CMP205: Computer Graphics

Lecture 6: Surface Shading

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Fall 2013

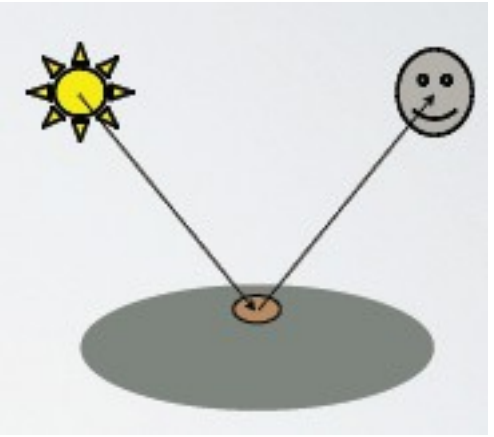
Agenda

- Lighting and Surface Rendering
- Shading Models
  - Diffuse
  - Ambient
  - Specular
- Light Sources
- Surface Rendering
  - Flat
  - Gourard
  - Phong

Acknowledgment: Some slides adapted from Steve Marschner and Maneesh Agrawala

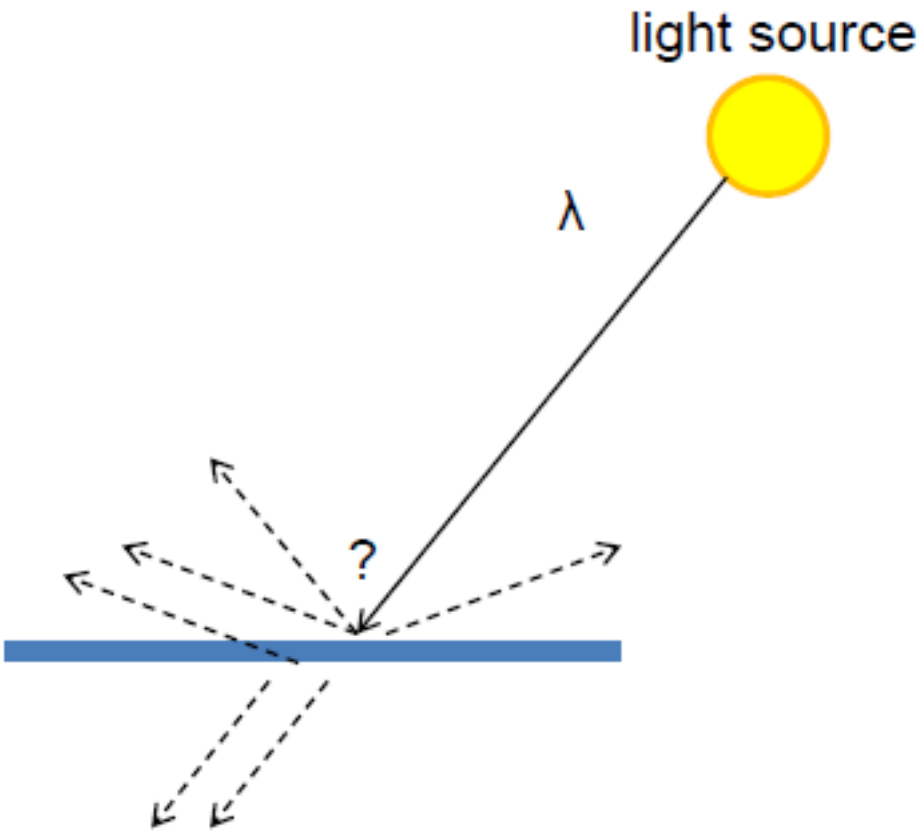
Lighting

- **Lighting Model**: what is the color of a particular position on the object surface
  - a.k.a.: Shading Model, Illumination Model



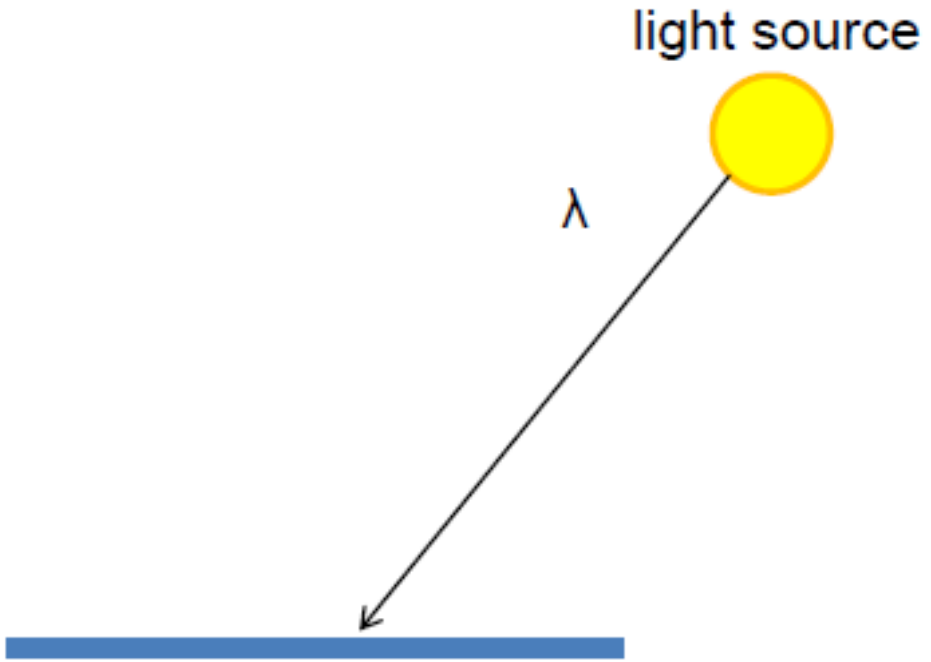
- **Surface Rendering Model**: what is the color of a pixel of a rasterized triangle
  - a.k.a.: Shading

Light and Surfaces



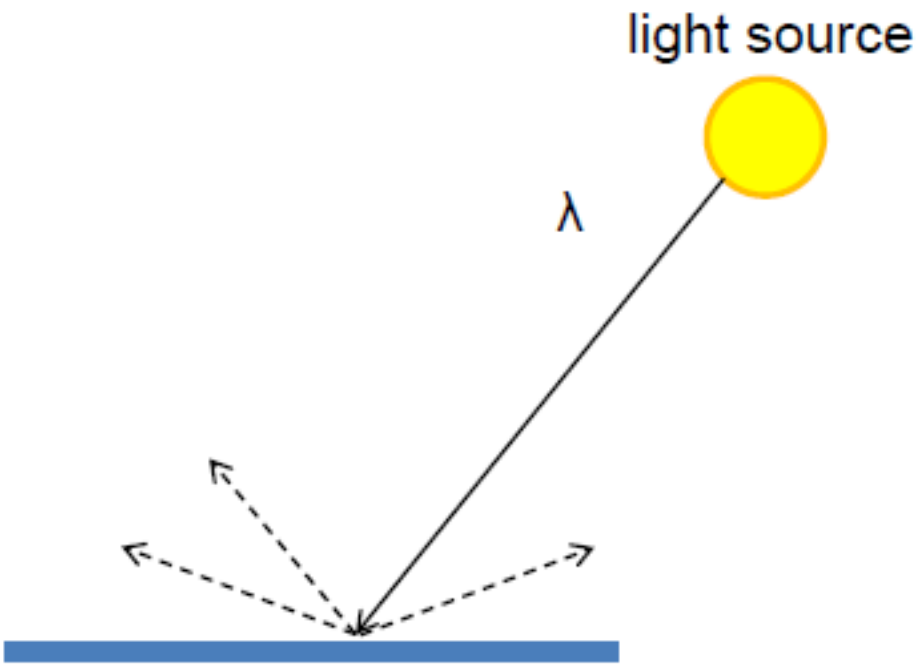
Light can interact with objects' surfaces in different ways

Light and Surfaces



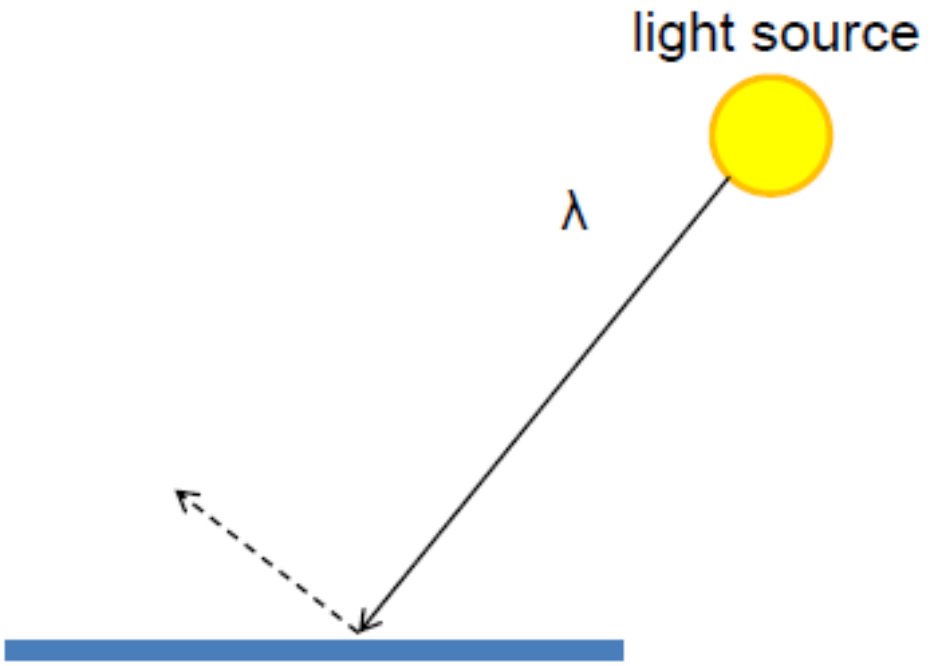
Absorption: the surface absorbs the light

Light and Surfaces



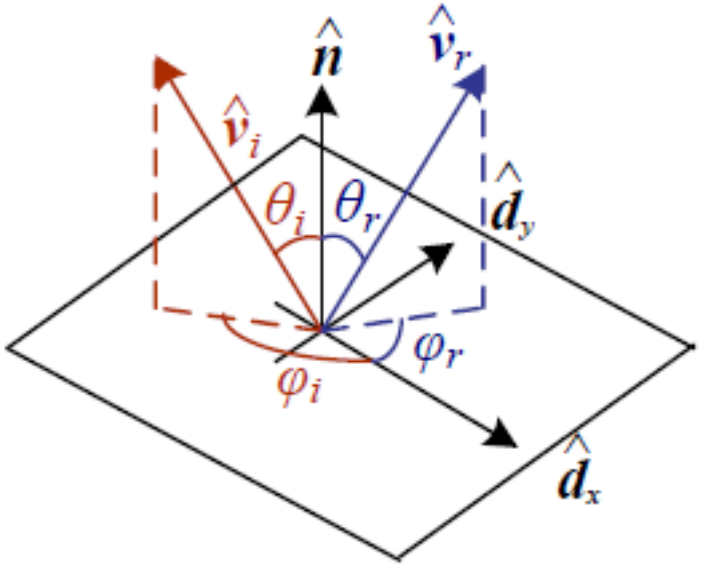
Diffusion: the surfaces reflects the light equally in all directions

Light and Surfaces



(Specular) Reflection: the surface reflects the light in one direction

Bidirectional Reflectance Distribution Function (BRDF)



$$\rho\left(\hat{v}_i, \hat{v}_r, \hat{n}\right)$$

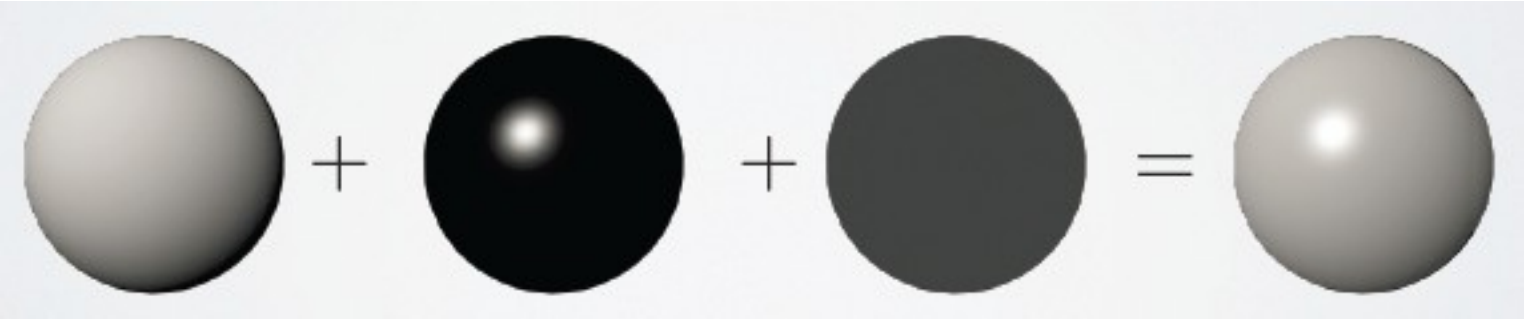
Used to describe the relationship between the incident and reflected light

Equals the ratio between reflected and incident light

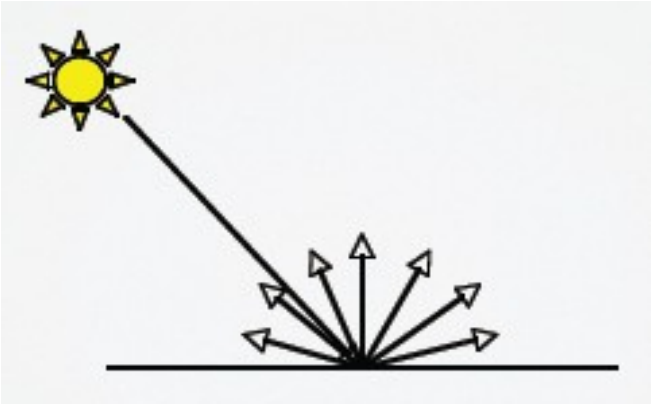
BRDF

Approximate BRDF as:

- A diffuse component
- A specular component
- An ambient component

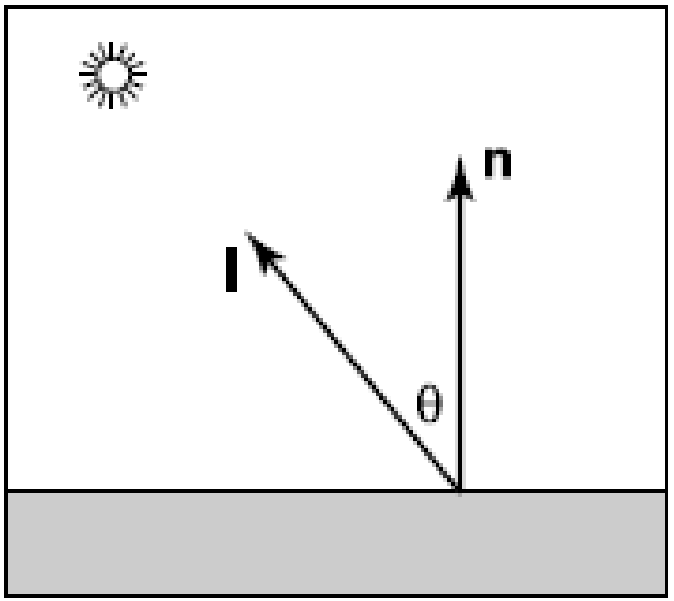


Diffuse Shading



Described as “matte” where objects are *not* shiny

Reflected light the same in all directions

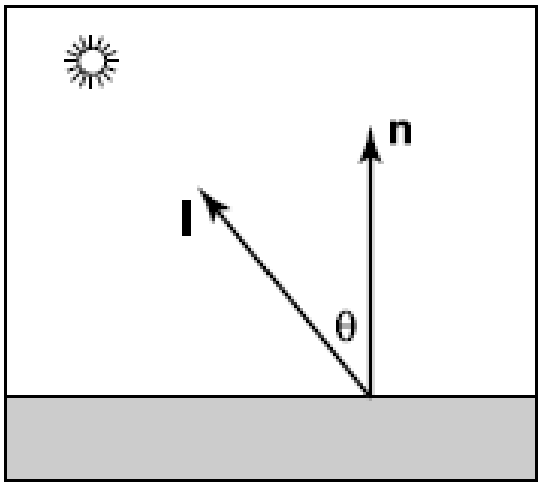


Reflected light depends on θ the angle between the surface normal and the light source

Diffuse Shading

Lambert's Cosine Law

$$\rho_d \propto \cos\theta \quad \text{or} \quad \rho_d \propto \boldsymbol{n}\cdot\boldsymbol{l}$$

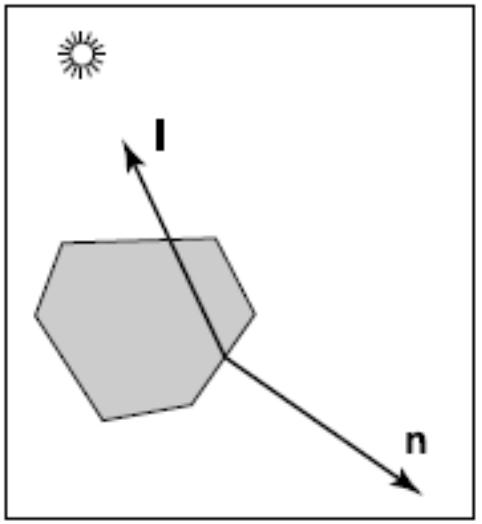


$$\rho_d = k_d(\boldsymbol{n}\cdot\boldsymbol{l})$$

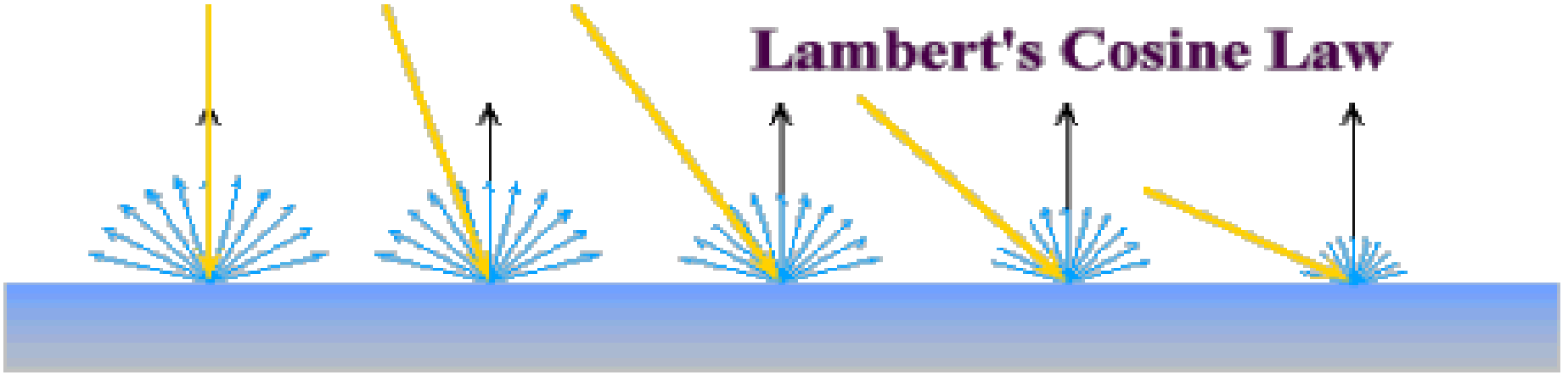
What if *cos* is negative?

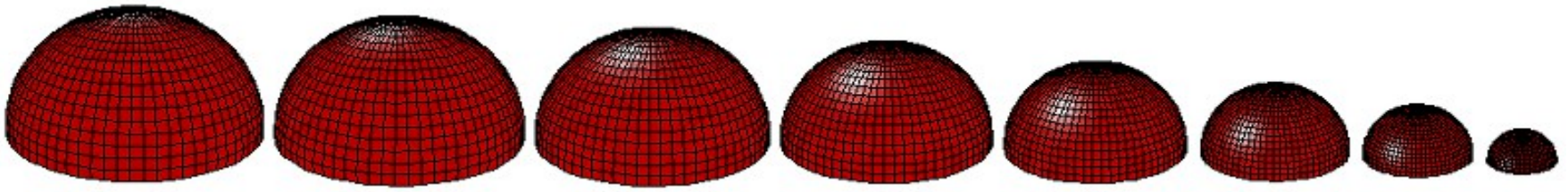
$$\rho_d = k_d \max(0, \boldsymbol{n}\cdot\boldsymbol{l})$$

$$R = k_d I \max(0, \boldsymbol{n}\cdot\boldsymbol{l})$$



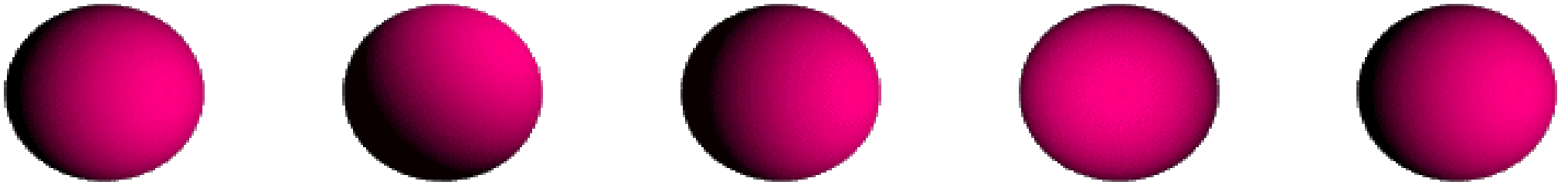
Diffuse Shading





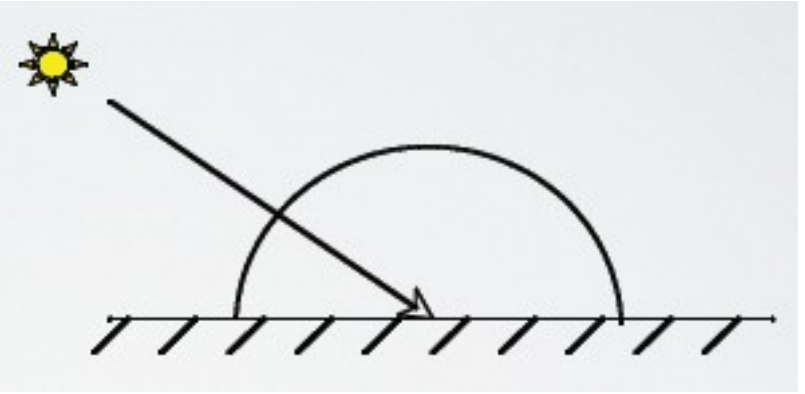
Reflected light independent of viewing direction for the same surface point

Diffuse Shading

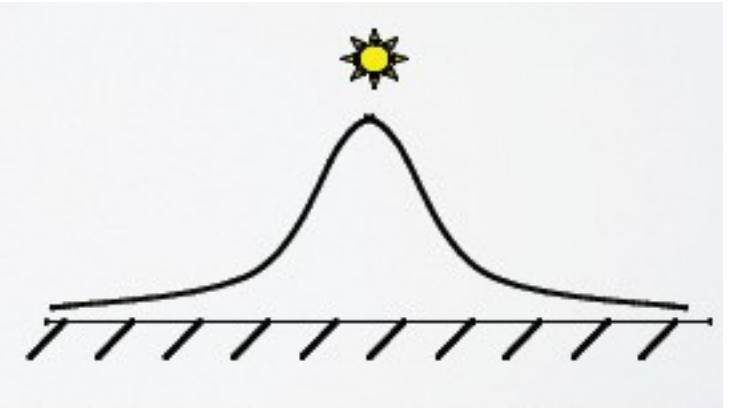


Reflected light depends on position of light source relative to the surface point

Diffuse Shading



Light leaving a surface point in a specific direction



Light leaving each point on the surface

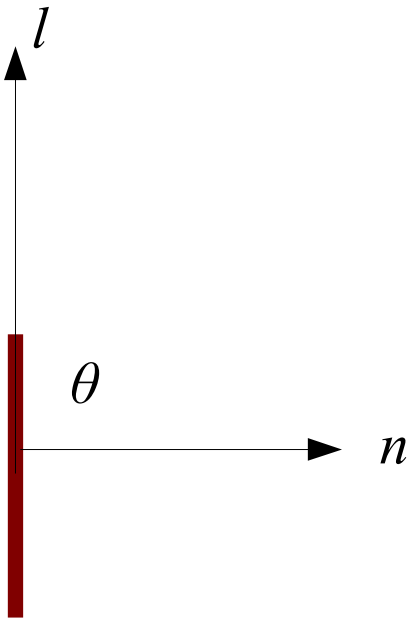
Ambient Shading

$$\rho_d = k_d \max(0, \boldsymbol{n} \cdot \boldsymbol{l})$$

What if $\theta \geq 90$?

$\rho_d = 0$ i.e. dark surface

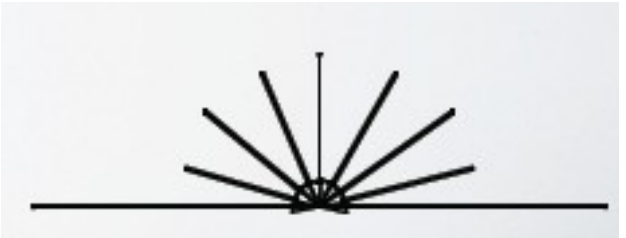
Solution?



Add *ambient* lighting component.

Accounts for light reflected from the surroundings.

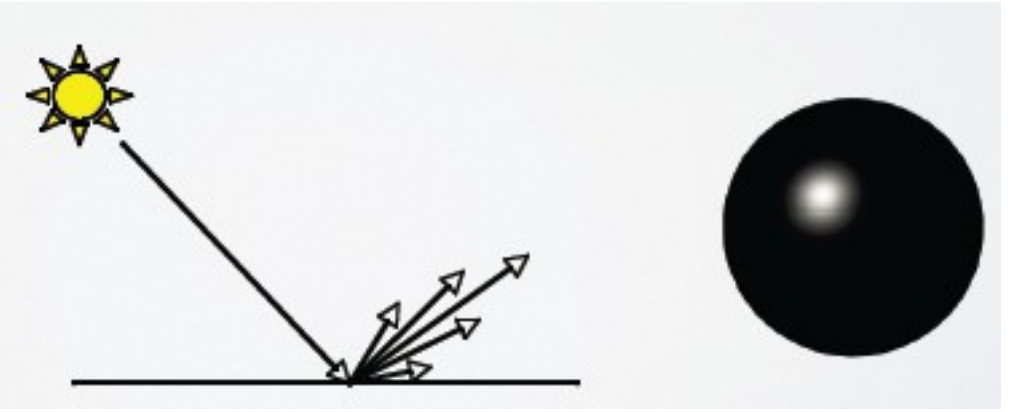
$$\rho_a = k_a$$



$$R = k_a I_a$$

Specular Shading

- Mirror-like reflection
- Good approximation for some surfaces
- Depends on the viewing direction
- Phong Ilumination Model



Specular Shading

Incidence angle equals Reflection angle

Specular highlight depends on viewing angle σ

$$\rho_s = k_s \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r}\right)$$

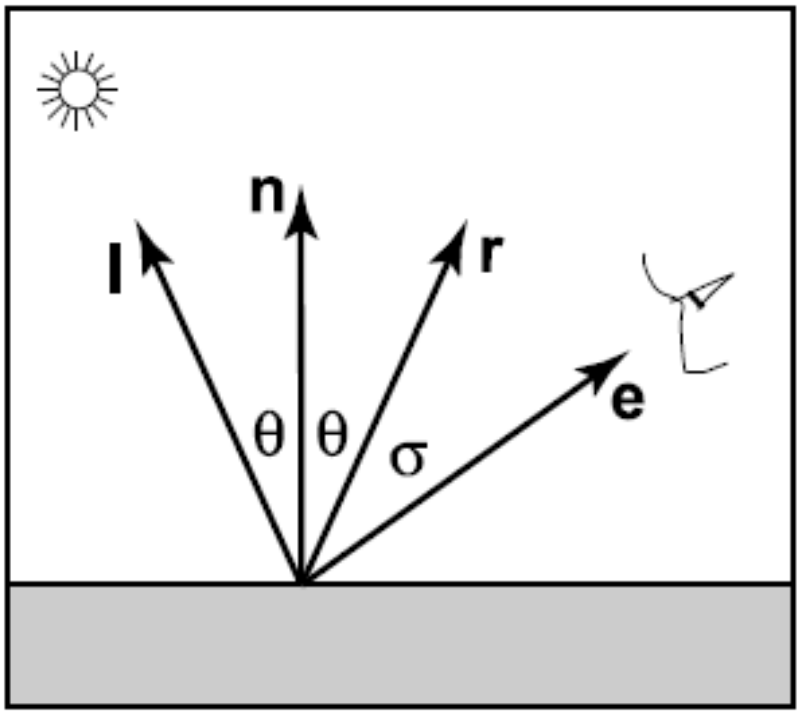
Problem?

The *highlight* produced is very wide!

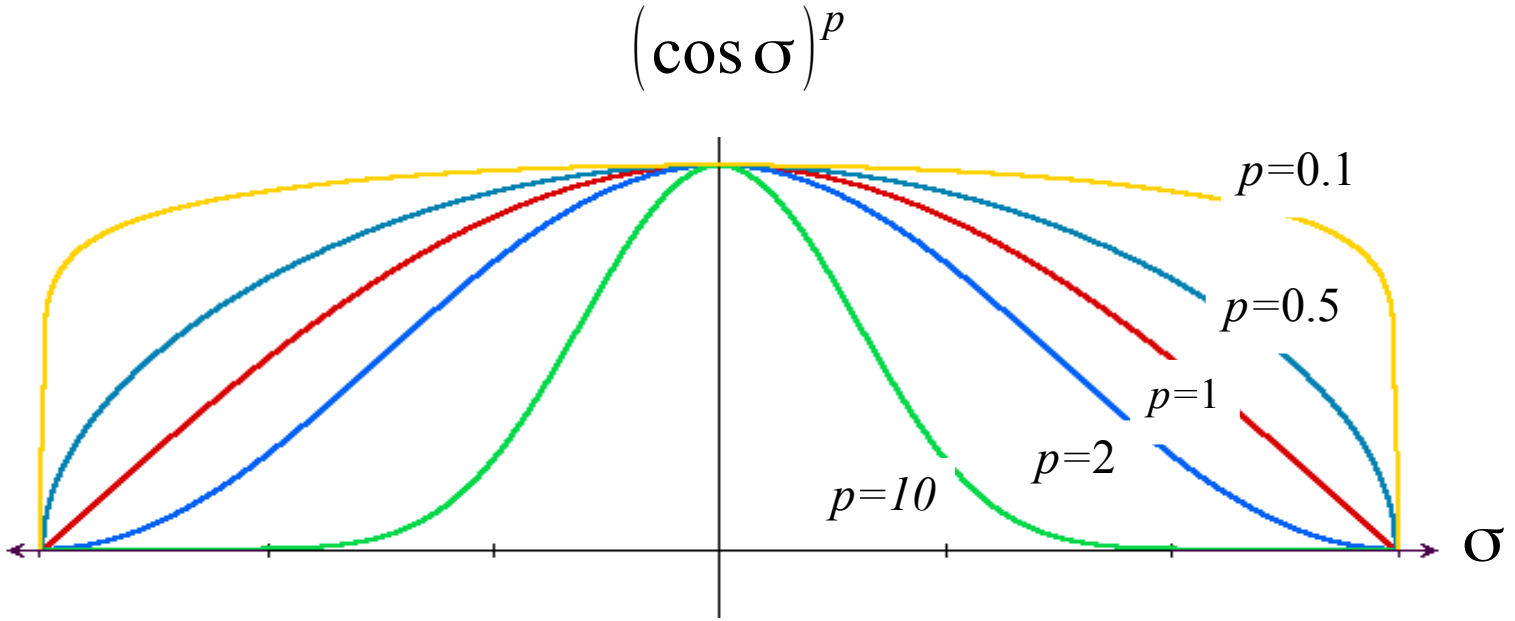
$$\rho_s = k_s \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r}\right)^p$$

p: Phong Exponent

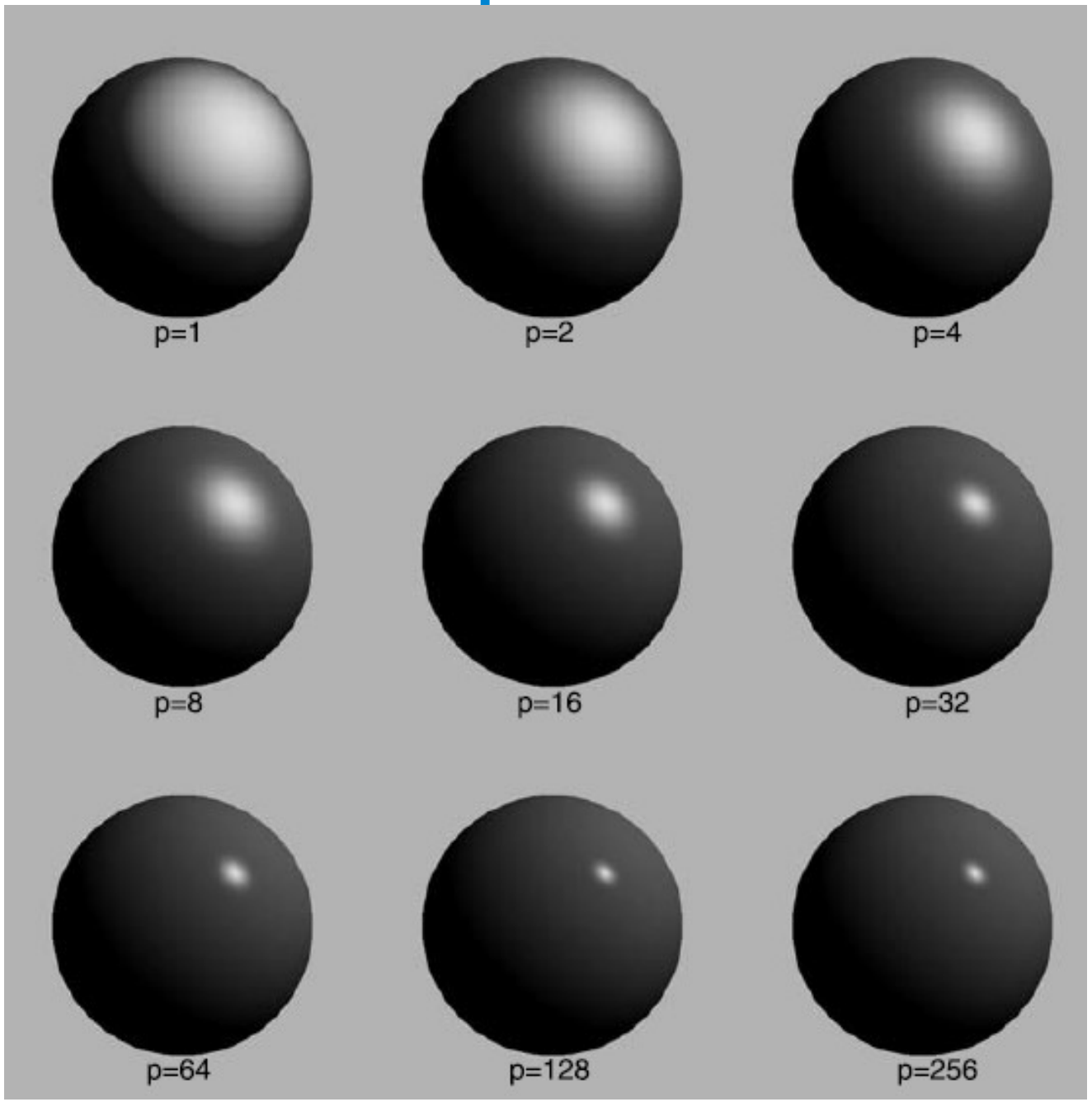
$$R = k_s I \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r}\right)^p$$



Specular Exponent

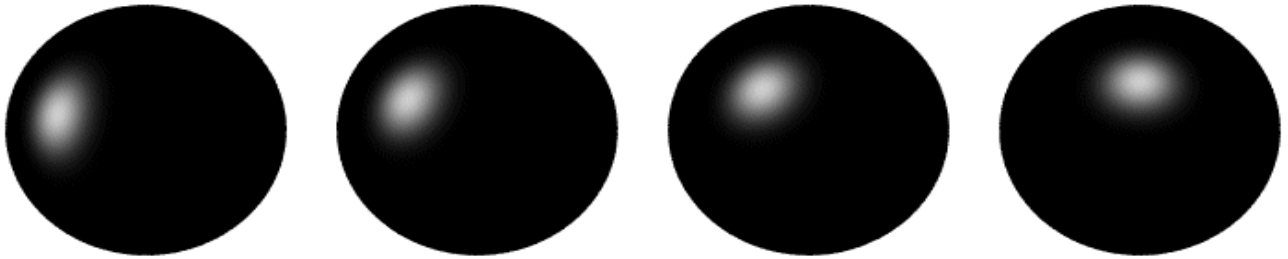


Specular Shading

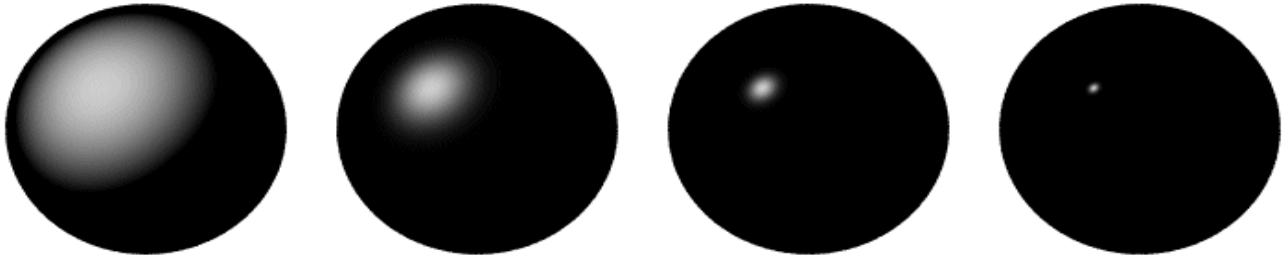


Size of the highlight for different values for *p*

Specular Shading



Different light source direction

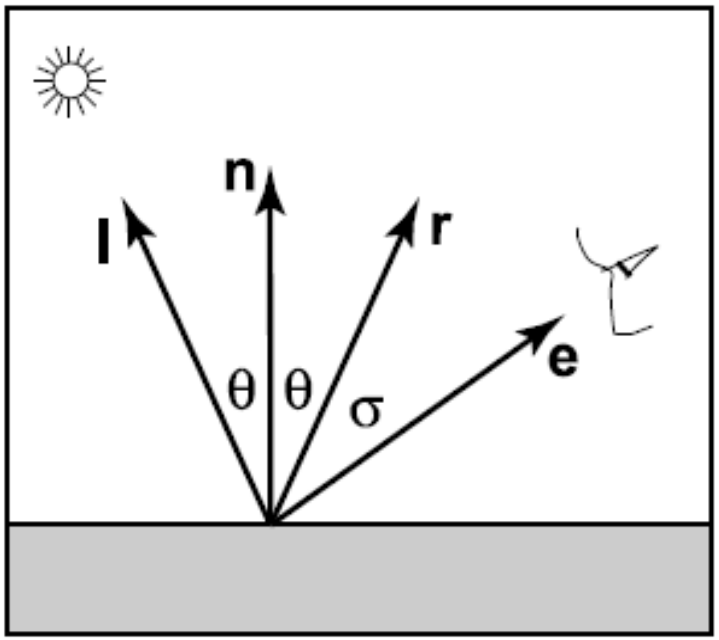


Different values for p

Specular Shading

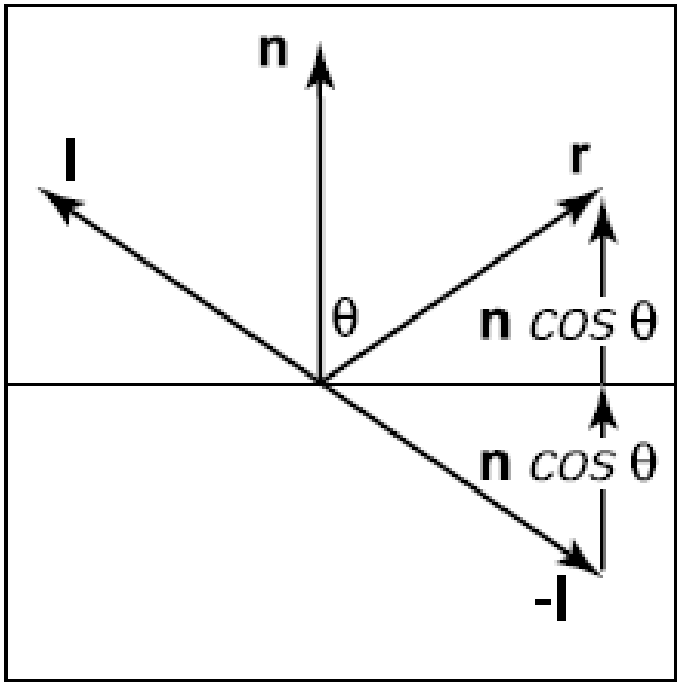
$$\rho_s = k_s \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r}\right)^p$$

How do we compute r from l and n?



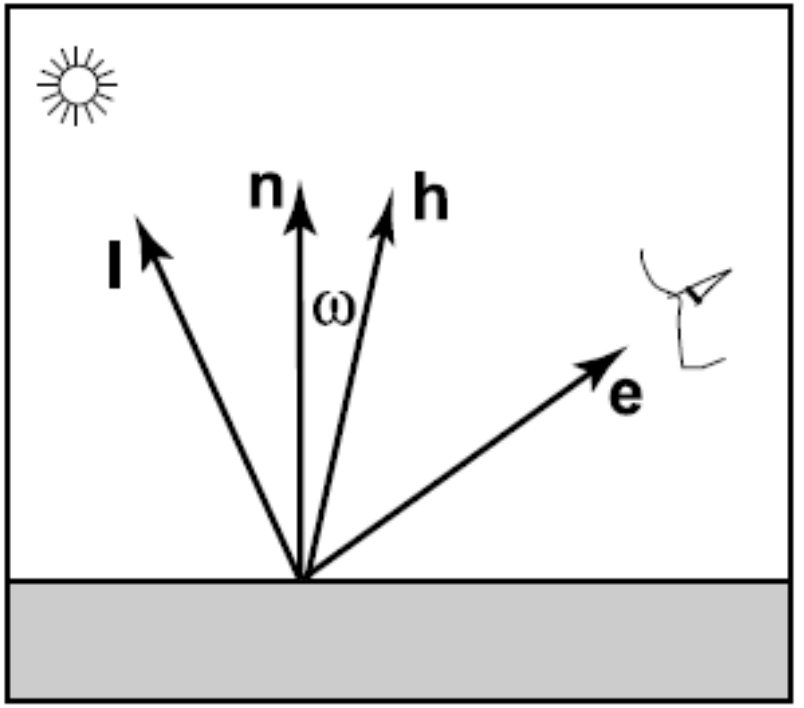
$$r = -\boldsymbol{l} + 2\cos\theta\,\boldsymbol{n}$$

$$r = -\boldsymbol{l} + 2\left(\boldsymbol{l} \cdot \boldsymbol{n}\right)\boldsymbol{n}$$



Specular Shading

Alternative: Look at halfway vector $\boldsymbol{h}$



Want $\boldsymbol{h}$ to line up with $\boldsymbol{n}$ i.e. $\boldsymbol{\omega = 0}$

$$\rho_s = k_s \left(\boldsymbol{h}\cdot\boldsymbol{n}\right)^p \quad \text{or} \quad R = k_s I \left(\boldsymbol{h}\cdot\boldsymbol{n}\right)^p$$

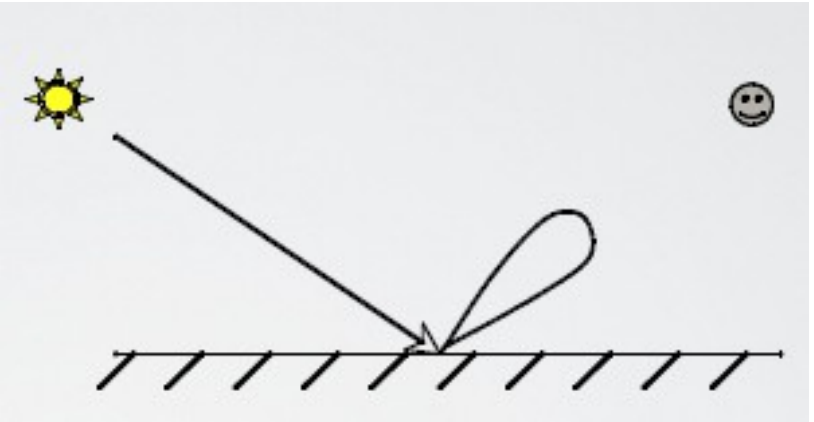
What is $\boldsymbol{h}$?

$$\boldsymbol{h} = \frac{\boldsymbol{l} + \boldsymbol{e}}{\|\boldsymbol{l} + \boldsymbol{e}\|}$$

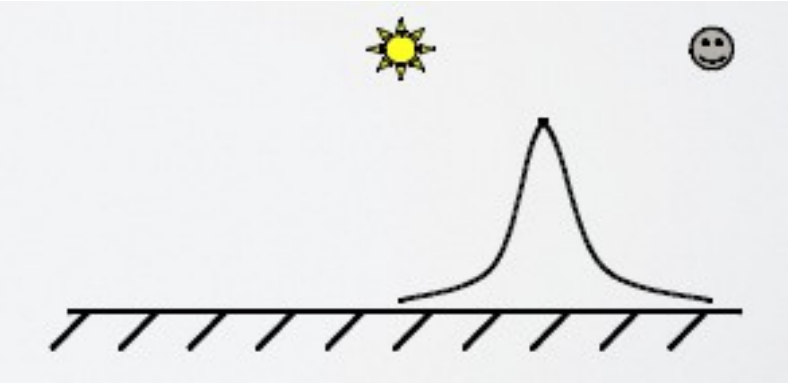
Advantage?
Dot product always +ve above the plane!

Disadvantage?
Square root and divide !

Specular Shading

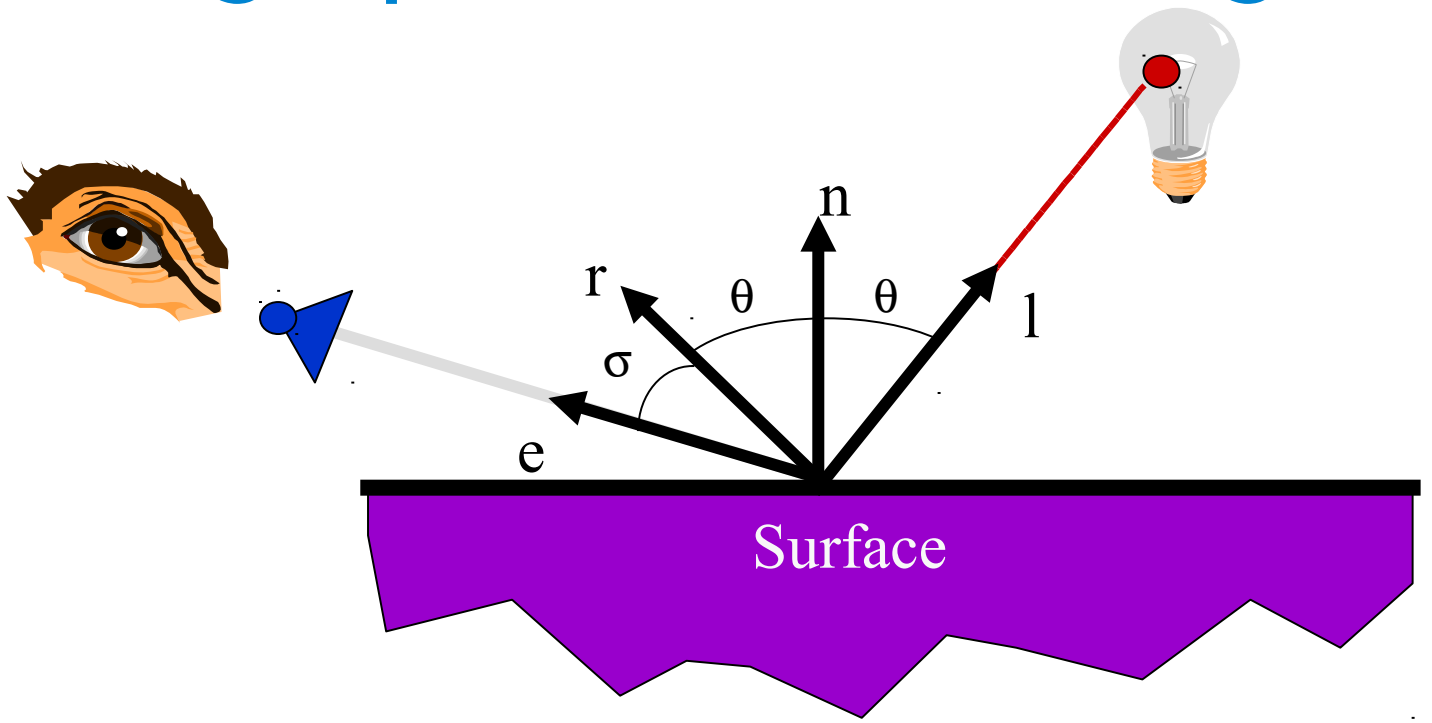


Light leaving a surface point in a specific direction



Light leaving each point on the surface

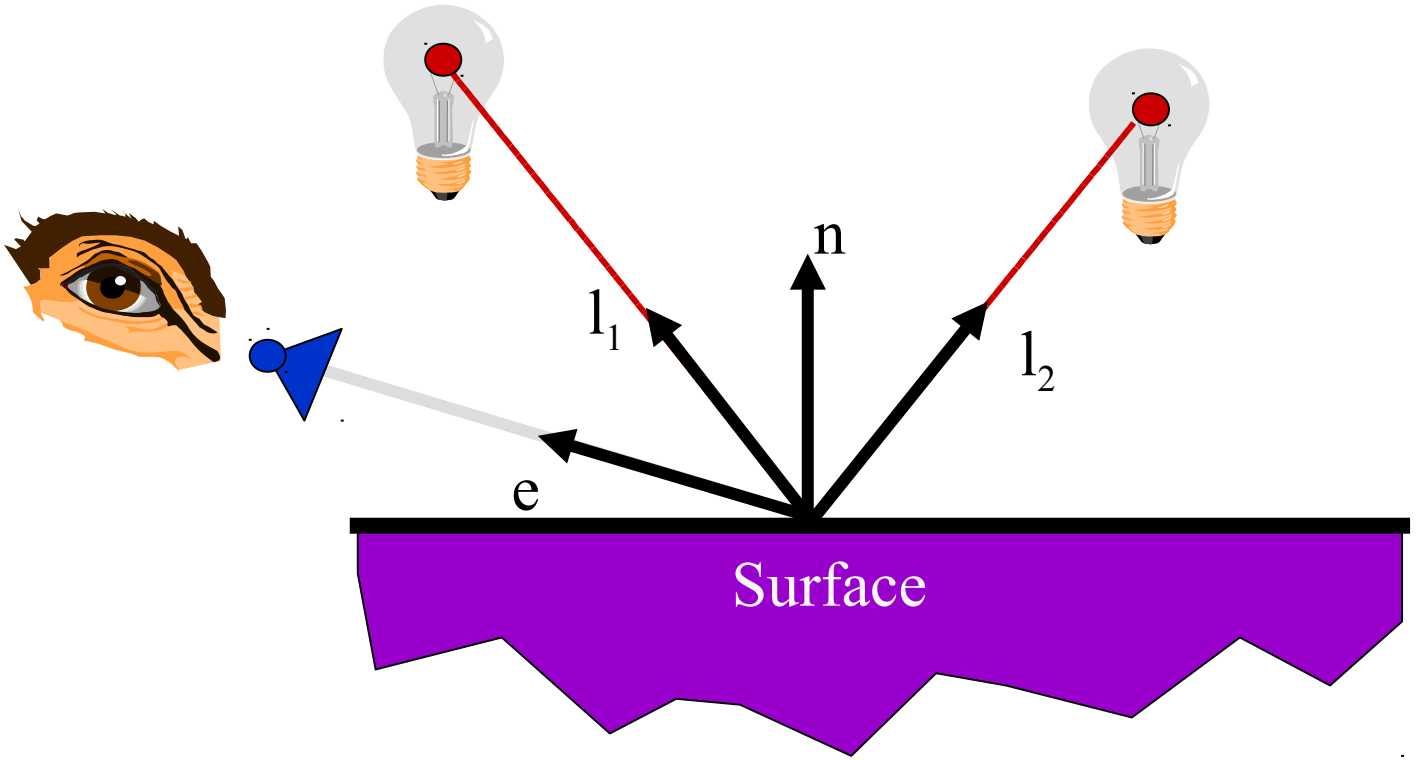
Summing Up: Phone Shading Model



$$R = k_a I_a + k_d I \max\left(0, \boldsymbol{l} \cdot \boldsymbol{n}\right) + k_s I \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r}\right)^p$$

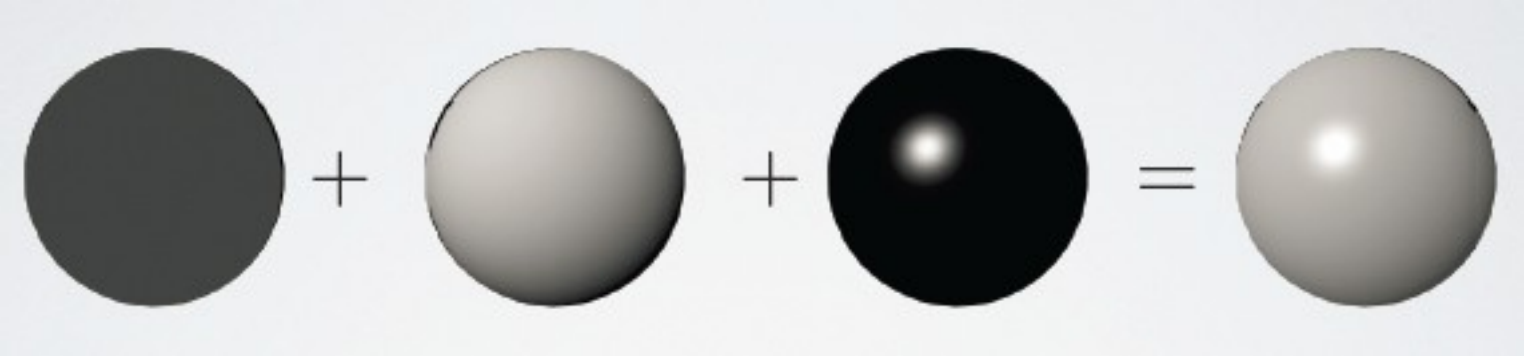
R: Reflected light
I: Incident light source

Summing Up: Phone Shading Model

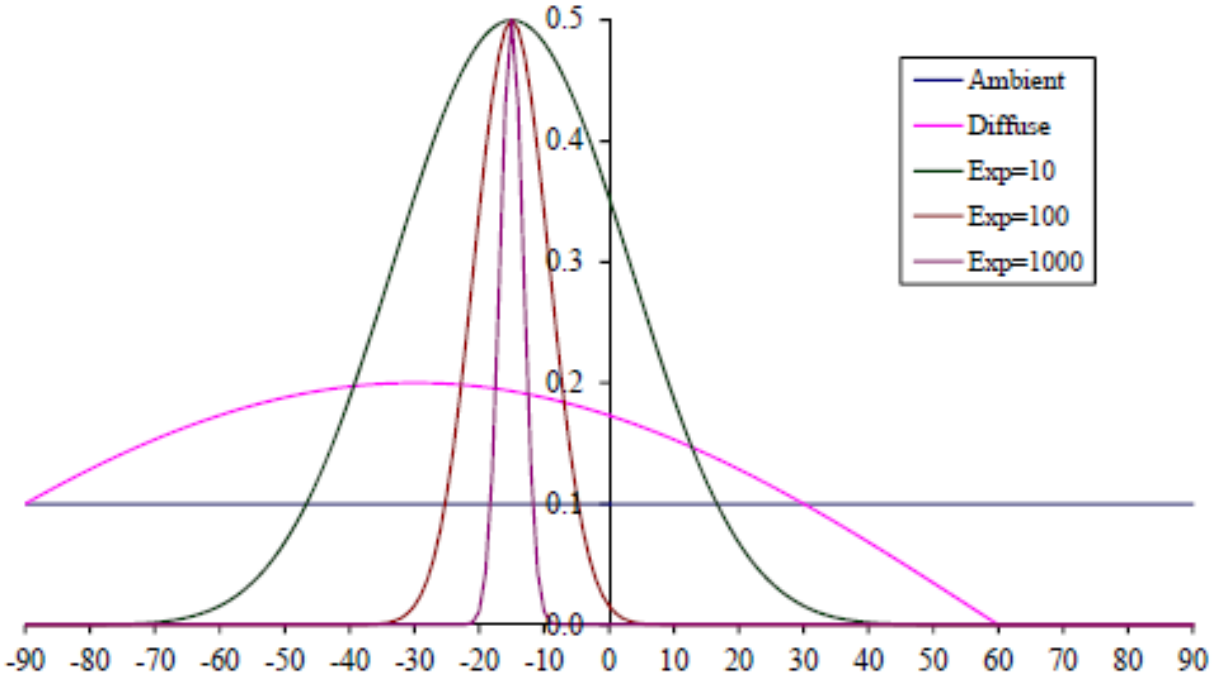


$$R = k_a I_a + \sum_i \left[k_d I_i \max\left(0, \boldsymbol{l_i} \cdot \boldsymbol{n}\right) + k_s I_i \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r_i}\right)^p \right]$$

Summing Up: Phone Shading Model



Ambient Diffuse Specular



Color

What about colored light?

Create different components for R, G, and B !

For example for the blue component:

$$R_B = k_{aB} I_{aB} + \sum_i k_{dB} I_{iB} \max\left(0, \boldsymbol{l_i} \cdot \boldsymbol{n}\right) + k_{sB} I_{iB} \max\left(0, \boldsymbol{e} \cdot \boldsymbol{r_i}\right)^p$$

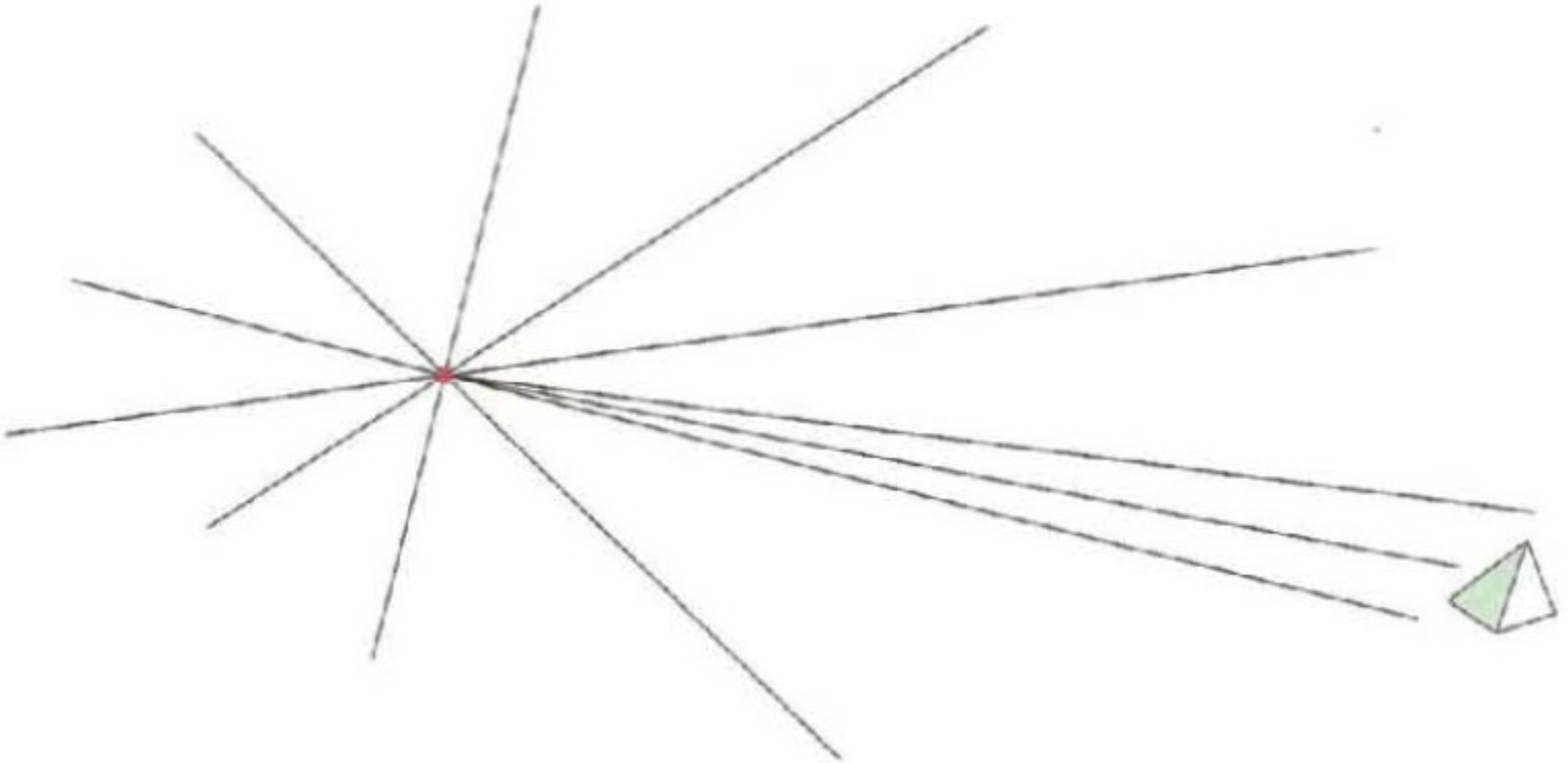
So we end up with 3 dimensional vectors for: $\boldsymbol{k_a}$, $\boldsymbol{k_d}$, $\boldsymbol{k_s}$

$$\boldsymbol{k_a} = \begin{bmatrix} k_{aR} \\ k_{aG} \\ k_{aB} \end{bmatrix} \;\&\; \boldsymbol{k_d} = \begin{bmatrix} k_{dR} \\ k_{dG} \\ k_{dB} \end{bmatrix} \;\&\; \boldsymbol{k_s} = \begin{bmatrix} k_{sR} \\ k_{sG} \\ k_{sB} \end{bmatrix} \in R^3$$

Light Sources

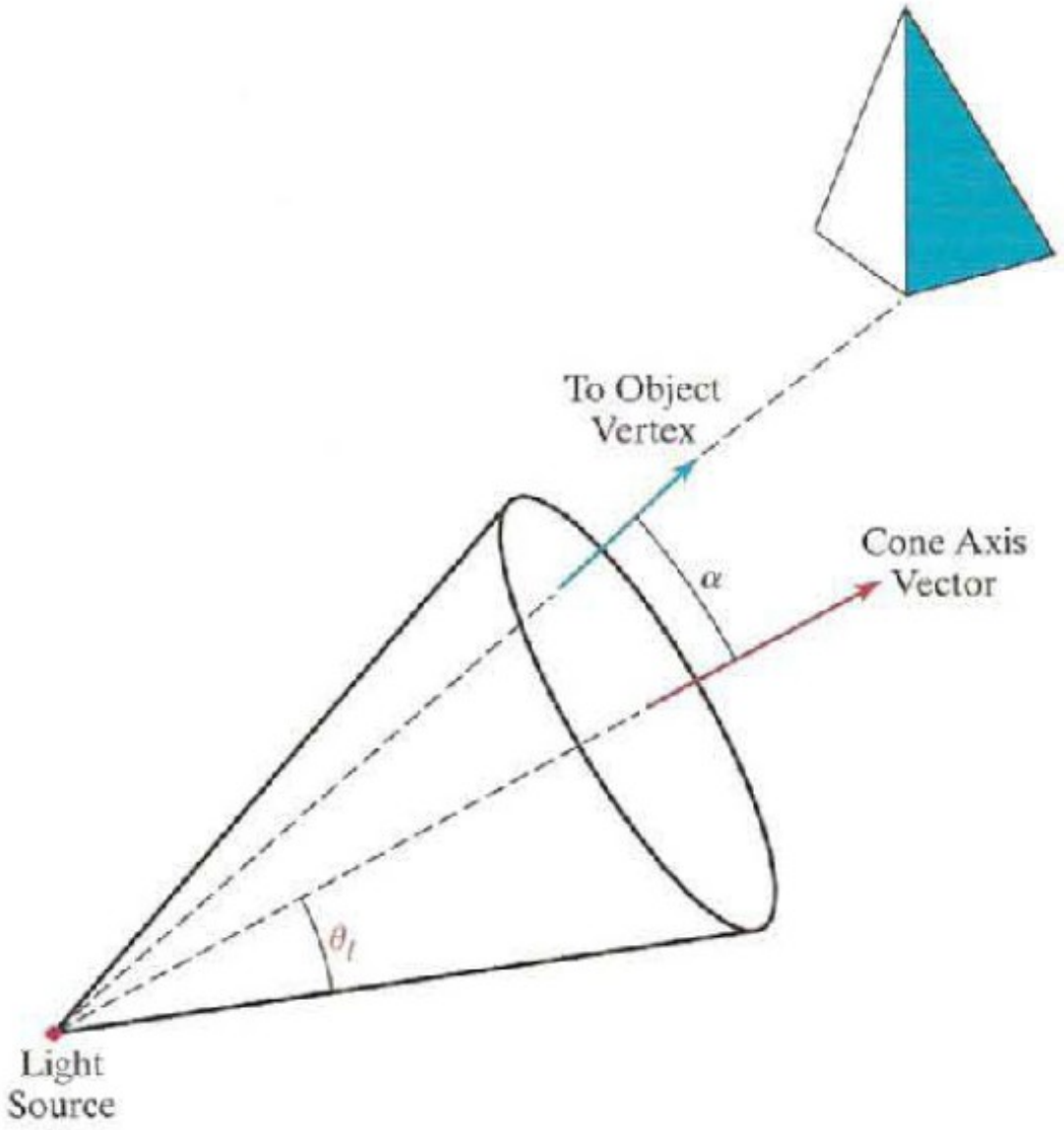
Point Light Source

Light Sources



Point Light Source at Infinity
Directional Light Source

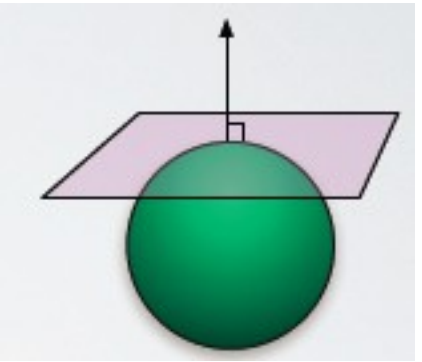
Light Sources



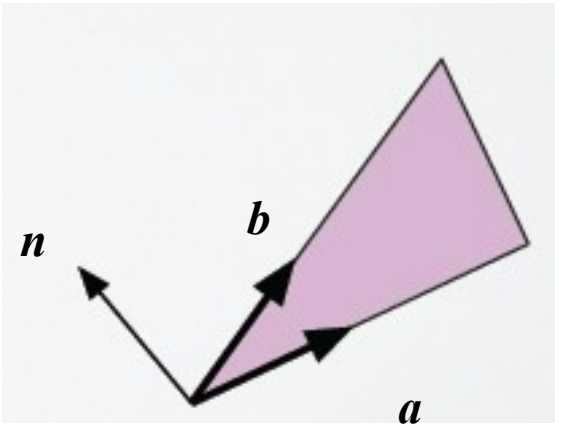
Spotlight Light Source

Surface Normals

Vector normal to all tangent vectors

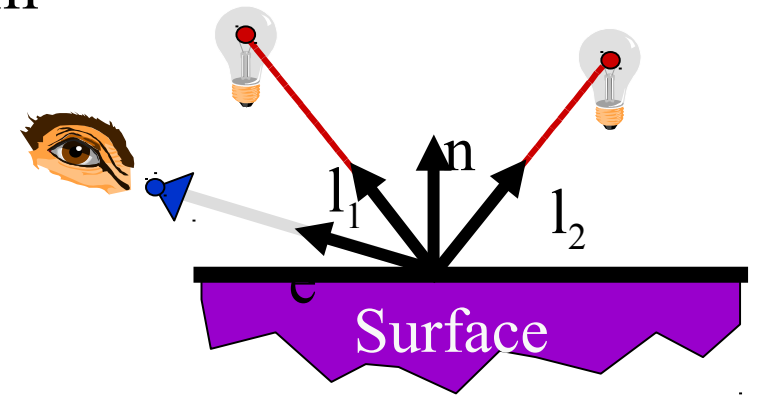


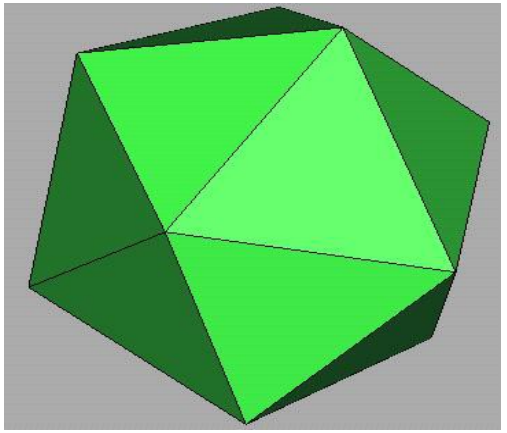
$$n = a \times b$$



Surface Rendering

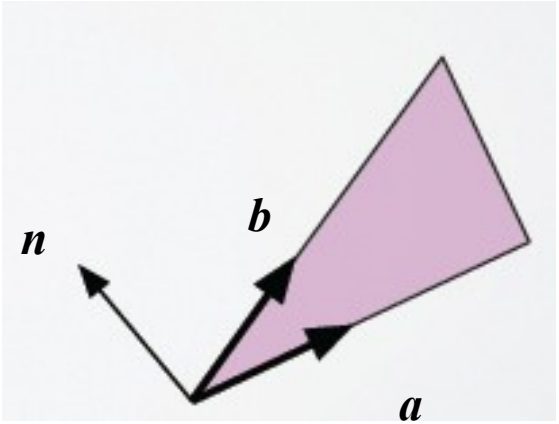
Now we can compute light reflected from any surface point





How can we rasterize a triangle to get pixel color values ?

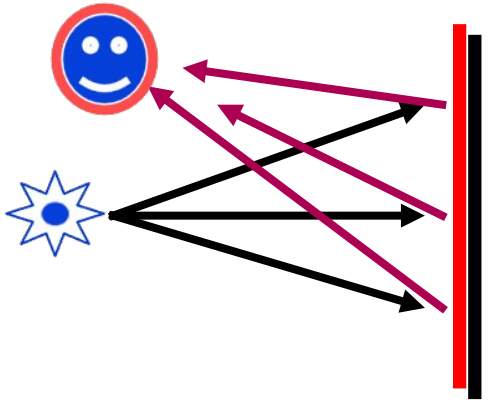
Flat Shading



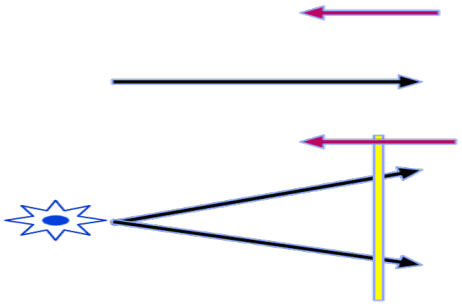
- Every triangle has only surface normal
- One computation per triangle
- One color per triangle

- Very cheap
- Faceted appearance
- Surfaces not smooth

Flat Shading



Viewing direction not constant !



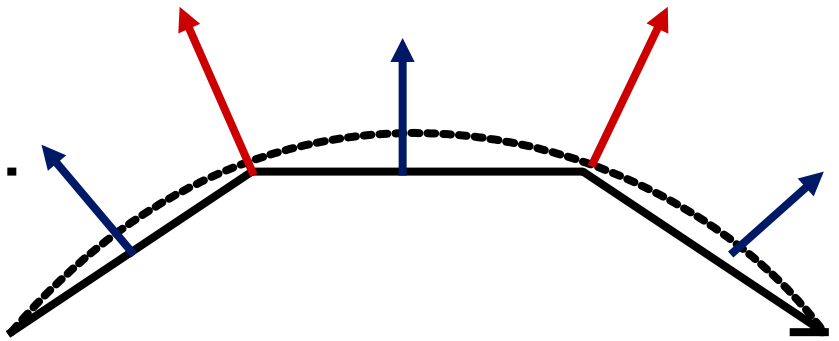
Light direction not constant !

Accurate when:

- Surface is already faceted
- Light source too far from surface
- Viewing direction too far from surface

Gourard Shading

- Normal vector at each *vertex*
- Can be
  - Average of face normals
  - Model supplied
- Used for shading

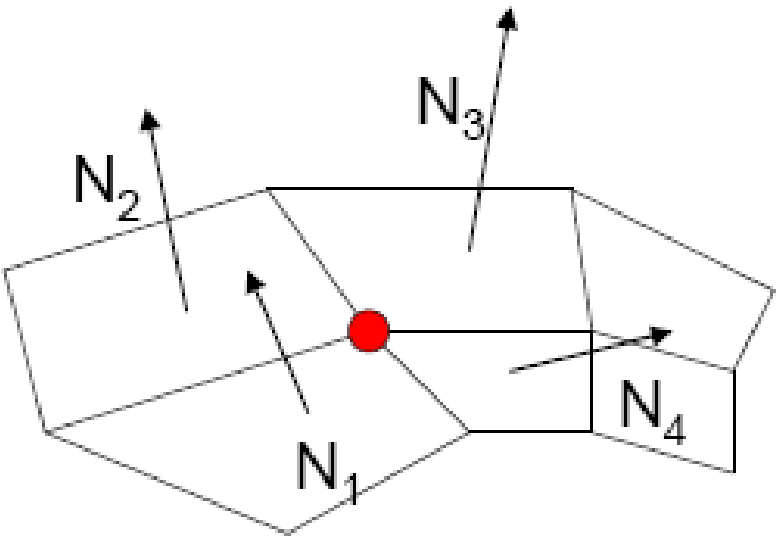


Vertex Normals

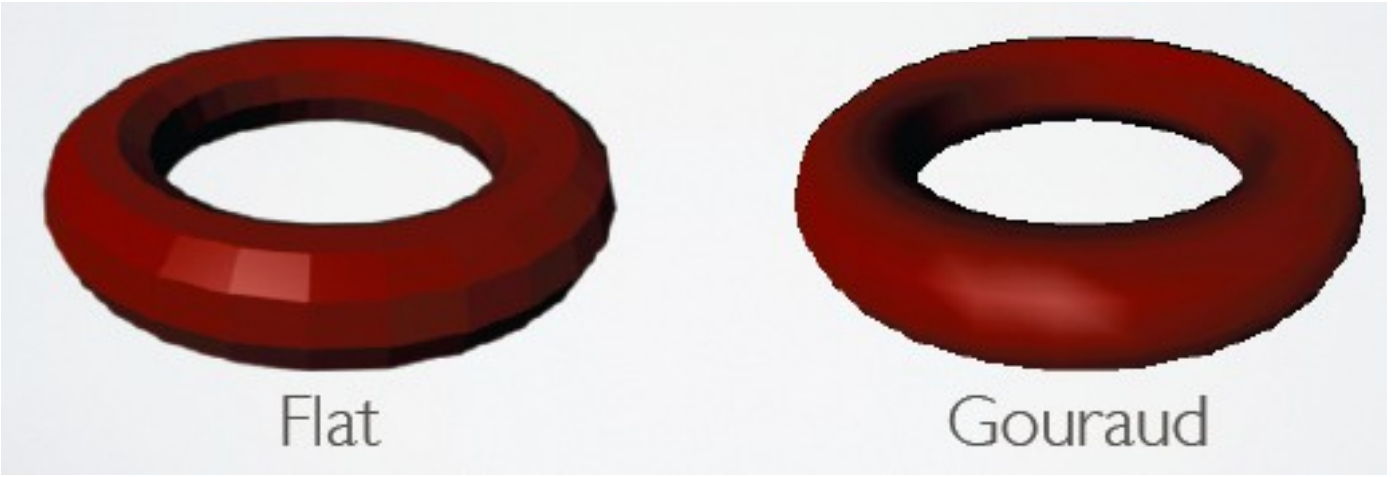
Gourard Shading

- Compute shading at each vertex using vertex normal
- Interpolate across triangle using Barycentric Coordinates

- Pros
  - Better than flat
  - Fast
- Cons
  - Bad speculars
  - Mach bands



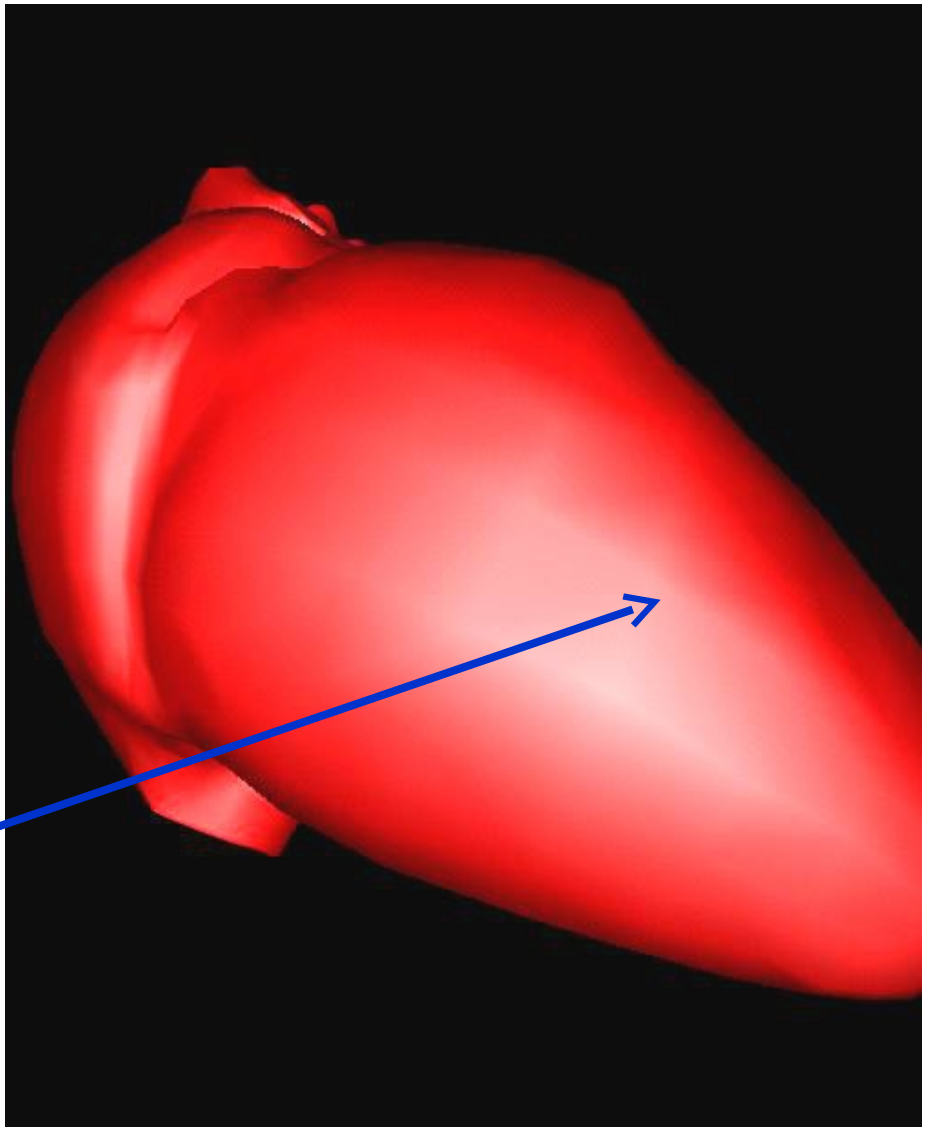
Gourard Shading



Gourard shading

Mach Banding

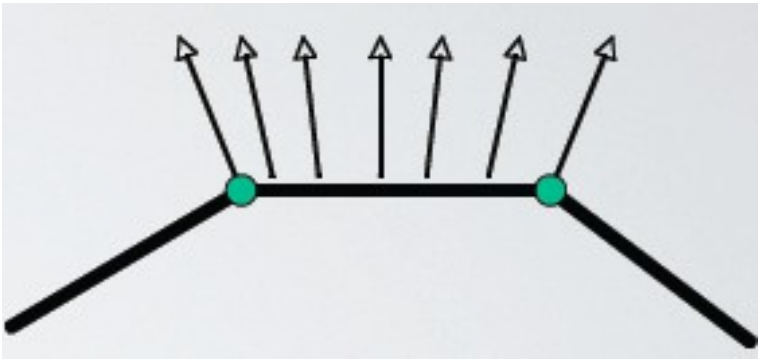
Discontinuities



http://www.edcenter.sdsu.edu/slides/GA/visteacher/

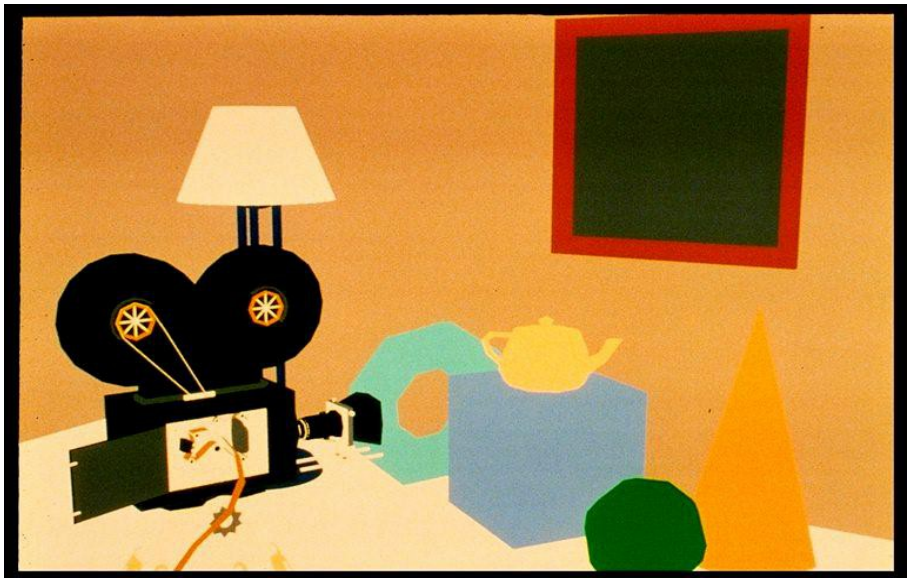
Phong Shading

- Interpolate surface normals at each pixel *not* intensities. *How?*
- Compute shading at each pixel
- Very expensive!

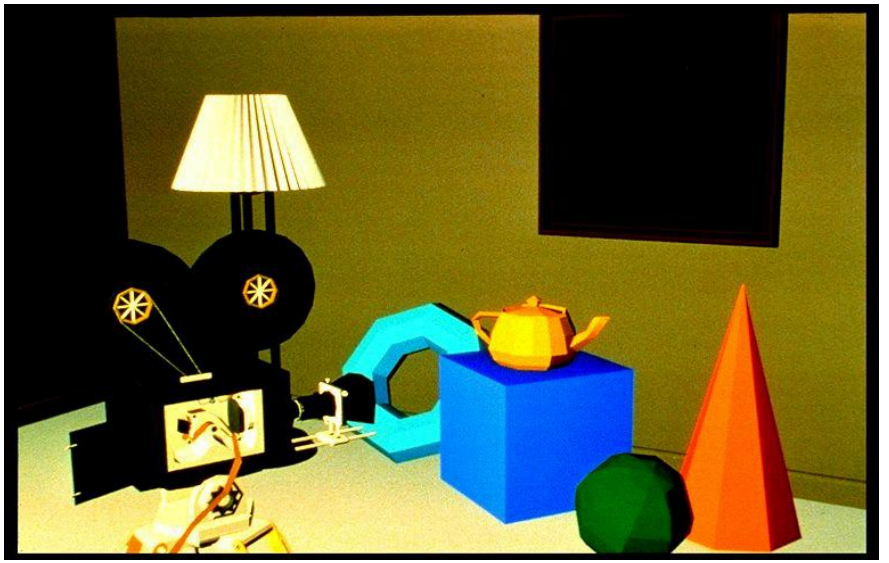


Phong Shading

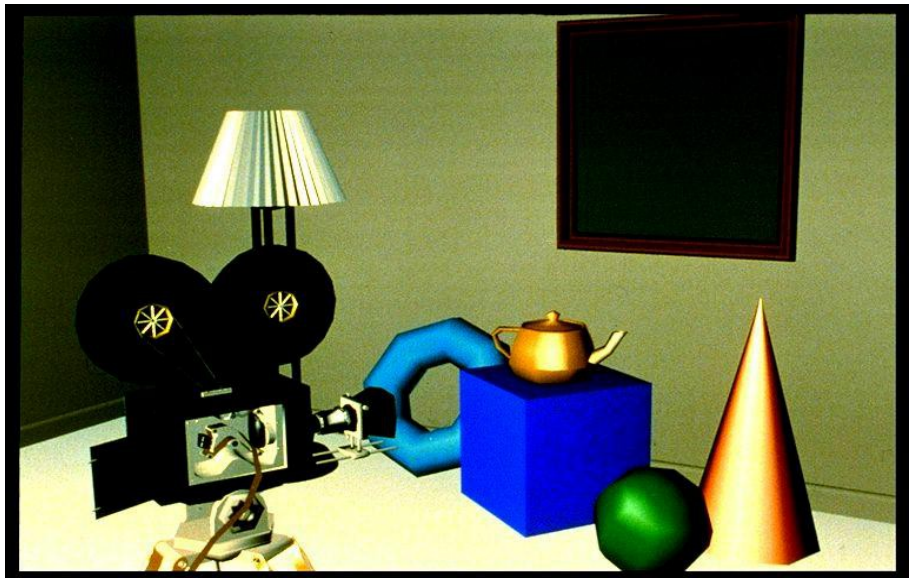
Surface Shading



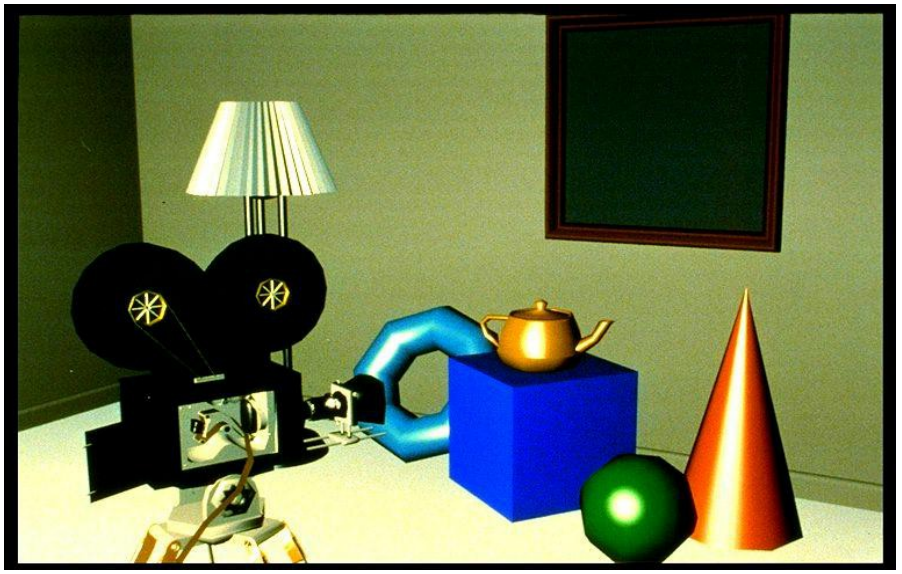
Ambient



Flat Shading



Gourard Shading



Phong Shading

Recap

- Lighting and Surface Rendering
- Shading Models
  - Diffuse
  - Ambient
  - Specular
- Light Sources
- Surface Rendering
  - Flat
  - Gourard
  - Phong