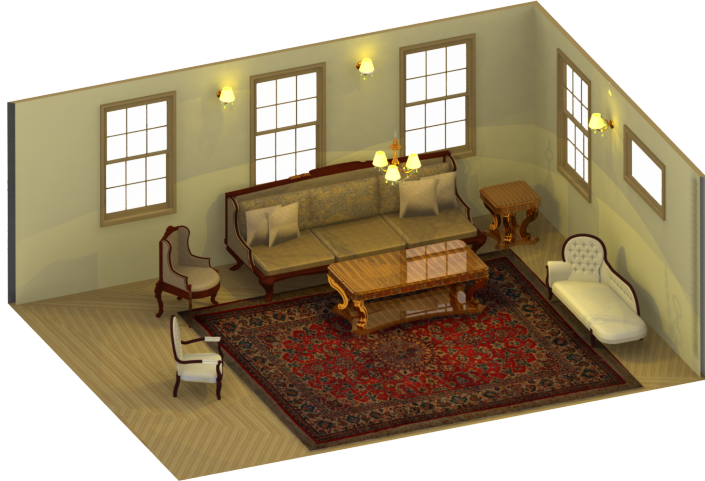


# LIGHTING / “SHADING”

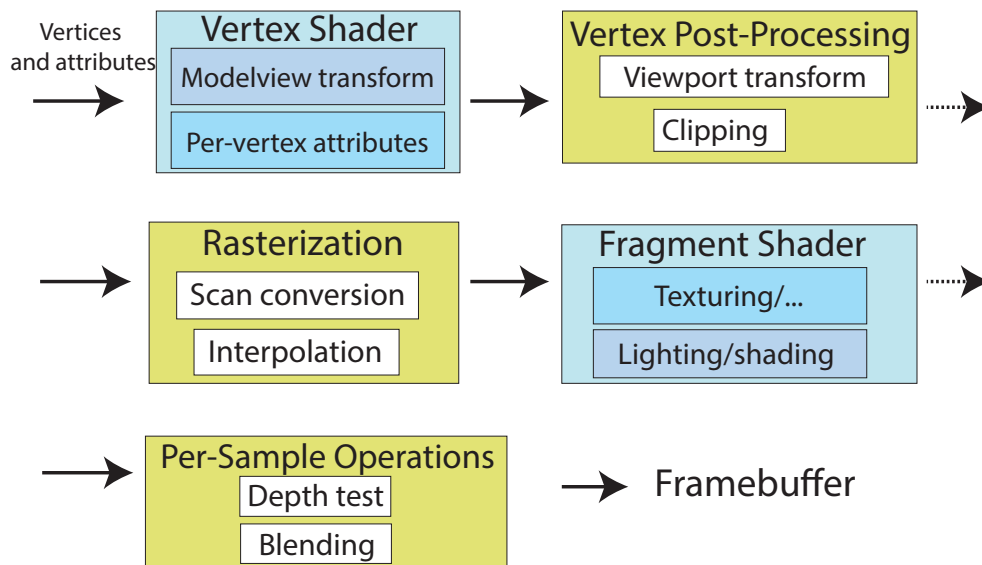
Models the interaction of light with surfaces. Generates a per (pixel/vertex) colour.

## FACTORS:

- Light sources
    - Location, type & color
  - Surface materials
    - How surfaces reflect light
  - Transport of light
    - How light moves in a scene
  - Viewer position
- 
- How can we do this in the pipeline?



## THE RENDERING PIPELINE



# ILLUMINATION MODELS/ALGORITHMS

## Local illumination – Fast

- assumes single-bounce path:  
light – surface – eye



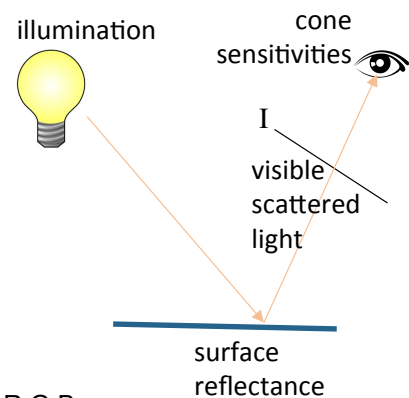
## Global illumination – Slow

- (More) Physically based computation of light transport throughout the scene



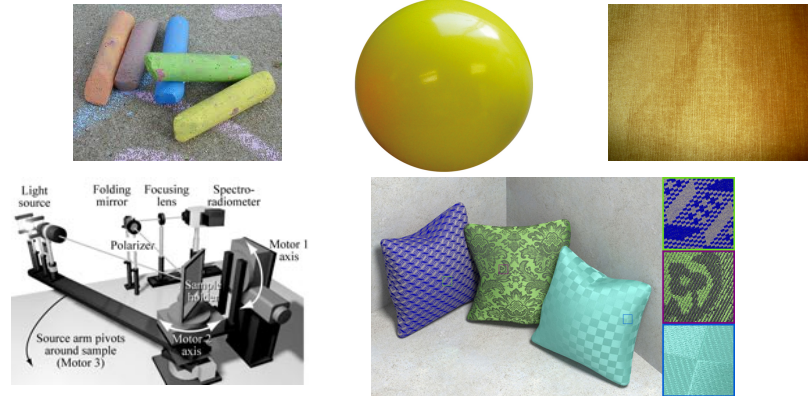
## THE BIG PICTURE

- Light: energy in a range of wavelengths
  - White light – all wavelengths
  - Colored (e.g. red) – subset of wavelengths
- Surface “color” – reflected wavelength
  - White – reflects all lengths
  - Black – absorbs everything
  - Colored (e.g. red) absorbs all but the reflected color
- Multiple light sources add (energy sums)
- big simplification: just work with three “wavelengths”: R,G,B which roughly correspond to the three types of cone-cells in the human eye.
  - white light (1,1,1) x yellow surf (0.8,0.8,0) = yellow visible (0.8,0.8,0)
  - yellow light (1,1,0) x cyan surf (0,1,1) = green visible(0,1,0)



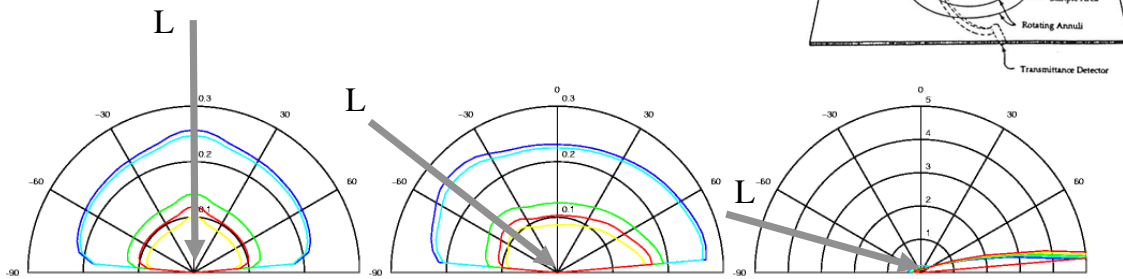
# MATERIALS

- Surface reflectance:
  - Illuminate surface point with a ray of light from different directions
  - How much light is reflected in each outgoing direction?



## BIDIRECTIONAL REFLECTANCE DISTRIBUTION MODEL

- How much light is reflected in every outgoing direction for each possible incoming direction of light?



BRDF of spray-painted latex blue paint, Pratt & Lambert, Vapex  
 Interior Wall Base 1, Color #1243, Cal.III.  
<http://www.graphics.cornell.edu/online/measurements/reflectance/housepaints/>

# PHONG MODEL

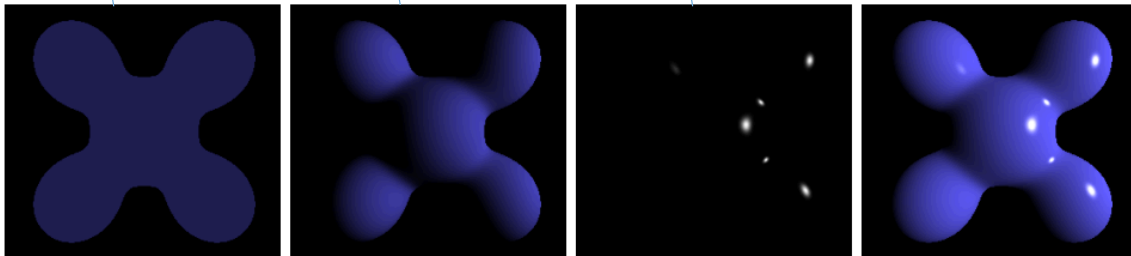
Widely used;  
you will implement this!

Named after Phong, who developed  
the model for the specular term.



$$I_a k_a + \sum_L I_L k_d (N \cdot L) + I_L k_s (R \cdot V)^n$$

ambient + diffuse + specular = total



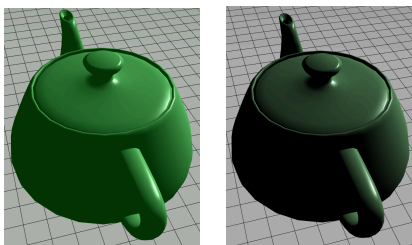
# AMBIENT TERM

• simple hack that provides a  
default minimal illumination

$$I_a k_a + \sum_L I_L k_d (N \cdot L) + I_L k_s (R \cdot V)^n$$

scene property  
ambient light color

surface property:  
ambient color



with ambient light

without ambient light

$$I \begin{bmatrix} 0.2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} I_a \\ I_a \\ I_a \end{bmatrix} \begin{bmatrix} k_a \\ k_a \\ k_a \end{bmatrix}$$

apply individually to RGB components

see: <http://www.realtimerendering.com/teapot/>

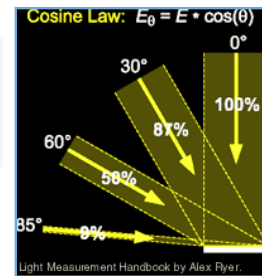


## DIFFUSE TERM

“Lambertian Surface”

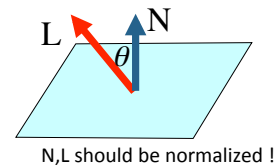
$$I_a k_a + \sum_L I_L k_d (N \cdot L) + I_L k_s (R \cdot V)^n$$

Intuition: Brightness depends on the angle of the surface with respect to the incoming light direction. Sharper angles mean that the surface receives less light.



$$N \cdot L = \cos(\theta)$$

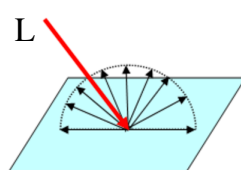
only consider angles from 0-90,  
i.e., if N.L negative, then set to zero



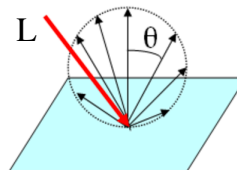
## DIFFUSE TERM

The apparent brightness (the reflected radiance)  
is **independent** of the viewing direction.

Two correct interpretations:



reflected radiance



reflected intensity

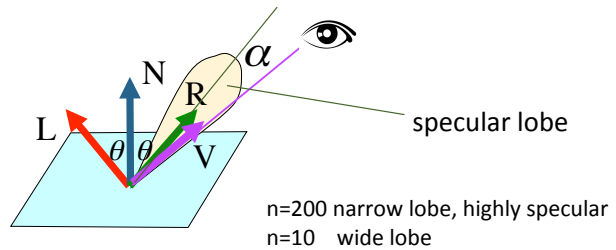
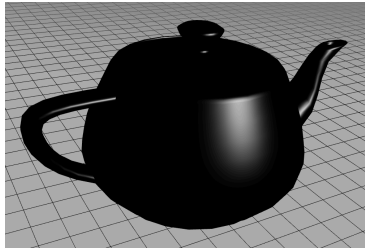
[[http://www.oceanopticsbook.info/view/surfaces/lambertian\\_brdfs](http://www.oceanopticsbook.info/view/surfaces/lambertian_brdfs)]

## SPECULAR (PHONG) TERM

$$I_a k_a + \sum_L I_L k_d (N \cdot L) + I_L k_s (R \cdot V)^n$$

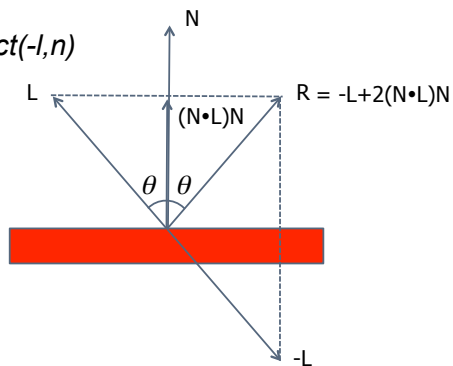
reflected ray  
viewing direction  
"shininess"  
 $R \cdot V = \cos(\alpha)$

Many surfaces are not perfect mirrors, but still reflect much light in the general direction of the reflected ray. As we get further away from the reflected ray, we see less light being reflected in those directions.



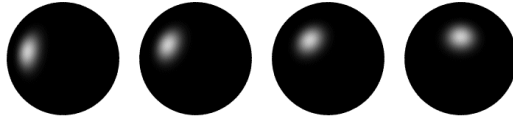
## SPECULAR TERM: COMPUTATIONS

- Geometry of specular (perfect mirror) reflection
  - Snell's law
  - In GLSL: use `reflect(-l,n)`

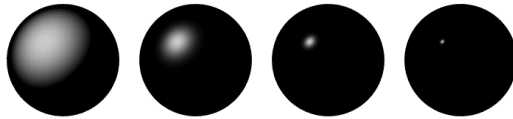


## PHONG EXAMPLES

varying light position



varying  $n_s$



The Phong specular term is an empirical model, i.e., not physics-based.

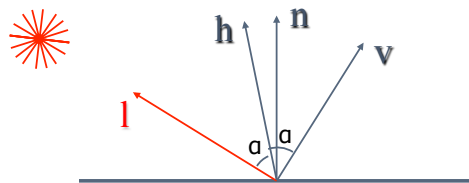
It generally produces a “plastic” appearance.

## ALTERNATIVE: BLINN-PHONG MODEL

(Jim Blinn, 1977)

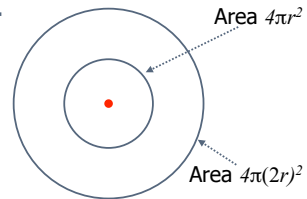
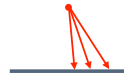
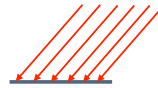
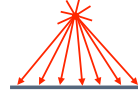
- Variation with better physical interpretation
  - $\mathbf{h}$ : halfway vector;  $r$ : roughness

$$I_{\text{specular}} = k_s \cdot (\mathbf{h} \cdot \mathbf{n})^{1/r} \cdot I_{\text{light}}; \text{ with } \mathbf{h} = (\mathbf{l} + \mathbf{v}) / 2$$

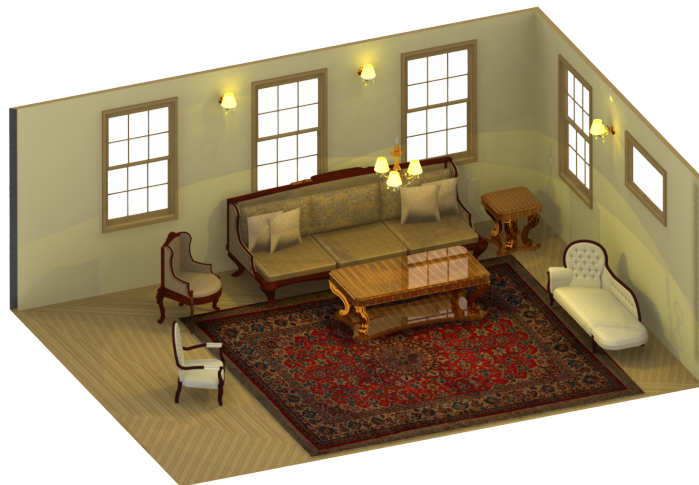


# LIGHT SOURCE TYPES

- Point Light
  - light originates at a point
  - defined by **location only**
- Directional Light (point light at infinity)
  - light rays are parallel
  - Rays hit a planar surface at identical angles
  - defined by **direction only**
- Spot Light
  - point light with limited angles
  - defined by **location, direction, and angle range**
- Light source fall-off: intensity drops with distance squared



## WHICH LIGHTS/MATERIALS ARE USED HERE?



# LIGHT AND MATERIAL SPECIFICATION

- Light source: amount of RGB light emitted
  - value = intensity per channel
  - 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)
- Interaction: multiply components
  - Red light (1,0,0) x green surface (0,1,0) = black (0,0,0)

# NOTES ON SHADING

- Typically compute lighting model in VCS. Therefore need:
  - VCS Vertex Coordinates, VCS Normals, VCS Light Positions
- How often to compute the lighting model?

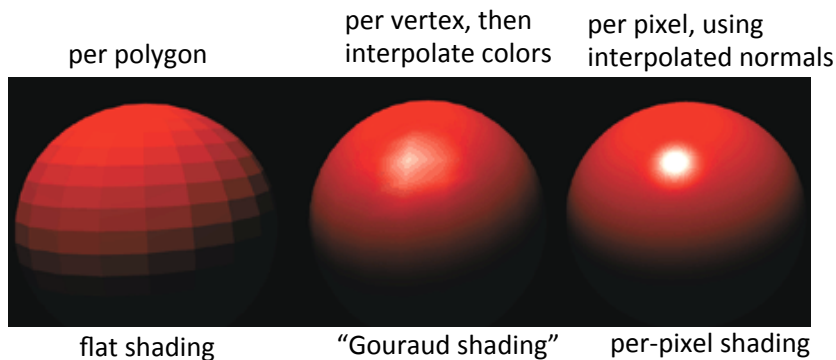
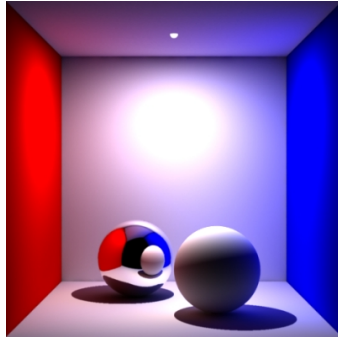


Image © Intergraph  
Computer Systems

# GLOBAL ILLUMINATION



# SUBSURFACE SCATTERING

