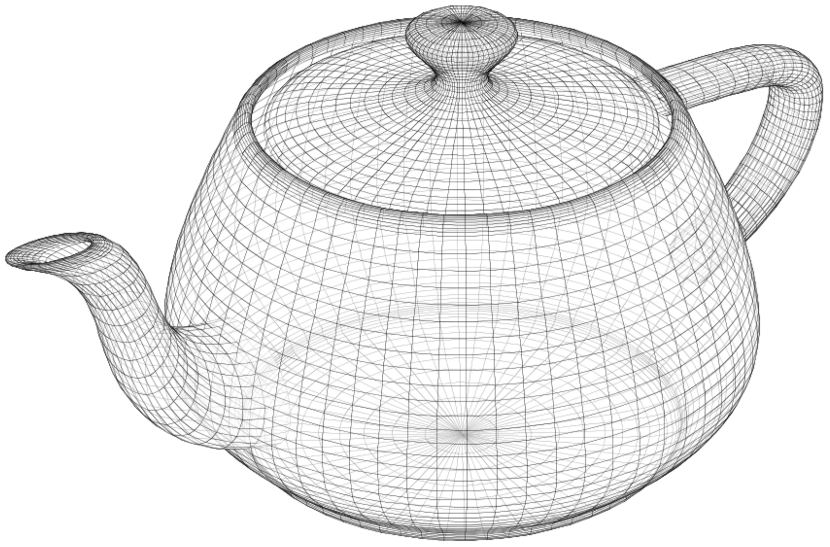


Shading

Phong Reflection Model

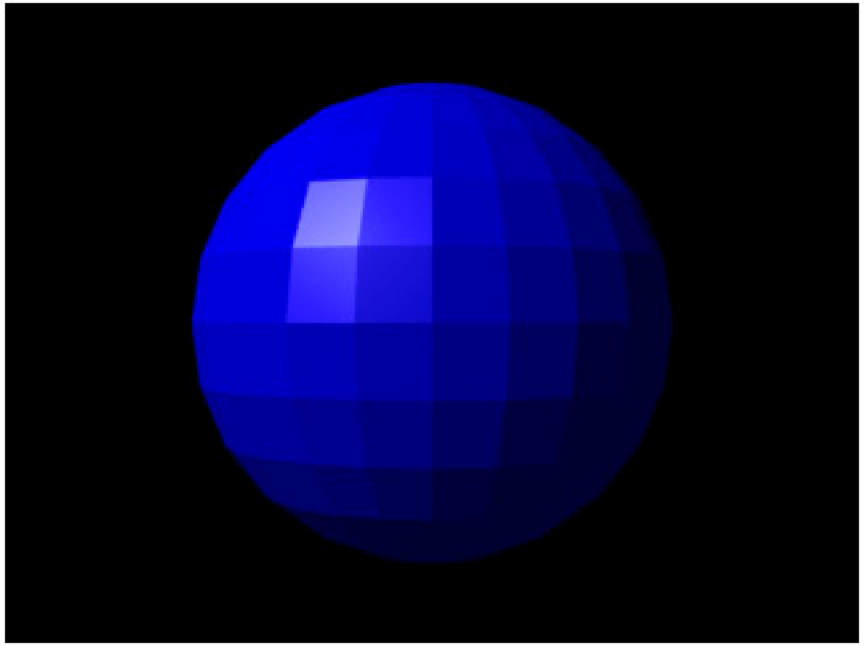
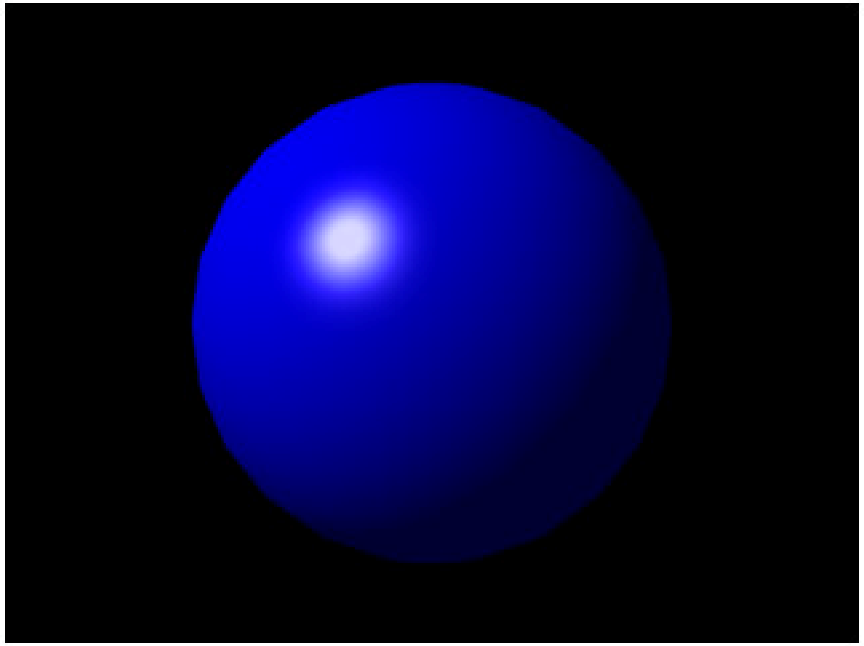
Interactive Computer Graphics

Eric Shaffer

ILLINOIS

Shading

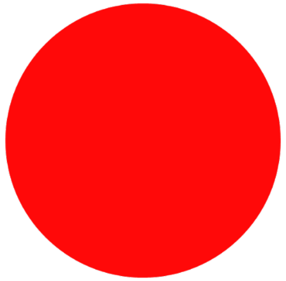
Shading refers to the process of determining the color for a pixel (or vertex…or polygon) during the rendering process

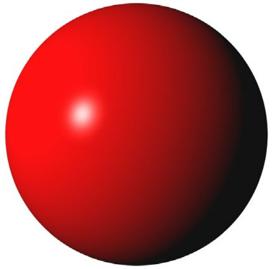
What is the difference between the two images?

Why we need shading

Shading is one of the key elements of 3D photorealistic rendering



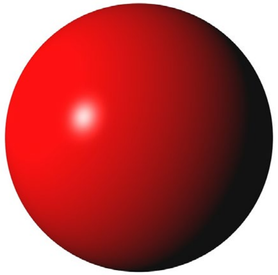
Flat shading
…not realistic



Shading with Phong reflection model
…more realistic

Shading

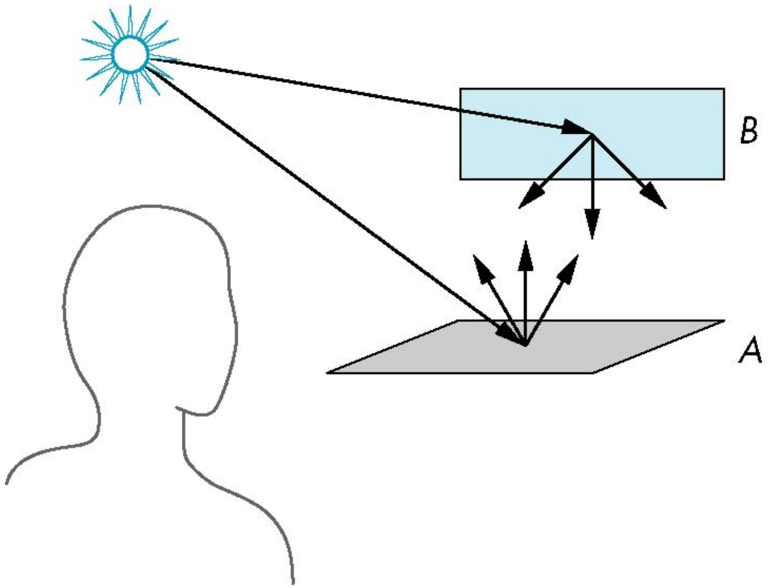
- Why does the image of a real sphere look like



- Light-material interactions cause each point to have a different color or shade
- Need to consider
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation

Scattering

- 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



Super-simple Model of Light-Material Interaction

- Light that strikes an object is
  - partially absorbed and
  - partially scattered (reflected)

- The amount reflected determines
  - color of the object
  - brightness of the object
  - A surface appears red under white light because the red component of the light is reflected

- How the reflected light is scattered depends on
  - the smoothness and orientation of the surface

Mathematically we can model this as component-wise multiplication of RGB values

Light $i = (r_i, g_i, b_i)$
Material $\mathrm{k} = (r_k, g_k, b_k)$
Light reflecting off surface $= (r_i r_k, g_i g_k, b_i b_k)$

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Shading

We will create a ***simple*** mathematical model for shading

It will be function that takes in:

- Light sources
- Material properties
- Location of viewer
- Surface orientation

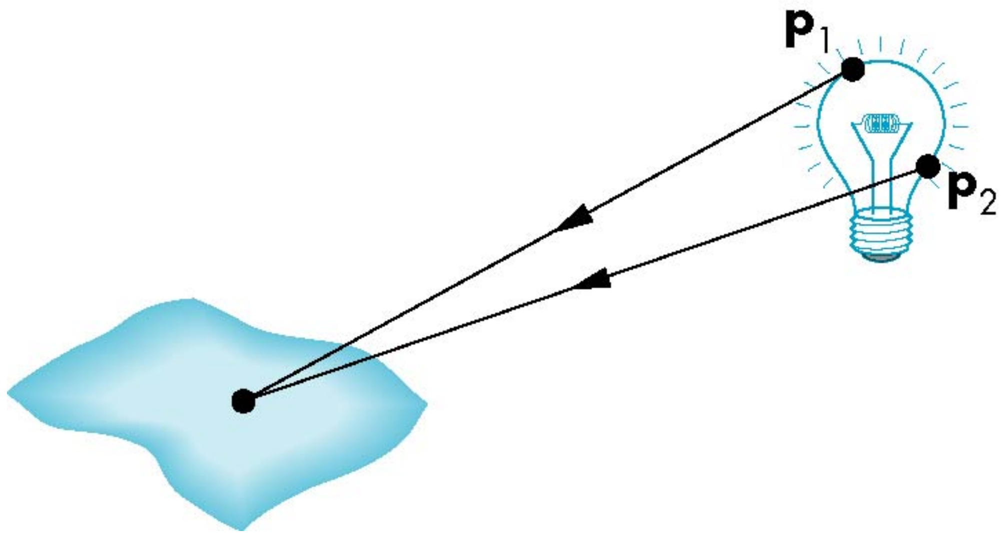
And returns a color….

Well…there's a lot of symbols but the ideas and math are simple

Light Sources

General light sources are complex to model

Would need to integrate light coming from all points on the source

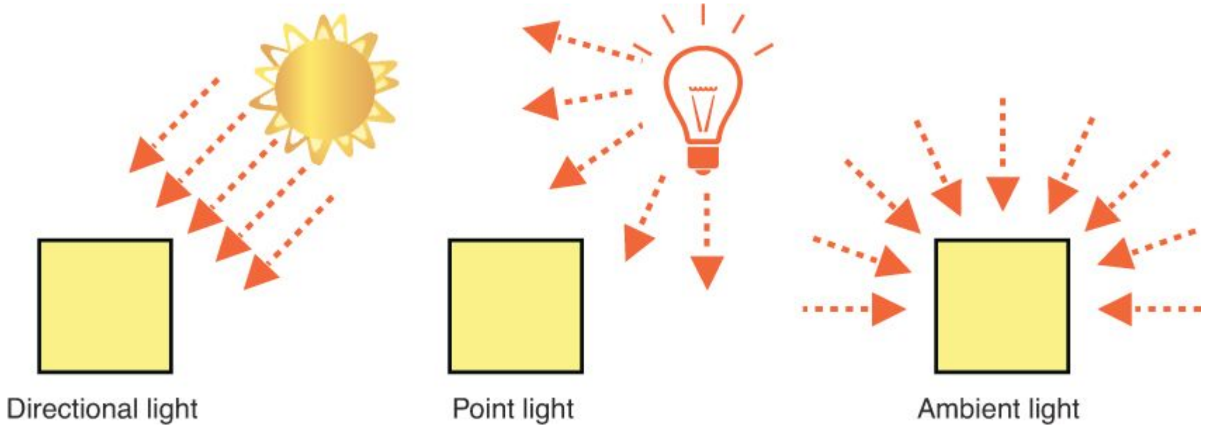


Simple Light Source Models

- Point source
  - Model with position and color
- Directional source
  - Distant source = infinite distance away (parallel)
- Ambient light
  - Same amount of light everywhere in scene
  - Models indirect light from reflecting surfaces

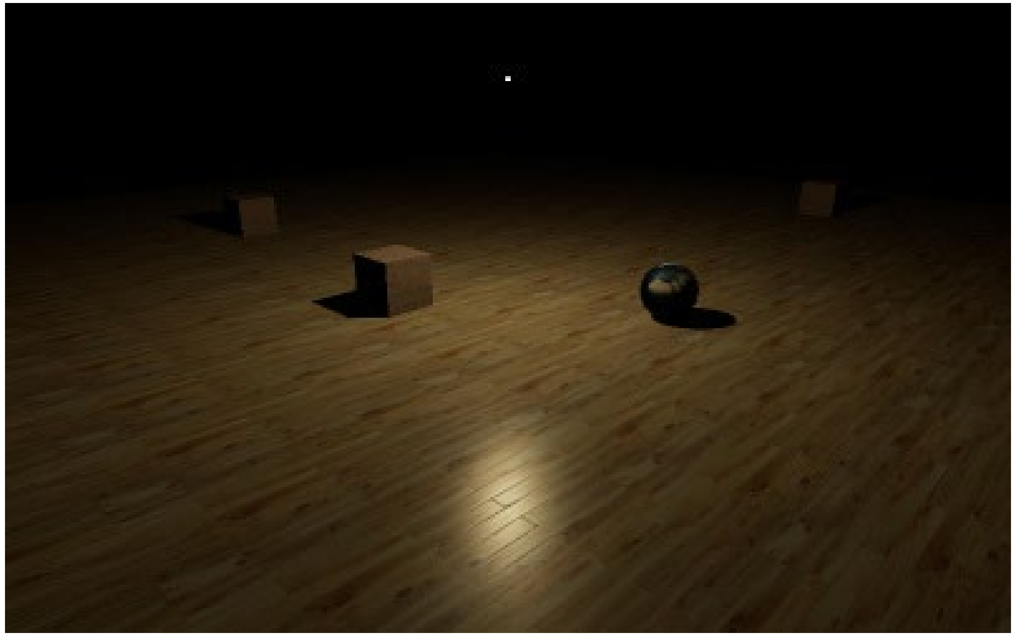
Creating a point light in JS code.....

```
var diffuse0 = glMatrix.vec4.fromValues(1.0, 0.0, 0.0, 1.0);
var specular0 = glMatrix.vec4.fromValues (1.0, 1.0, 1.0, 1.0);
var light0_pos = glMatrix.vec4.fromValues (1.0, 2.0, 3,0, 1.0);
```



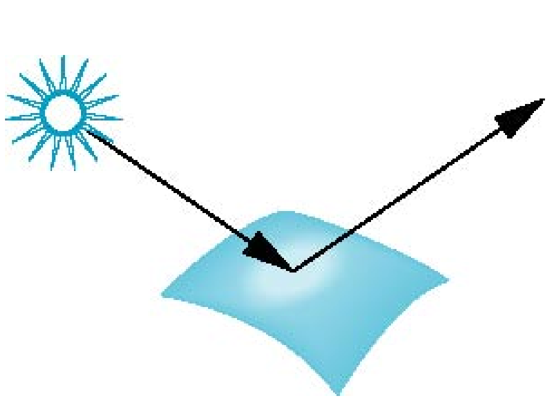
Moving Light Sources

- Point light sources are geometric objects
- Positions and directions can be affected a model-view matrix
- **Should you apply the view transformation to a light?**
  - **Yes (usually)**
  - **Exception is when the light should move with the viewpoint**

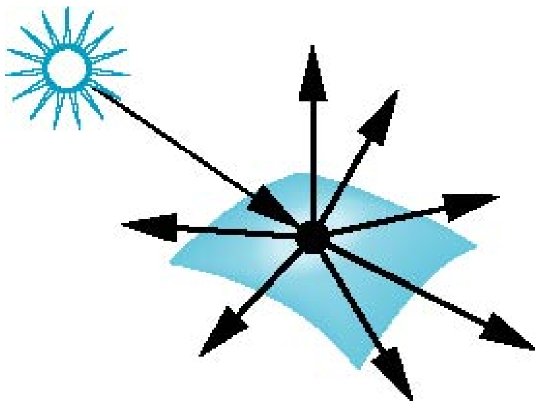


Surface Types

- Consider light traveling along a specific ray
- The smoother a surface, the more reflected light is concentrated in a single direction
    - Perfect mirror reflects perfectly in a single direction
- A very rough surface scatters light in all directions



smooth surface

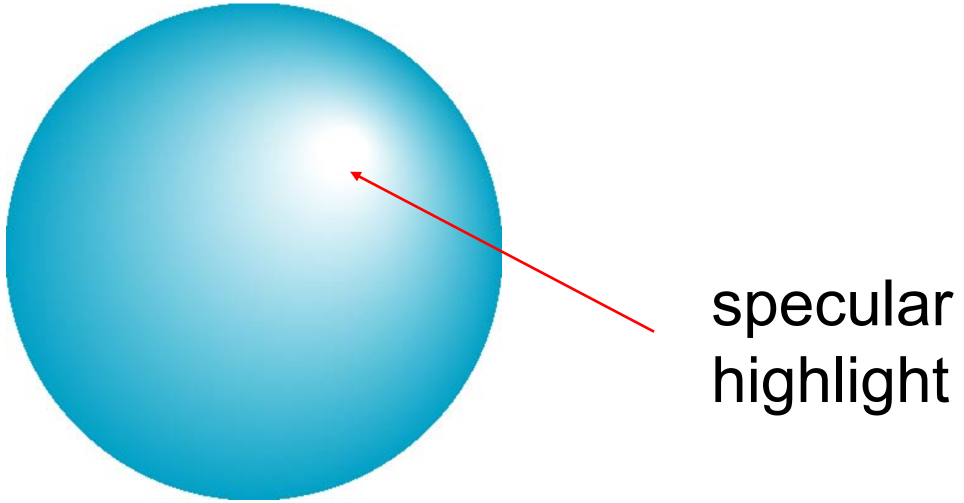


rough surface

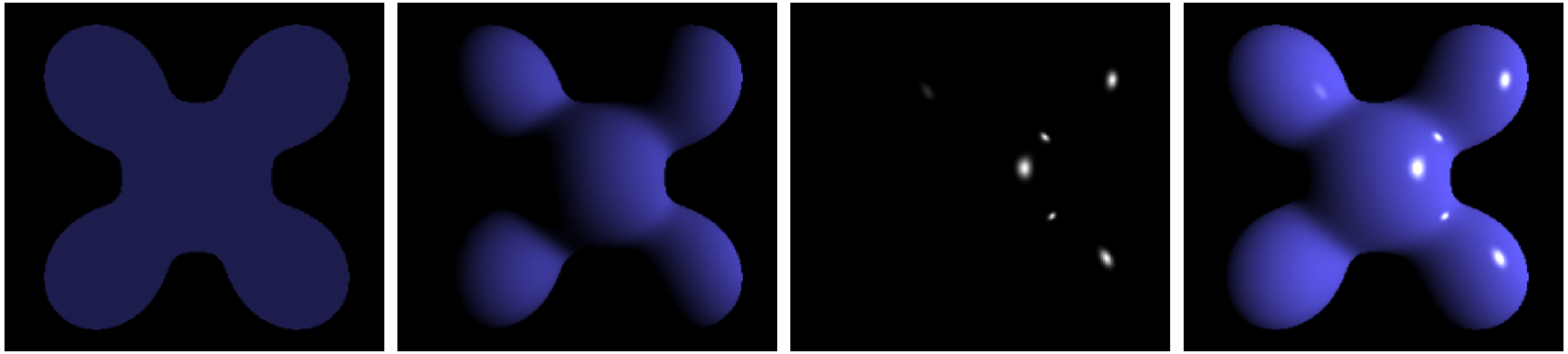
Specular and Diffuse Surfaces

- Most surfaces are neither ideal diffusers nor perfectly specular (ideal reflectors)

- Smooth surfaces show specular highlights
  - incoming light is reflected in directions concentrated close to the direction of a perfect reflection



Phong Reflection Model

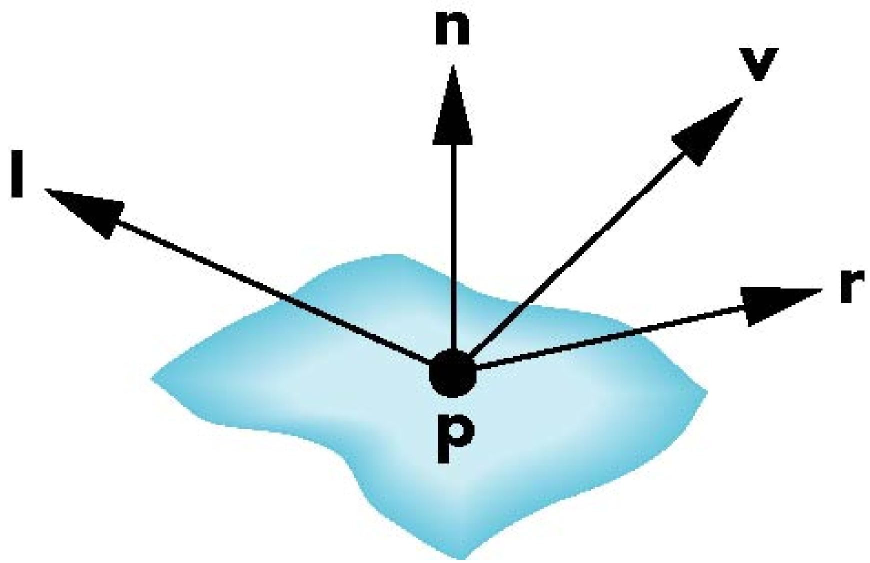


Ambient + Diffuse + Specular = Phong Reflection

$$I_{\mathrm{p}} = k_{\mathrm{a}} i_{\mathrm{a}} + \sum_{m \in \text{lights}} \left(k_{\mathrm{d}} (\hat{L}_m \cdot \hat{N}) i_{m,\mathrm{d}} + k_{\mathrm{s}} (\hat{R}_m \cdot \hat{V})^{\alpha} i_{m,\mathrm{s}} \right)$$

The Phong Reflection Model

- A simple model that can be computed rapidly
- Has three components
  - Diffuse
  - Specular
  - Ambient
- Uses four vectors
  - To source
  - To viewer
  - Normal
  - Perfect reflector



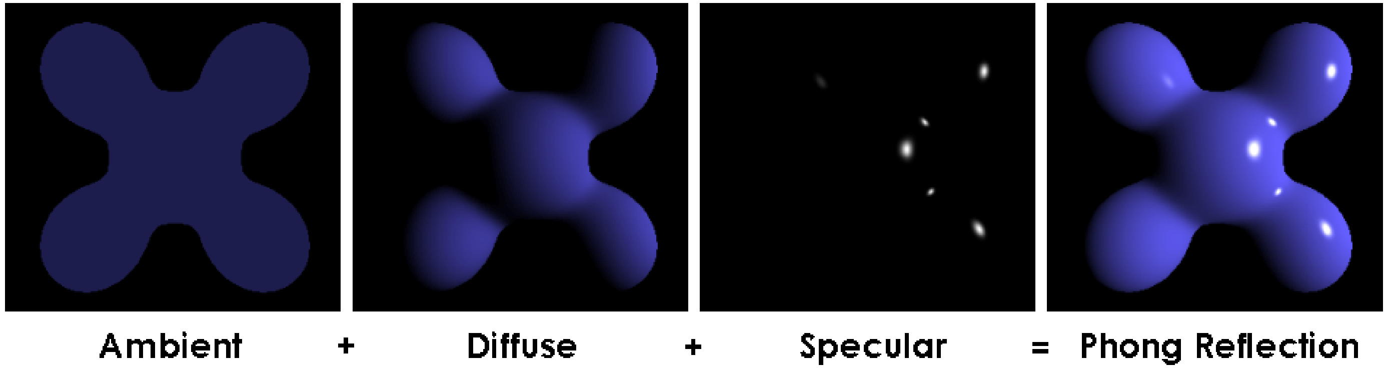
Ambient Light

- Result of multiple interactions between light sources and surfaces
- Amount and color depend on the color of the light(s) and the material properties
- Add k_a I_a to diffuse and specular terms

reflection

intensity of ambient light

Remember that ki multiplications are component-wise multiplications of rgb values
$(k_r, k_g, k_b)(i_r, i_g, i_b) = (k_r i_r, k_g i_g, k_b i_b)$



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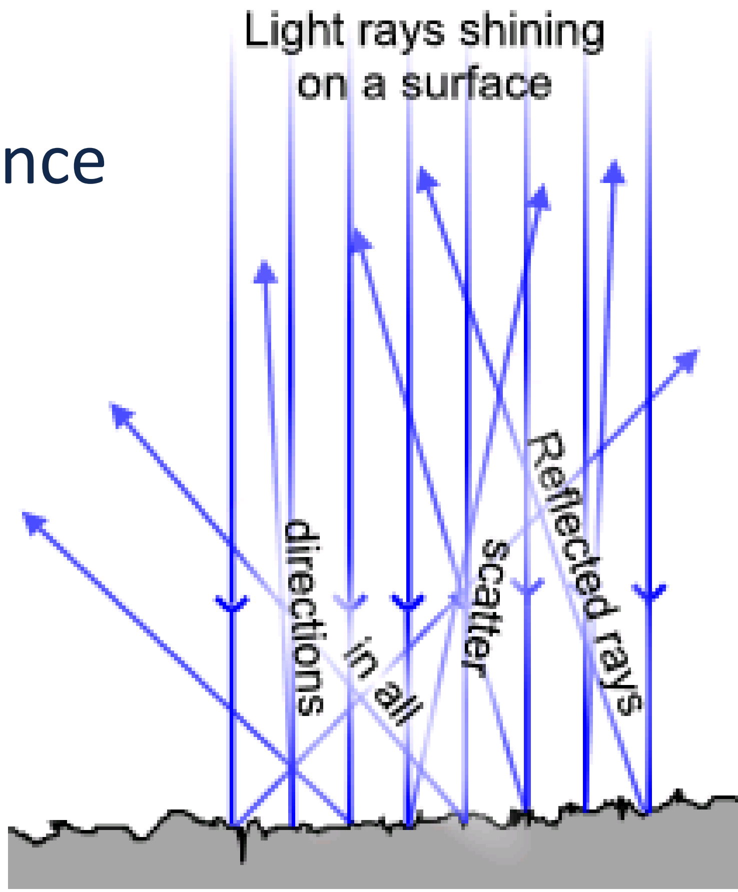
Modeling a Lambertian Surface – Diffuse Reflection

- Perfectly diffuse reflector
- Light scattered equally in all directions
- Amount of light reflected is affected by the angle of incidence
  - reflected light proportional to ***cosine of angle between l and n***
  - if vectors normalized

$$\cos(\theta) = n \cdot l$$



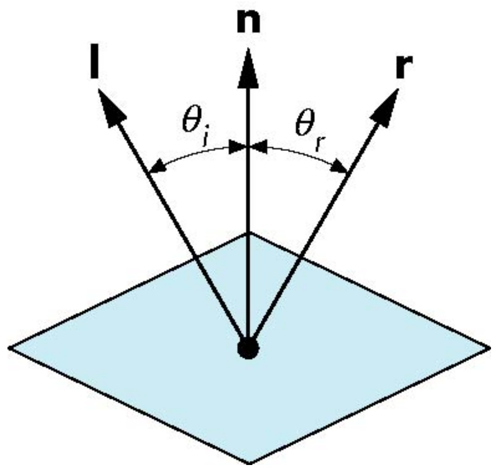
- Amount of reflected light also affected by k_d and i_d
  - Each is an rgb value with each channel in [0,1]

Modeling a Ideal Reflector – Specular Reflection

- Incoming light ray is reflected in a single
- Normal is determined by local orientation
- Given the direction of incoming light…we can find r
  - l and n are unit vectors
  - Angle of incidence = angle of reflection
  - The three vectors will be coplanar
- What is another name for an ideal reflector?

- ***r*** is computed as

$$\boxed{\boldsymbol{r} = 2(\boldsymbol{l} \cdot \boldsymbol{n})\boldsymbol{n} - \boldsymbol{l}}$$



Deriving the Reflection Vector

R_i is the incoming light vector

R_1 is the reversed light vector used in shading

The reflection vector R_r can be seen as a vector sum:

$R_r = N(R_1 \cdot N) + \mathrm{a}$

Similarly

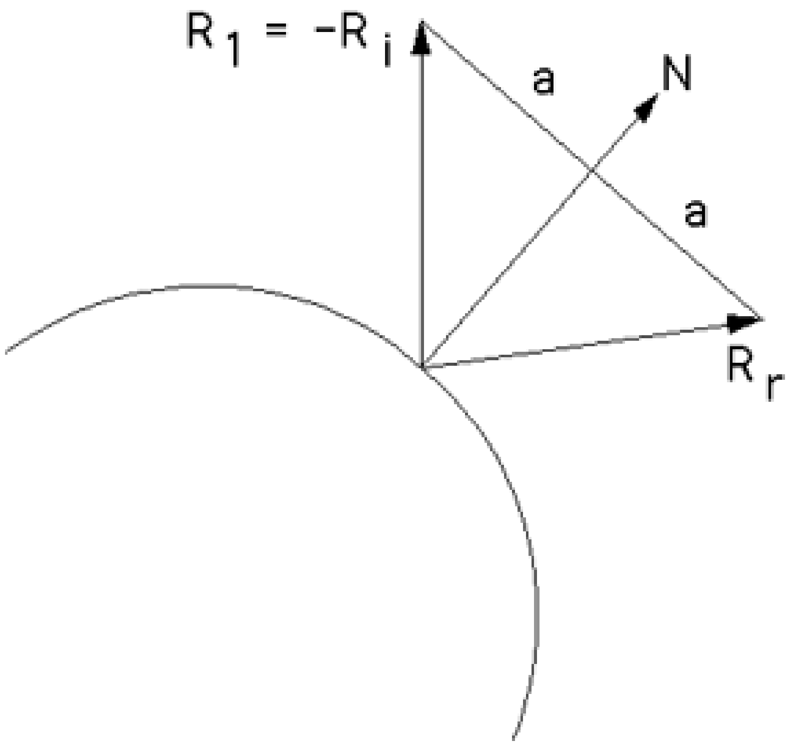
$R_1 + \mathrm{a} = N(R_1 \cdot N)$

so

$\mathrm{a} = N(R_1 \cdot N) - R_1$

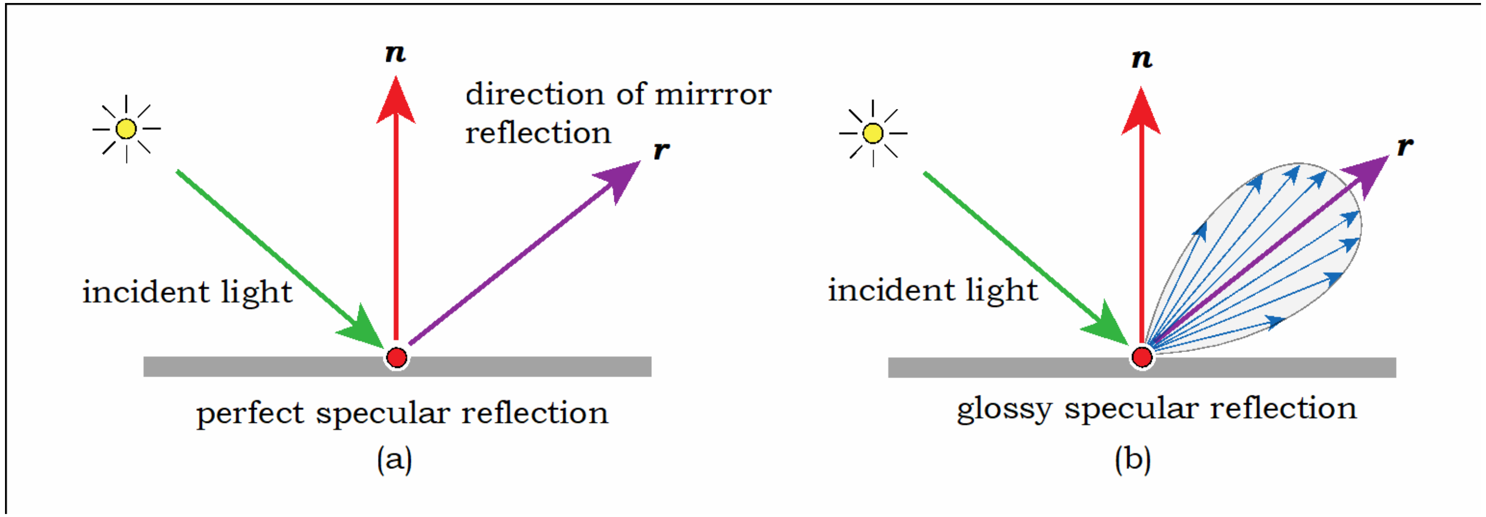
And substituting that expression for back into our first equation we have

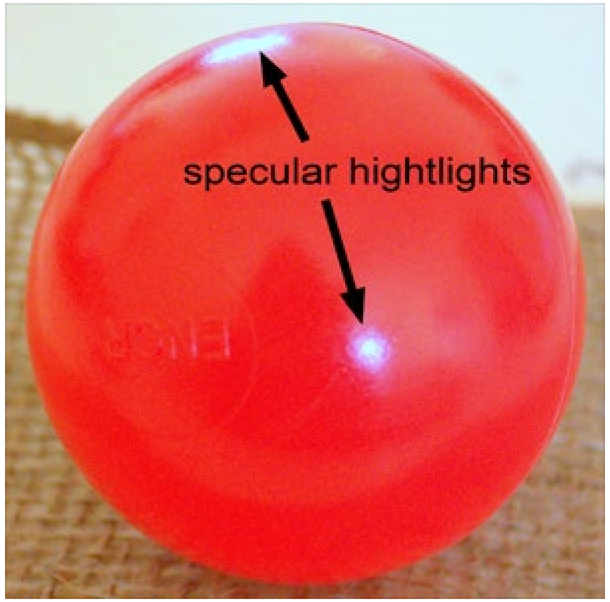
$R_r = 2N(R_1 \cdot N) - R_1$



Specular Reflection

- Perfect specular reflection
  - Light is reflected in the single direction r
  - …the mirror reflection direction
- Glossy specular reflection
  - Scattering clustered around mirror reflection direction





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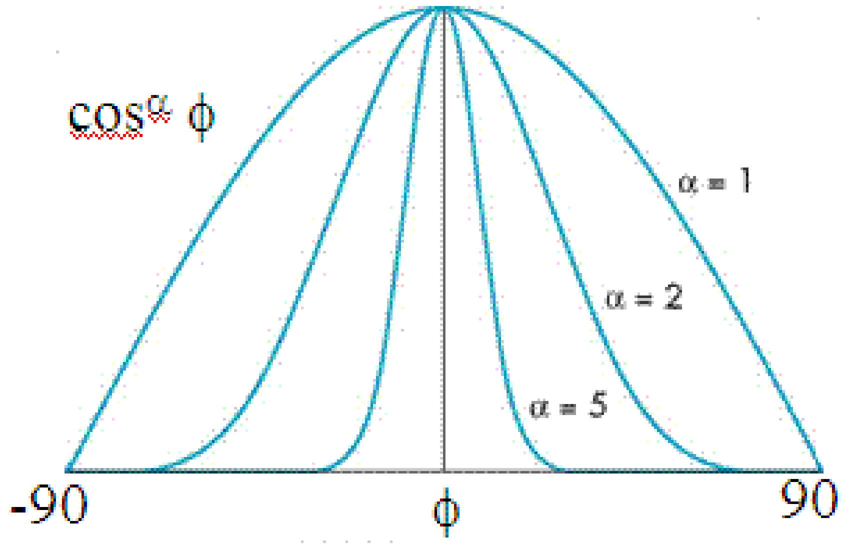
Specular Reflection

- Reflectance determined by
  - Alignment of view vector with mirror reflection vector
  - Shininess coefficient
- High coefficient means smoother look
  - Maybe 100 for metal
  - Maybe 10 for plastic



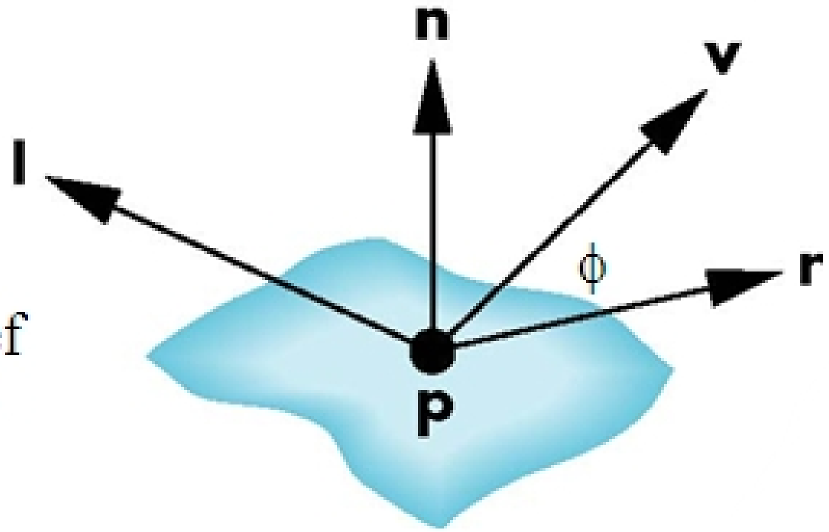
$$I_r \sim k_s\, I \cos^{\alpha}\phi$$

reflected intensity

absorption coef

incoming intensity

shininess coef



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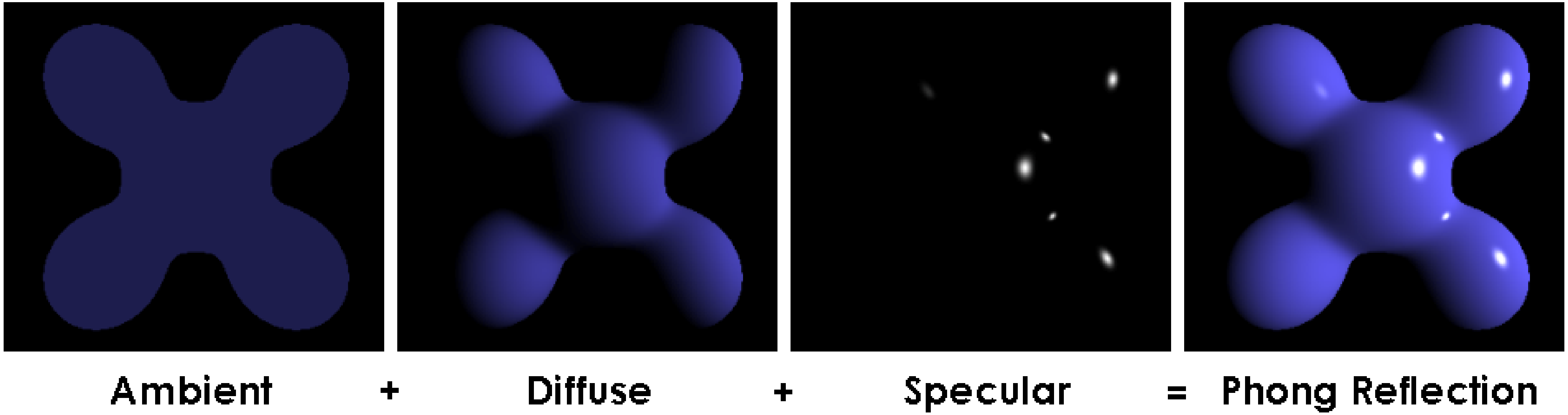
Phong Reflectance Model

Summing over all the light sources, the Phong model can be written as



$$I_{\mathrm{p}} = k_{\mathrm{a}} i_{\mathrm{a}} + \sum_{m \, \in \, \mathrm{lights}} \left(k_{\mathrm{d}} (\hat{L}_m \cdot \hat{N}) i_{m,\mathrm{d}} + k_{\mathrm{s}} (\hat{R}_m \cdot \hat{V})^{\alpha} i_{m,\mathrm{s}} \right)$$

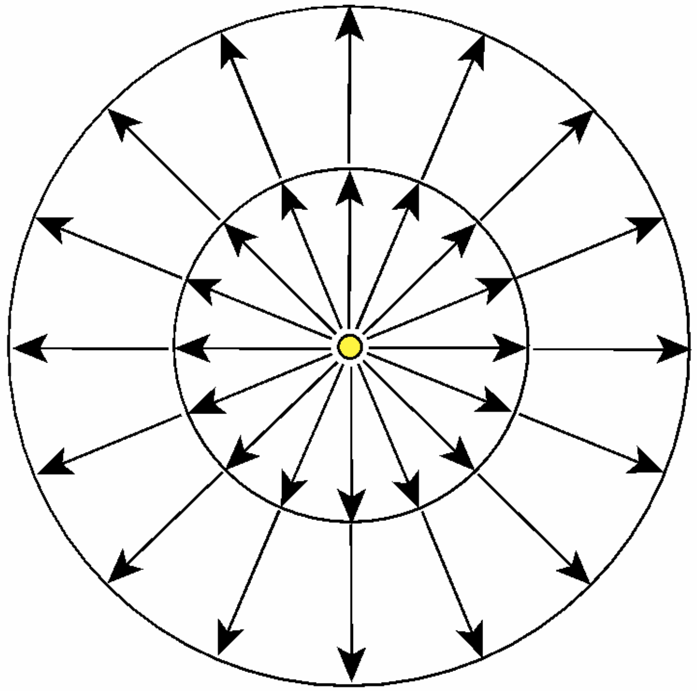
Distance Terms

- The light from a point source that reaches a surface is ***attenuated***
  - Intensity falls off with the square of the distance

- We can add a factor of to the diffuse and specular terms

$$\frac{1}{ad^2+bd+c}$$

- **d** is the distance from the light to surface
- **a,b,c** are constants you choose to get different effects



Blinn-Phong Reflectance Model

- Jim Blinn suggested an approximating changing specular term
- Replace $(\mathbf{V} \cdot \mathbf{R})^a$ by $(\mathbf{N} \cdot \mathbf{H})^b$ where
  - "Halfway vector"

$$H = \frac{L + V}{\|L + V\|}$$

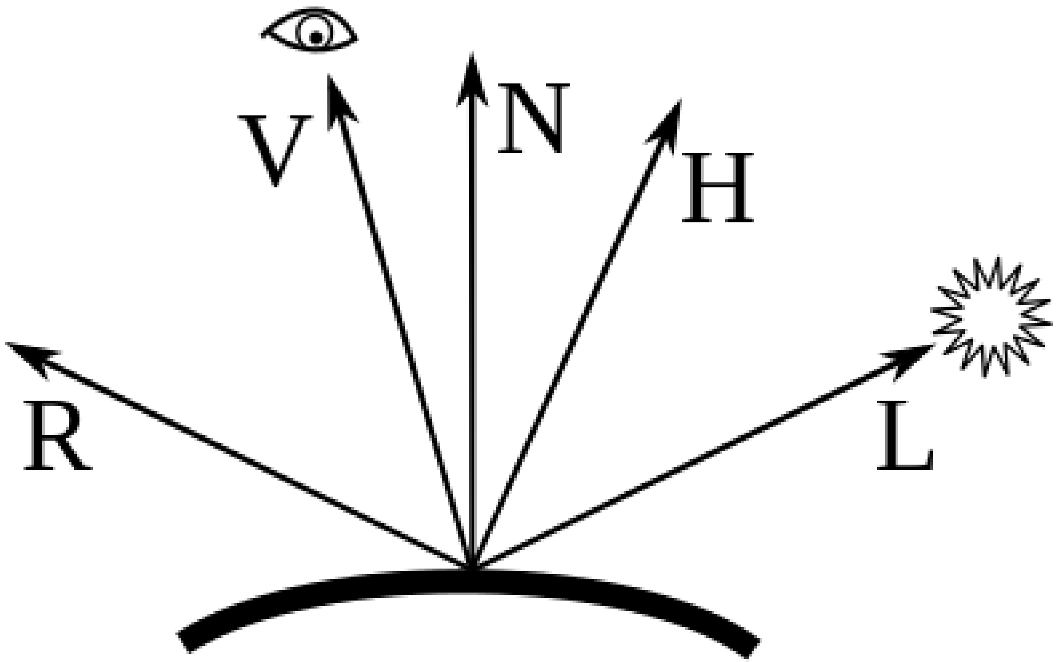
- More efficient in terms of the operations used
- Closer to physically correct lighting
- Pick exponent ***b*** to match what you want
  - Using higher ***b>a*** will make output similar to Phong with ***a***

The Halfway Vector

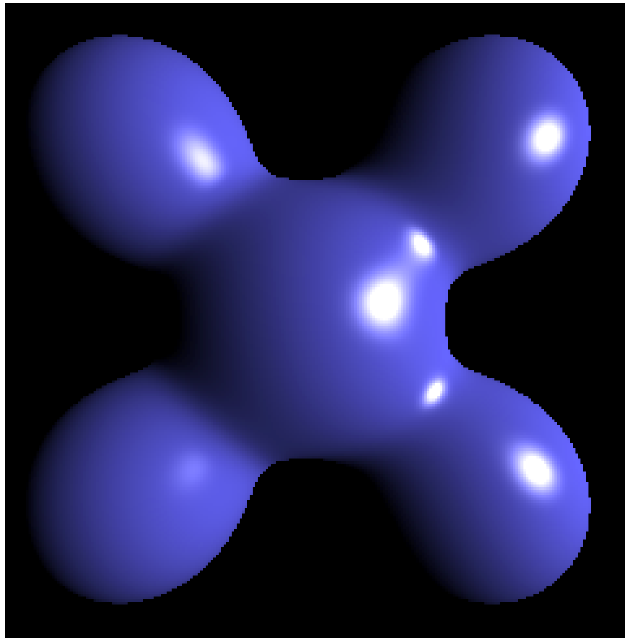
H is normalized vector halfway between **L** and **V**

$$\boxed{H = \frac{L + V}{\|L + V\|}}$$

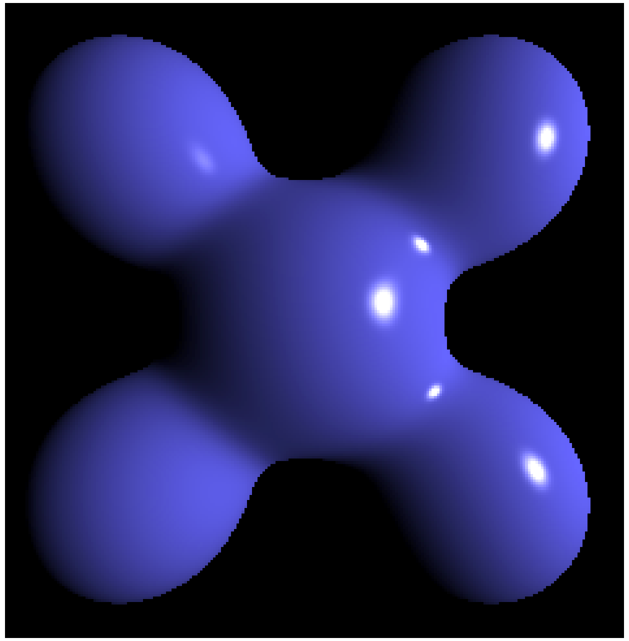
$$\boxed{\boldsymbol{r} = 2(\boldsymbol{l} \cdot \boldsymbol{n})\boldsymbol{n} - \boldsymbol{l}}$$



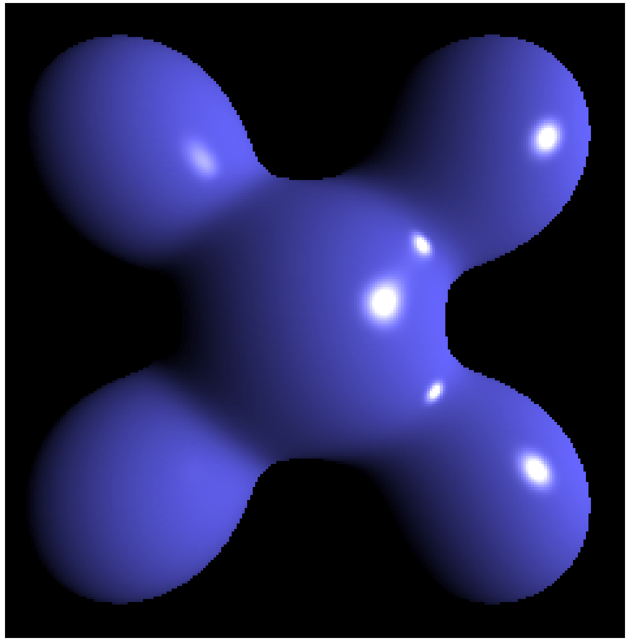
Phong versus Blinn-Phong



Blinn–Phong



Phong



Blinn–Phong
(higher exponent)

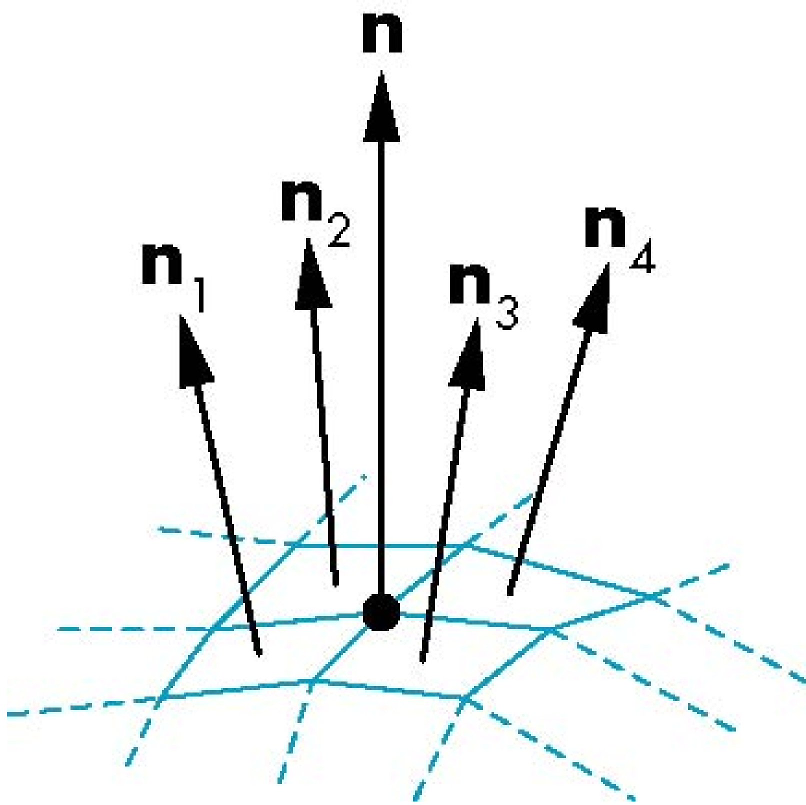
Smooth Shading on a Sphere Mesh

- I know…silhouette edge is bumpy for a sphere…
  - How do you make it less bumpy?
  - Why does the middle look smooth?
- We set a new normal at each vertex
- Per-vertex normal easy for a sphere model
  - If centered at origin **n** = **p**

What is the normal at the vertex (1,0,0)?

Mesh Shading

- The previous example is not general
  - We knew the normal at each vertex analytically
- For polygonal meshes, Henri Gouraud proposed we
  - use the average of the normals around a vertex



$$\mathbf{n} = (\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4) / \, |\mathbf{n}_1+\mathbf{n}_2+\mathbf{n}_3+\mathbf{n}_4|$$

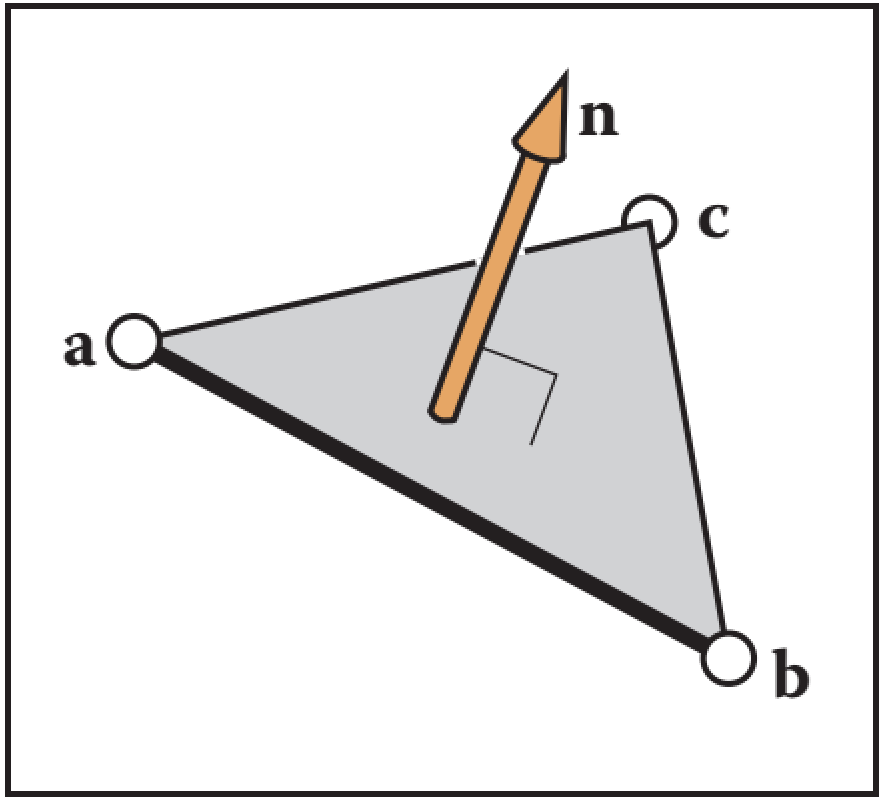
Computing a Normal for a Triangle

$$\vec{\boldsymbol{n}} = (b - a) \times (c - a)$$

To make unit length:

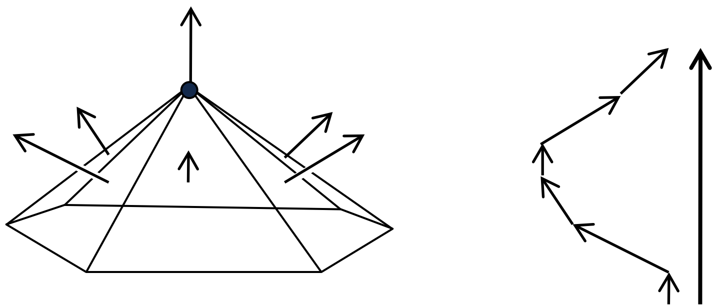
$$\vec{\boldsymbol{n}}_{unit} = \frac{\vec{\boldsymbol{n}}}{\|\vec{\boldsymbol{n}}\|}$$

You can use the glMatrix library to compute normals for vertices
Remember to make them unit-length for shading



(a,b,c) must be specified in counter-clockwise relative to us looking at the outward facing side of the triangle...this assumes a righthanded coordinate system...you would use CW for left-handed

Computing per-Vertex Normals



To compute per-vertex normal on a mesh with M vertices

- Initialize an array NArray containing M normals
    - Each normal starts as [0,0,0]
- Iterate over all triangles T=[v1,v2,v3] with vertices in CCW order
    - Compute normal N for T using N = (v2-v1)X(v3-v1)
        - NArray[v1]+=N
        - NArray[v2]+=N
        - NArray[v3]+=N
- Normalize each normal in Narray to unit length

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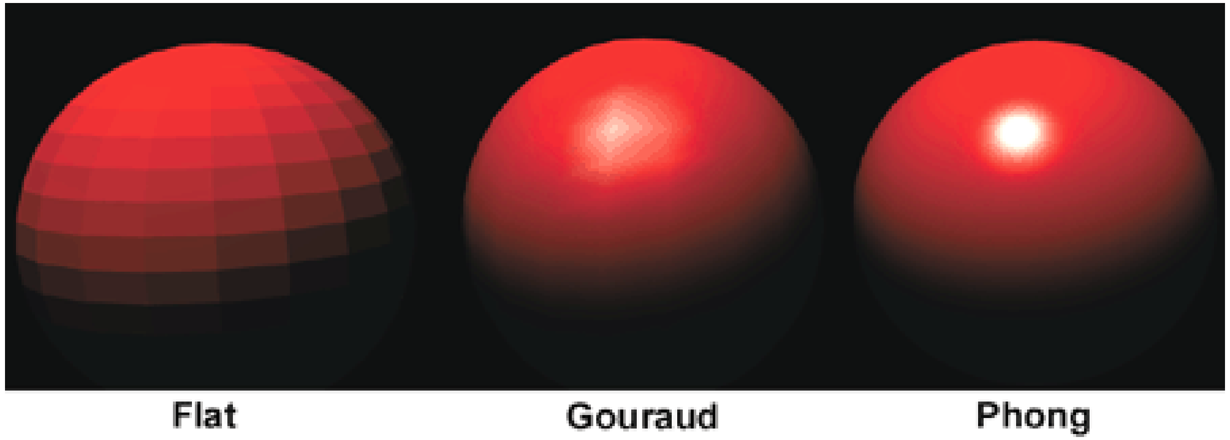
Gouraud and Phong Shading

Gouraud Shading

- Find average normal at each vertex
- Apply Blinn-Phong model at each vertex
- Interpolate vertex shades across each polygon

Phong Shading

- Find average normal at each vertex
- Interpolate vertex normals across edges
- Interpolate edge normals across polygon
- Apply Blinn-Phong model at each fragment



Bui Tuong Phong

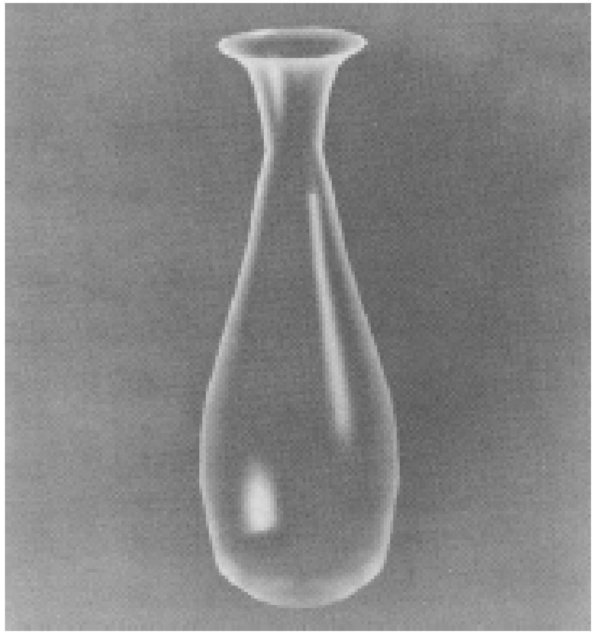
- December 14, 1942 – July 1975
- Born in Hanoi
- Earned his PhD in 2 years at the University of Utah (1973)
  - Worked with Professor Ivan Sutherland
  - Dissertation work was the Phong reflectance model
  - Also produced model and realistic image of a VW bug

Graphics and Image Processing
W. Newman Editor

Illumination for Computer Generated Pictures

Bui Tuong Phong
University of Utah

Fig. 9. Improved shading, applied to the example of Figure 2.



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