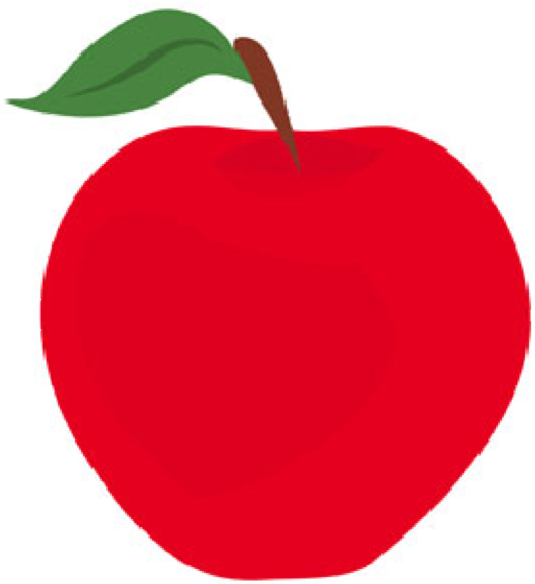
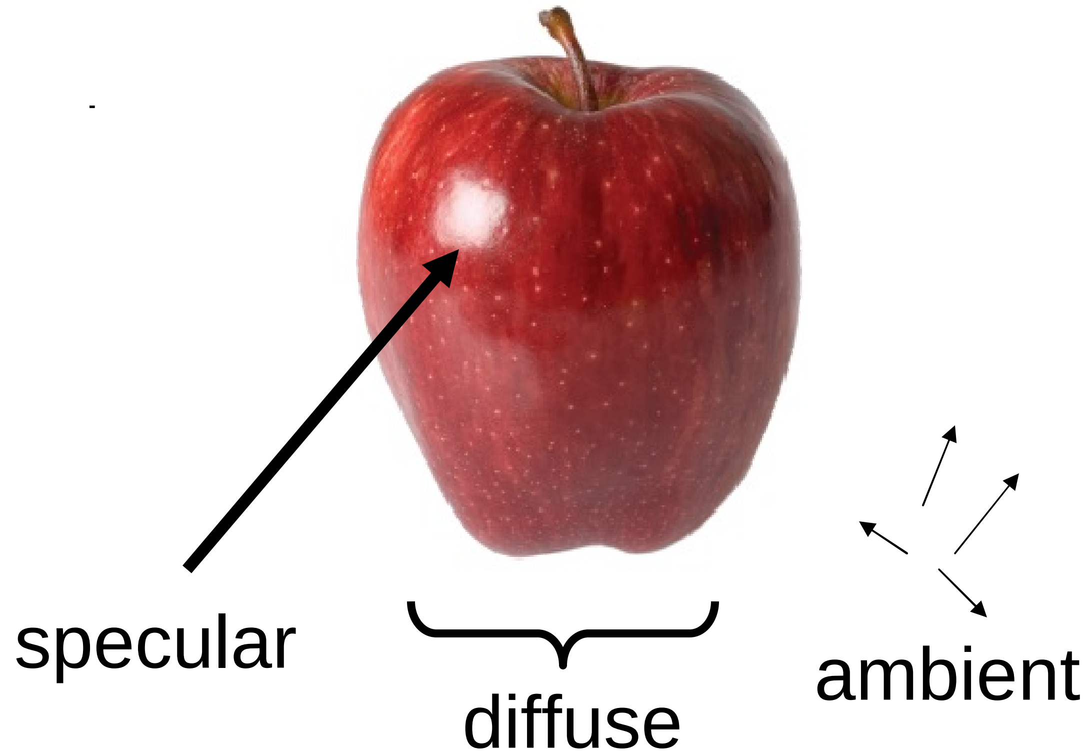
What makes an apple red?





Child's view:
"an apple is red"

Image synthesis view:
"light, surface, and material interact to reflect light perceived as color, modeled via simplifying assumptions"

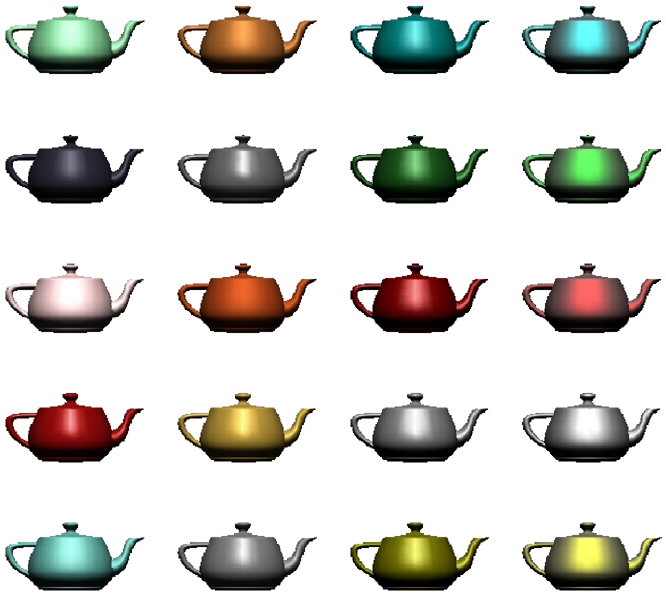
Complex Realistic Lighting

OptiX

iray

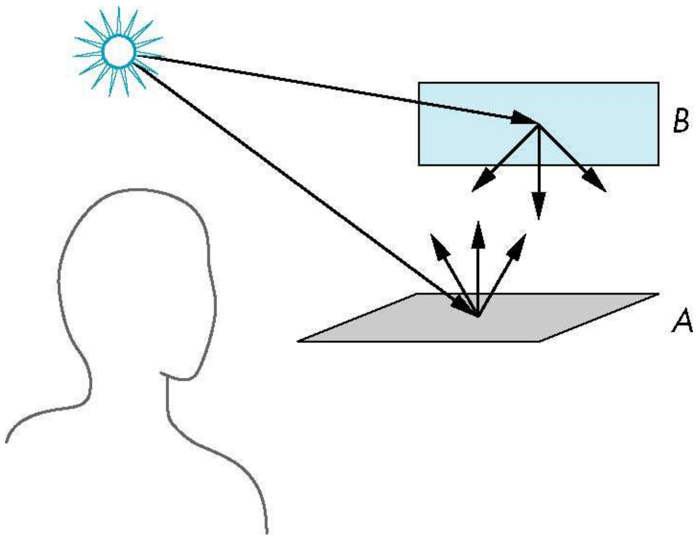
Why lighting?

Teapots rendered with different material parameters



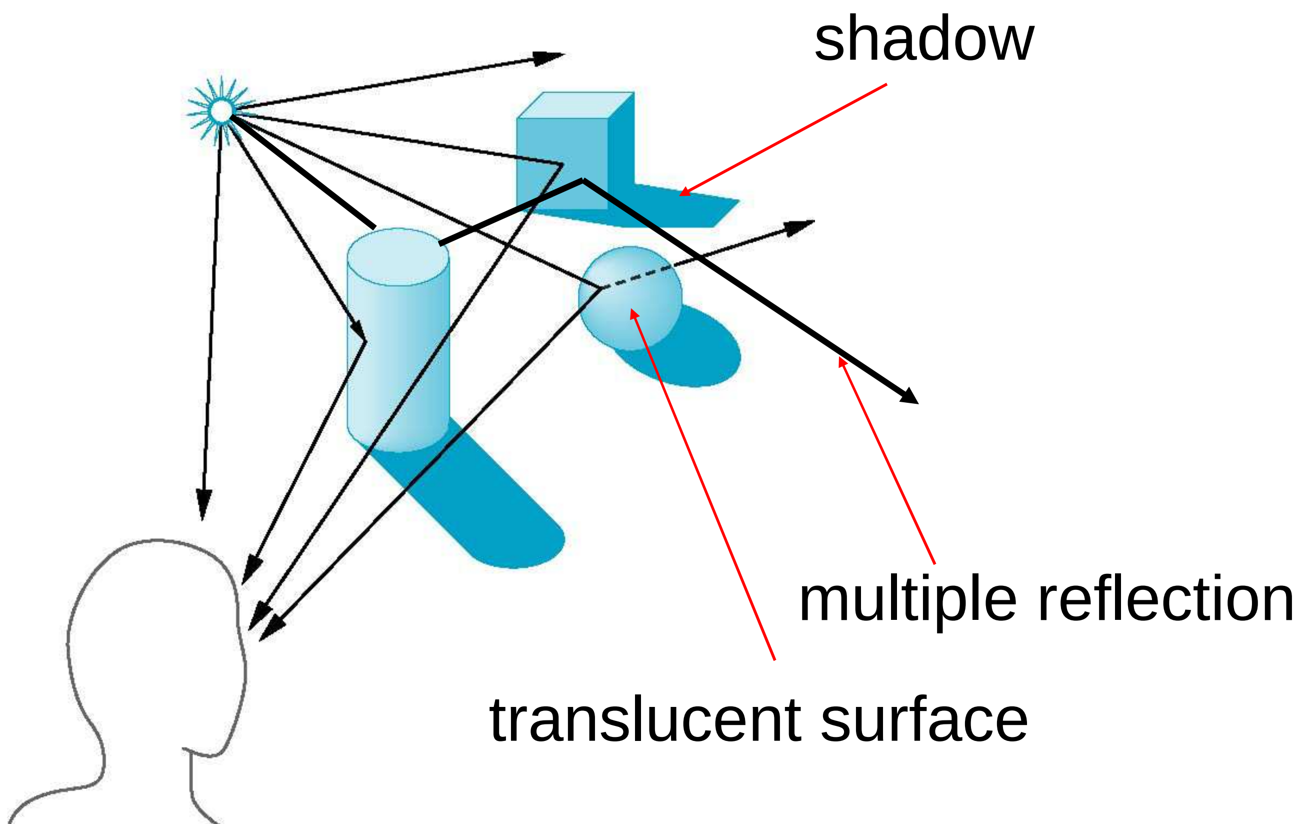
- Convey sense of surface roughness/smoothness
- Convey sense of material
  - Visual appearance of plastic is different than copper or ebony
- Realism
- Emotion

Light Scatters



- Light strikes A
  - Some scattered
  - Some absorbed
- Some of scattered light strikes B
  - Some scattered
  - Some absorbed
- Some of this scattered light strikes A and so on
  - Inherently recursive
  - Massively parallel
  - Points to the ray tracing methodology for rendering

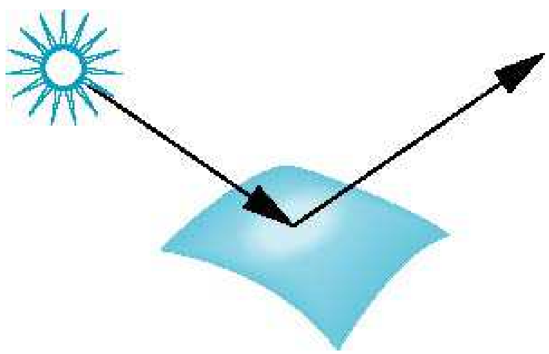
Global Lighting Effects



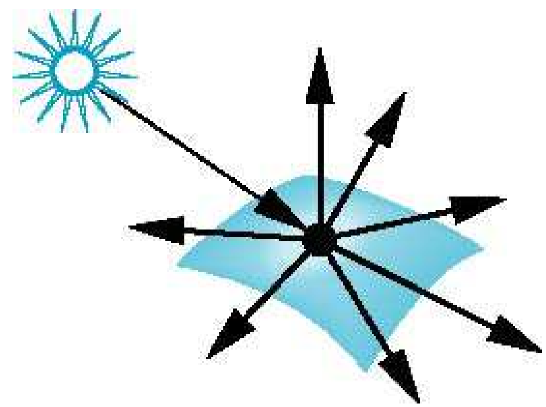
Common interactive graphics rendering assumption: *only model local lighting effects*

Surface Types

- Smooth surfaces reflect like mirrors
- Rough surfaces scatter light
- *Real surfaces act as mixture of both*



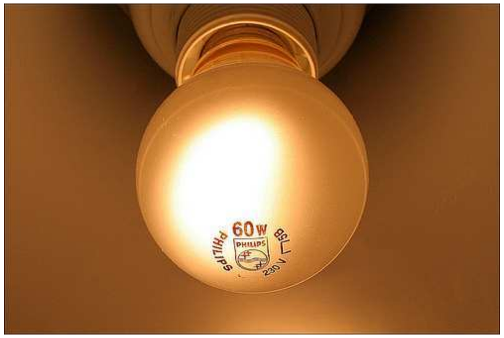
Smooth reflective surface



Rough diffuse surface

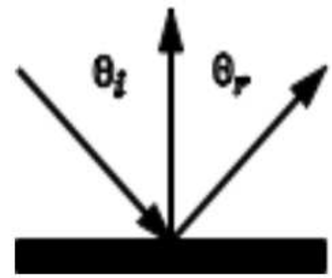
Emissive Light

- Certain objects emit light
  - Various reasons: incandesce, burning, fluorescence, phosphorescence
  - Typically models as a emissive color

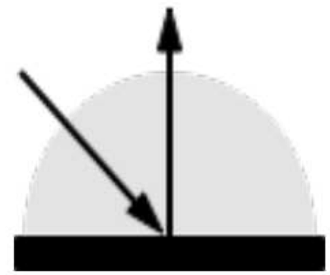


Types of Reflected Light

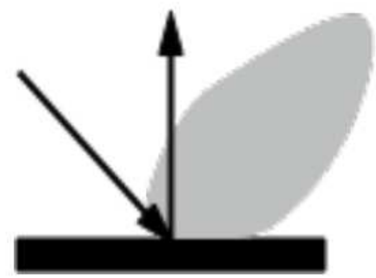
- Mirror reflection
  - Ideal reflection
  - Reflection Law
- Diffuse reflection
  - Matte, flat finish
  - Lambert's Law
- Specular
  - Highlights and gloss
  - Micro-facet model



Phong lighting



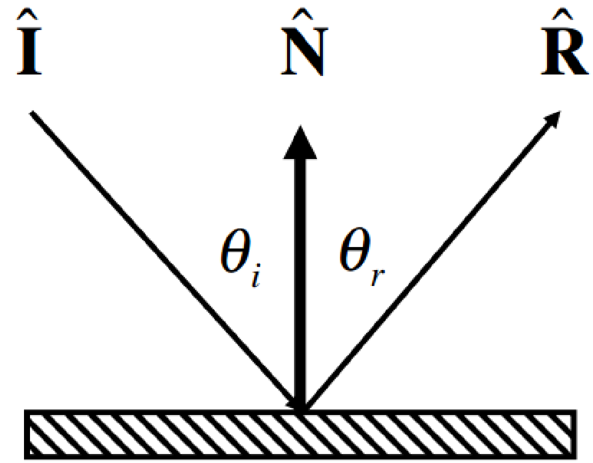
Lambertian lighting



Blinn lighting

Mirror: Law of Reflection

Planar reflectance



$$\theta_r = \theta_i$$

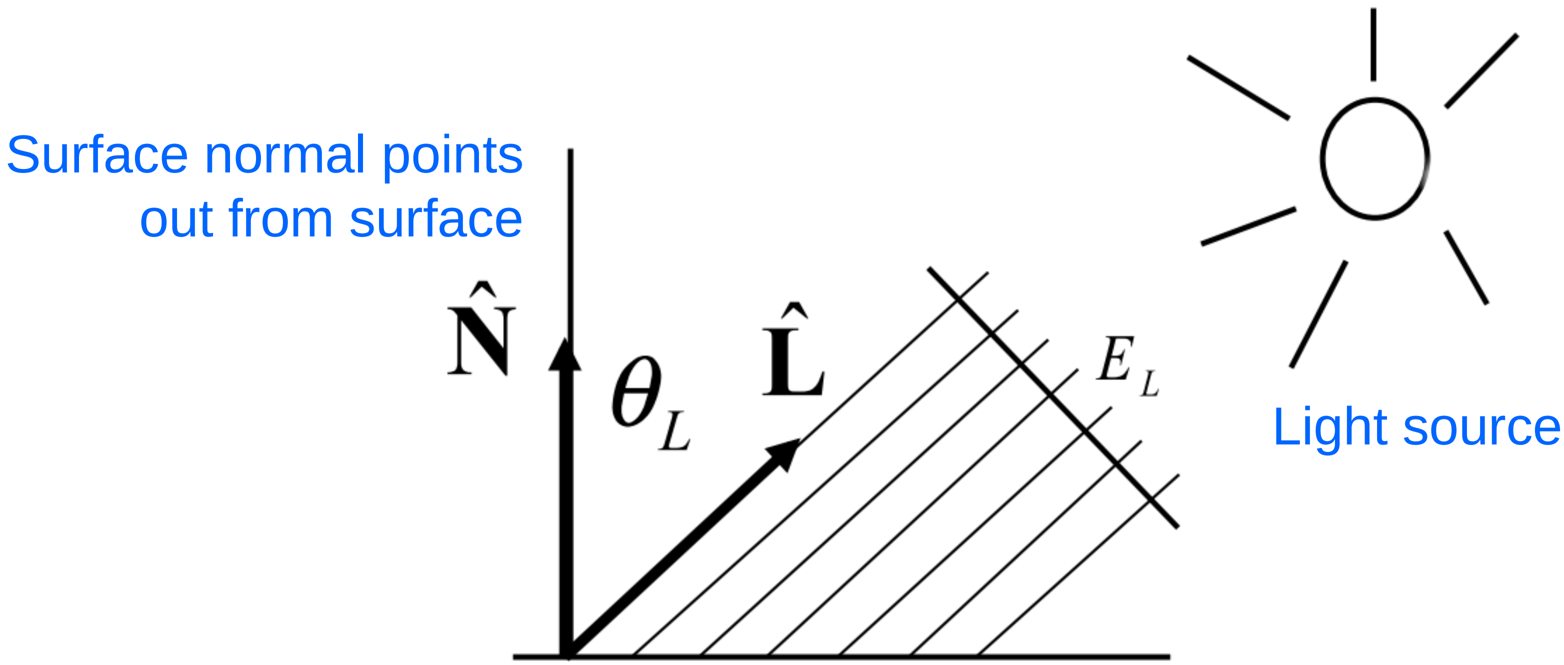
Spherical reflectance

$$\hat{\mathbf{R}} + (-\hat{\mathbf{I}}) = 2\cos\theta_i \hat{\mathbf{N}} = -2(\hat{\mathbf{I}} \bullet \hat{\mathbf{N}})\hat{\mathbf{N}}$$

$$\hat{\mathbf{R}} = \hat{\mathbf{I}} - 2(\hat{\mathbf{I}} \bullet \hat{\mathbf{N}})\hat{\mathbf{N}}$$

Angle of incidence = angle of reflection

Lambert's Law, or Diffuse Illumination

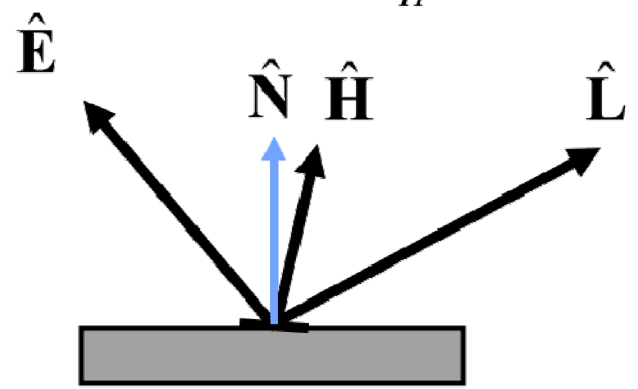


$$diffuse = \max(0, \hat{\mathbf{N}} \bullet \hat{\mathbf{L}})$$
$$= \cos\,\theta_L$$

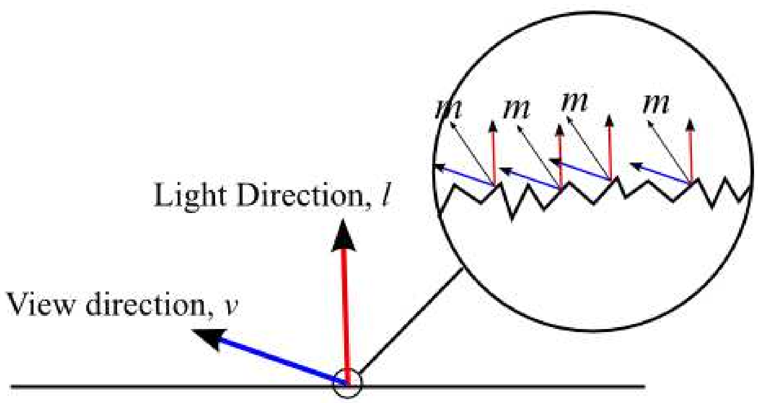
Micro-facet Specular

- Think of the surface as have a statistical distribution of facet orientations
  - OpenGL's fixed-function specular model

$$\cos\theta_H = \hat{\mathbf{N}} \bullet \hat{\mathbf{H}}$$



Halfway vector $\hat{\mathbf{H}} = \dfrac{\hat{\mathbf{L}} + \hat{\mathbf{E}}}{\left|\hat{\mathbf{L}} + \hat{\mathbf{E}}\right|}$



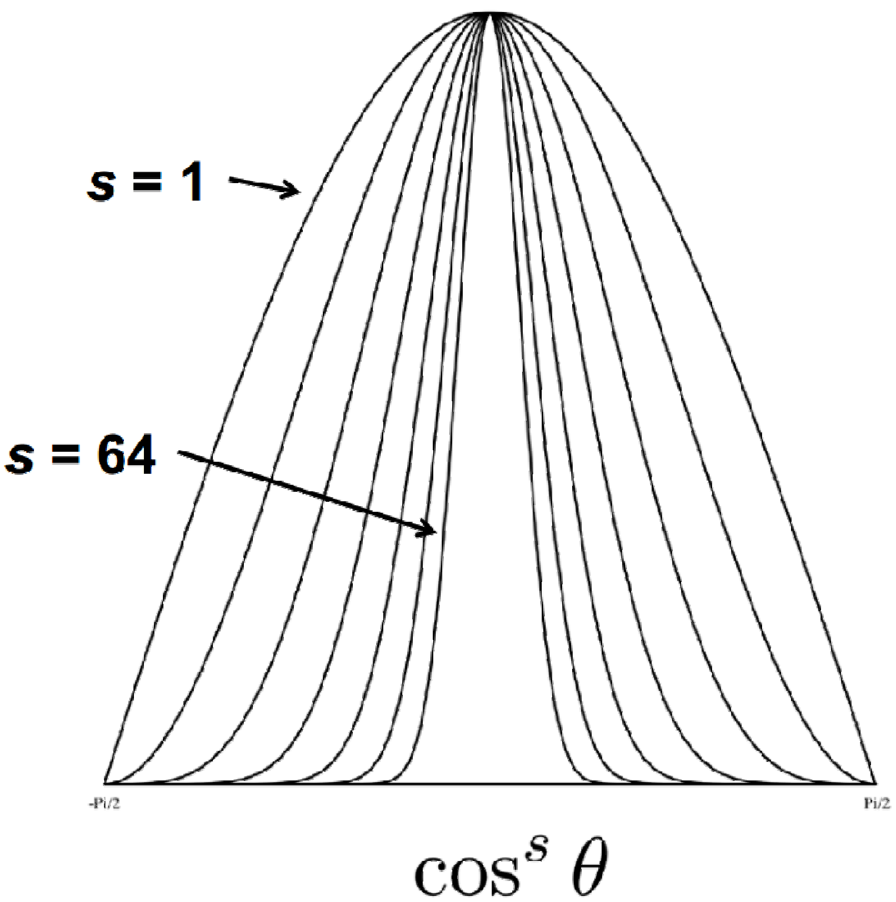
Microfacet distribution

$$(\cos\theta_H)^s = (\hat{\mathbf{N}} \cdot \hat{\mathbf{H}})^s$$

Shininess *s*

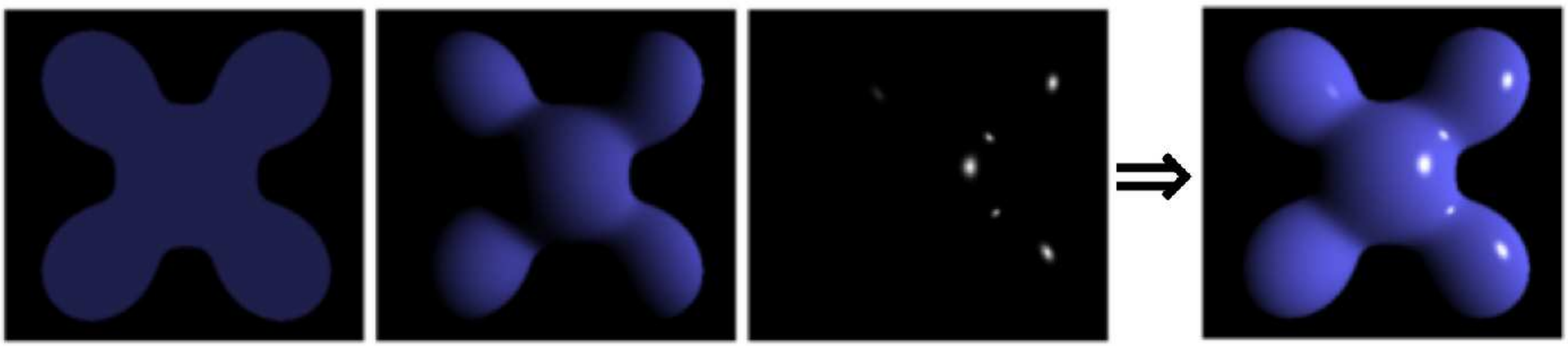
Shininess

- Modeled as exponential fall-off function
  - Larger shininess exponent values means a tighter specular highlight
  - Complement of shininess is roughness
- Exponential fall-off also use to model
  - Spotlight attenuation
  - Fog effects



Combining Lighting Contributions

- Contributions can be summed
  - Since RGB color components are additive
  - Illumination color modulated by material color



Ambient Diffuse Specular Result

Summing Multiple Lights

- For each light source and each color component, the Blinn or Phong model can be written (without the distance terms) as

$$I = k_d \, l_d \; \mathbf{l} \cdot \mathbf{n} \; + k_s \, I_s \, (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_a \, I_a \qquad \text{Phong}$$

$$I = k_d \, l_d \; \mathbf{l} \cdot \mathbf{n} \; + k_s \, I_s \, (\mathbf{h} \cdot \mathbf{n})^{\alpha} + k_a \, I_a \qquad \text{Blinn}$$

- For each color component, we add contributions from all sources

OpenGL Fixed-function Lighting Equation

surface result color

$$
\begin{aligned}
\mathbf{c} &= \mathbf{e}_{cm} \\
&+ \mathbf{a}_{cm} * \mathbf{a}_{cs} \\
&+ \sum_{i=0}^{n-1} (att_i)(spot_i)\left[\mathbf{a}_{cm} * \mathbf{a}_{cli}\right. \\
&\qquad + (\mathbf{n} \odot \overrightarrow{\mathbf{VP}}_{pli})\mathbf{d}_{cm} * \mathbf{d}_{cli} \\
&\qquad \left. + (f_i)(\mathbf{n} \odot \hat{\mathbf{h}}_i)^{s_{rm}} \mathbf{s}_{cm} * \mathbf{s}_{cli}\right]
\end{aligned}
$$

emissive

global ambient

per-light ambient

for each light source

diffuse

specular

$$
f_i = \begin{cases} 1, & \mathbf{n} \odot \overrightarrow{\mathbf{VP}}_{pli} \neq 0, \\ 0, & \text{otherwise}, \end{cases}
$$

diffuse squashes specular

OpenGL Lighting Equation Terms

half-angle

local viewer assumption

$$\mathbf{h}_i = \begin{cases} \overrightarrow{\mathbf{VP}}_{pli} + \overrightarrow{\mathbf{VP}}_e, & v_{bs} = \texttt{TRUE}, \\ \overrightarrow{\mathbf{VP}}_{pli} + \begin{pmatrix} 0 & 0 & 1 \end{pmatrix}^T, & v_{bs} = \texttt{FALSE}, \end{cases}$$

infinite viewer assumption

distance attenuation

$$att_i = \begin{cases} \dfrac{1}{k_{0i} + k_{1i}\|\mathbf{VP}_{pli}\| + k_{2i}\|\mathbf{VP}_{pli}\|^2}, & \text{if } \mathbf{P}_{pli}\text{'s } w \neq 0, \\ 1.0, & \text{otherwise}, \end{cases}$$

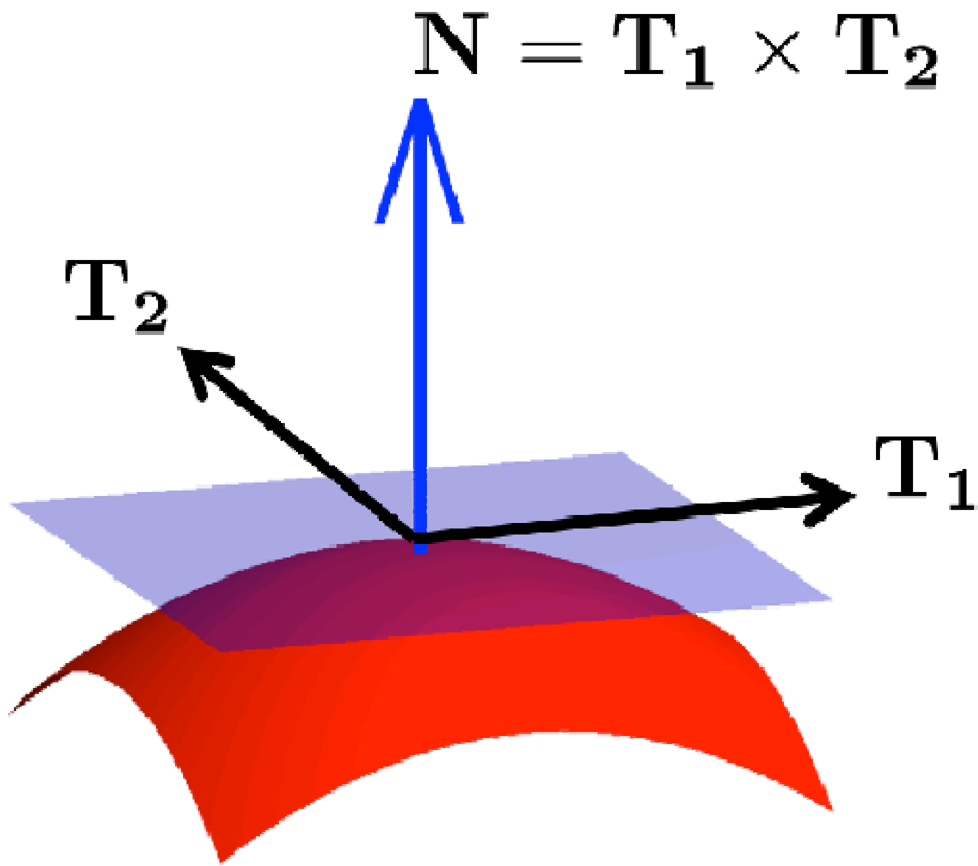
inverse square fall-off

spotlight attenuation

$$spot_i = \begin{cases} (\overrightarrow{\mathbf{P}_{pli}\mathbf{V}} \odot \hat{\mathbf{s}}_{dli})^{s_{rli}}, & c_{rli} \neq 180.0, \overrightarrow{\mathbf{P}_{pli}\mathbf{V}} \odot \hat{\mathbf{s}}_{dli} \geq \cos(c_{rli}), \\ 0.0, & c_{rli} \neq 180.0, \overrightarrow{\mathbf{P}_{pli}\mathbf{V}} \odot \hat{\mathbf{s}}_{dli} < \cos(c_{rli}), \\ 1.0, & c_{rli} = 180.0. \end{cases}$$

Surface Normal

- Surface normal = cross product of surface gradients



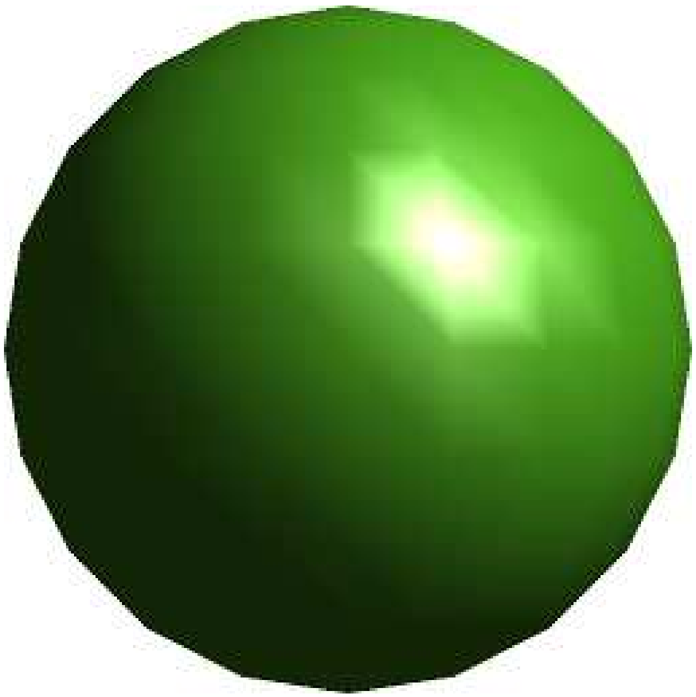
$$(x, y, z) = F(u, v)$$

$$T_1 = \frac{\partial F}{\partial u}$$

$$T_2 = \frac{\partial F}{\partial v}$$

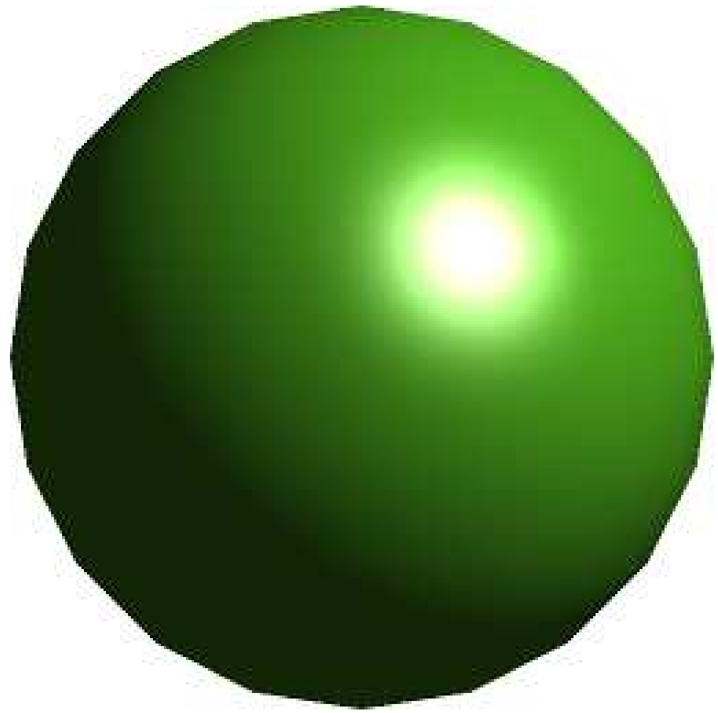
Frequency of Lighting Computations

- Per-vertex



Specular highlight “wobbles” under animation

- Per-fragment



Specular highlight has stable structure