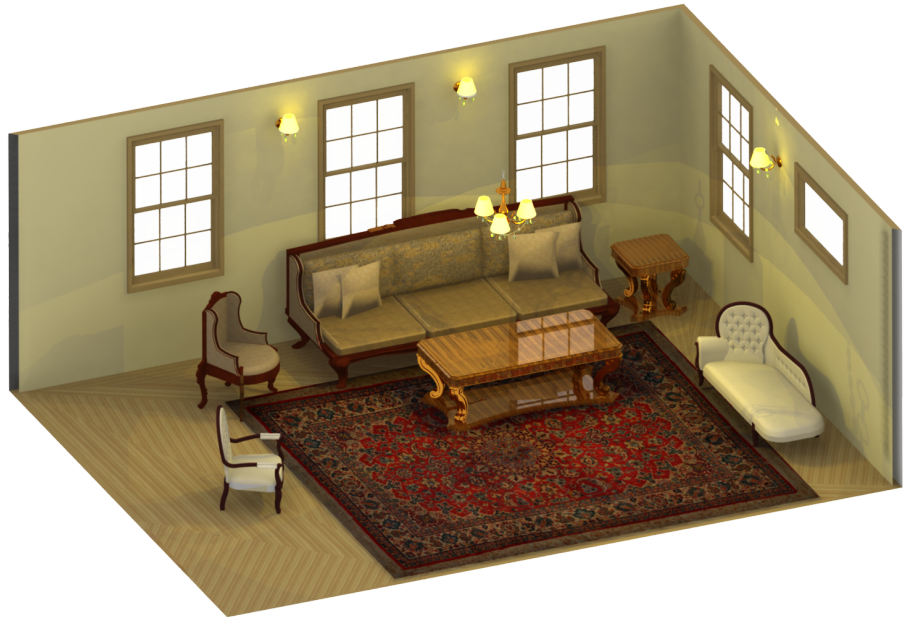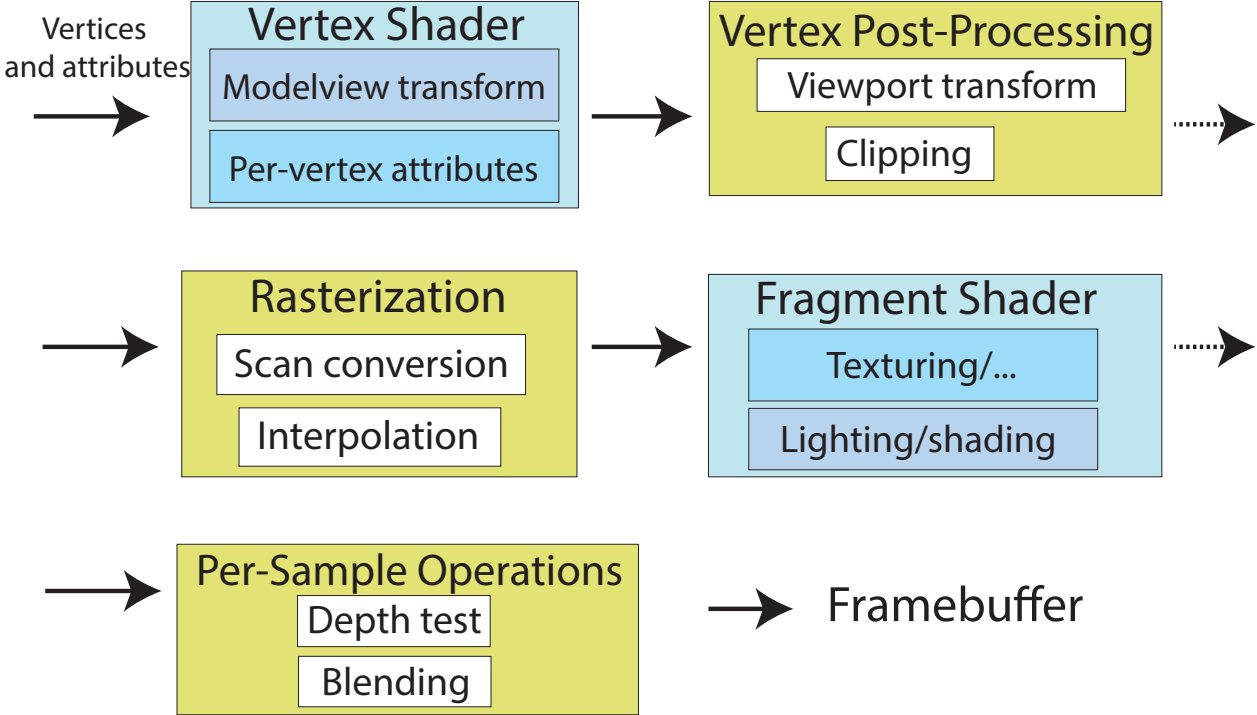# LIGHTING / "SHADING"

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

Vertices
and attributes

Vertex Shader
- Modelview transform
- Per-vertex attributes

Vertex Post-Processing
- Viewport transform
- Clipping

Rasterization
- Scan conversion
- Interpolation

Fragment Shader
- Texturing/...
- Lighting/shading

Per-Sample Operations
- Depth test
- Blending

Framebuffer

ILLUMINATION MODELS/ALGORITHMS

Local illumination – Fast
- assumes single-bounce path:
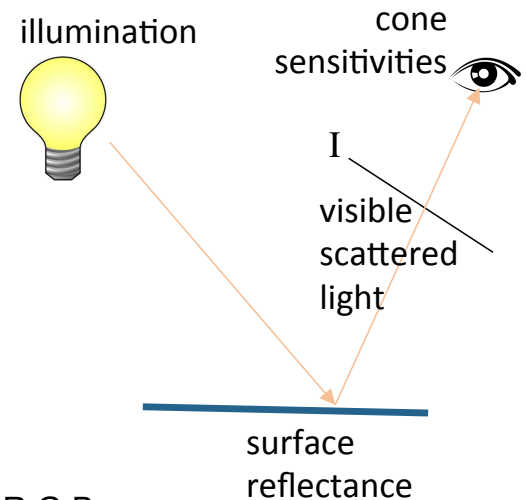 light – surface – eye
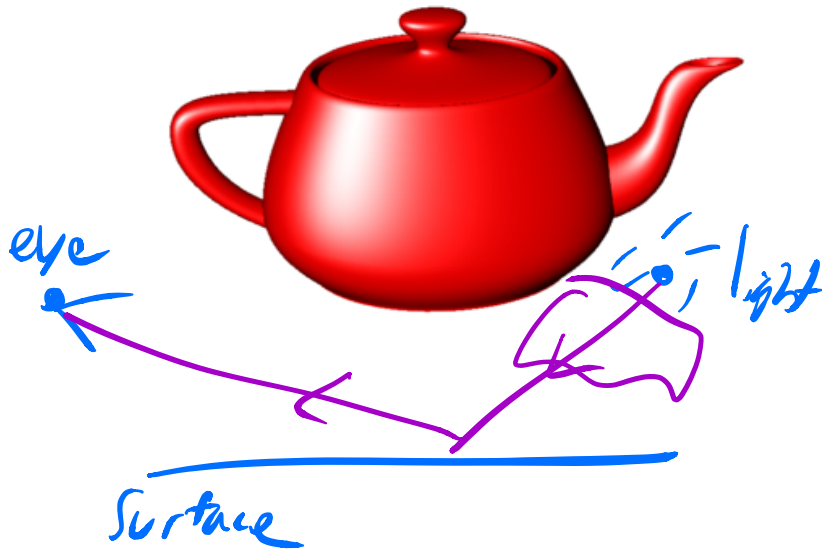
Global illumination – Slow
- (More) Physically based computation of light transport throughout the scene

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)

illumination

cone
sensitivities

I

visible
scattered
light

surface
reflectance

MATERIALS

- Surface reflectance:
  - Illuminate surface point with a ray of light from different directions
  - How much light is reflected in each outgoing direction?
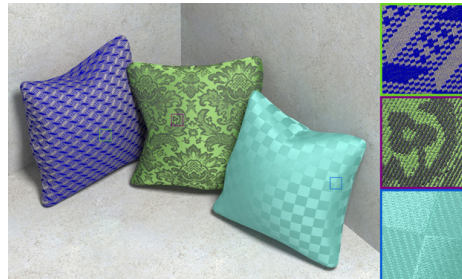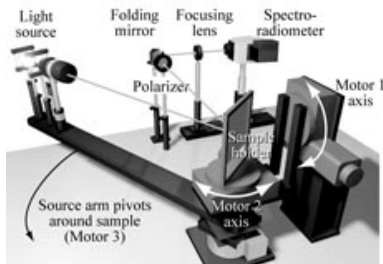
(BRDF)
BIDIRECTIONAL REFLECTANCE DISTRIBUTION MODEL

• How much light is reflected in every outgoing direction for each possible incoming direction of light?
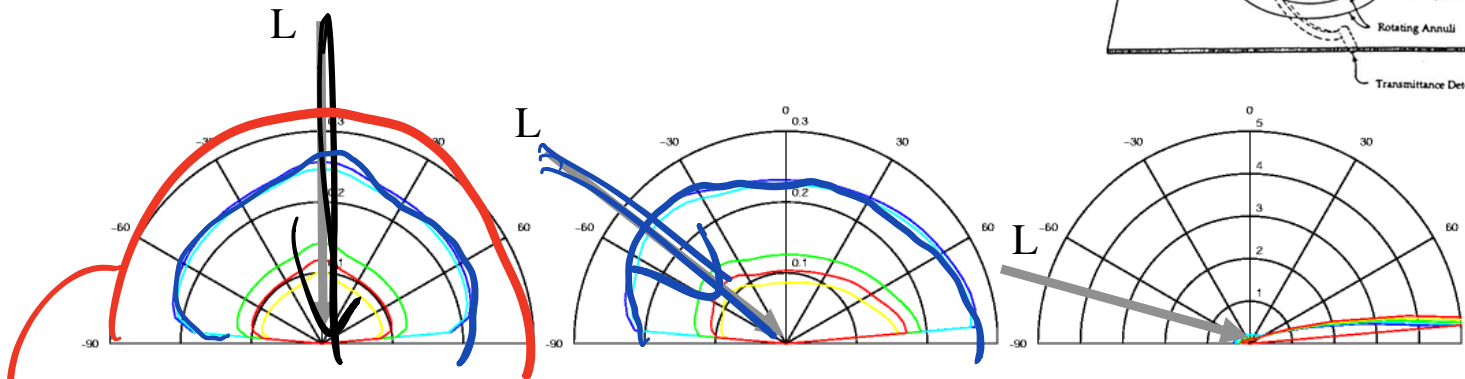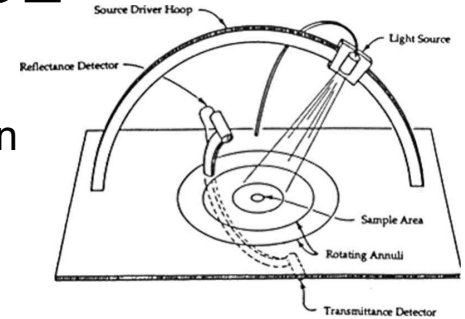
BRDF of spray-painted latex blue paint, Pratt & Lambert, Vapex Interior Wall Base 1, Color #1243, Cal.III.
http://www.graphics.cornell.edu/online/measurements/reflectance/housepaints/

diffuse surface reflects light equally in all directions

PHONG MODEL

Widely used;
you will implement this!

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

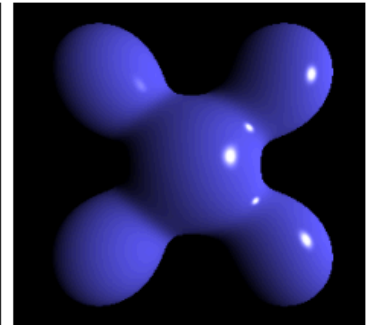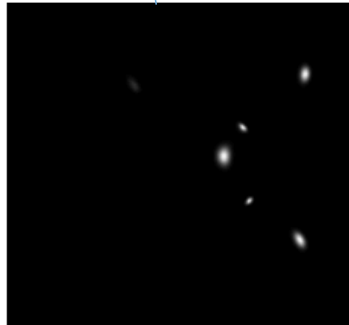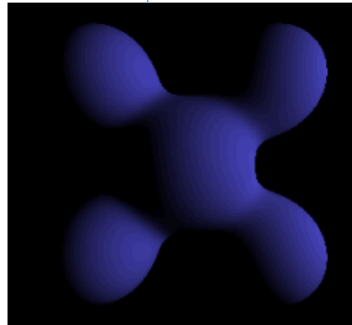$$I_a k_a + \sum_L \left(I_L k_d (N \cdot L) + I_L k_s (R \cdot V)^n \right)$$

ambient   +   diffuse   +   specular   =   total

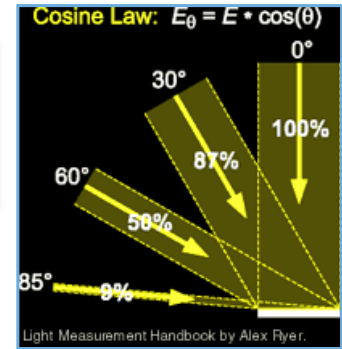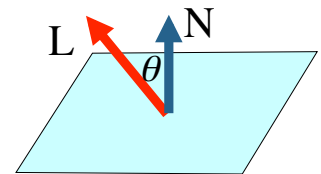# DIFFUSE TERM   "Lambertian Surface"

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

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.

Cosine Law: $E_\theta = E \cdot \cos(\theta)$

Light Measurement Handbook by Alex Ryer.

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

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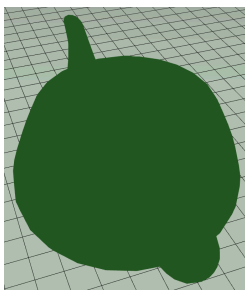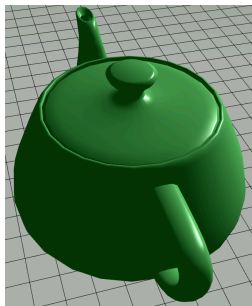
N,L should be normalized !

AMBIENT TERM

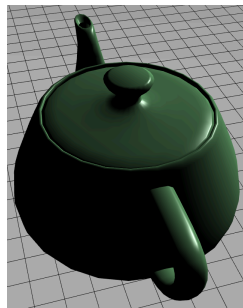• simple hack that provides a default minimal illumination

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

ambient term

with ambient light

without ambient light

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

scene property
ambient light color

surface property:
ambient color

$$I \qquad I_a \qquad k_a$$

$$\begin{bmatrix} 0.2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \begin{bmatrix} 0.2 \\ 0 \\ 0 \end{bmatrix}$$
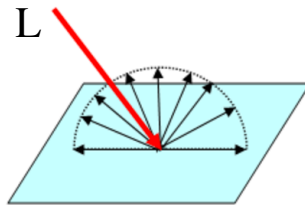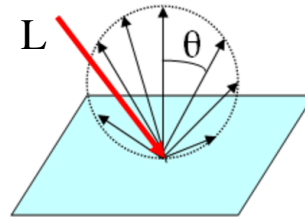
apply individually to RGB components

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]

SPECULAR (PHONG) TERM

reflected ray

viewing direction

"shininess"

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

$$R \cdot V = \cos(\alpha)$$

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.

N

R

L

θ θ

V

α
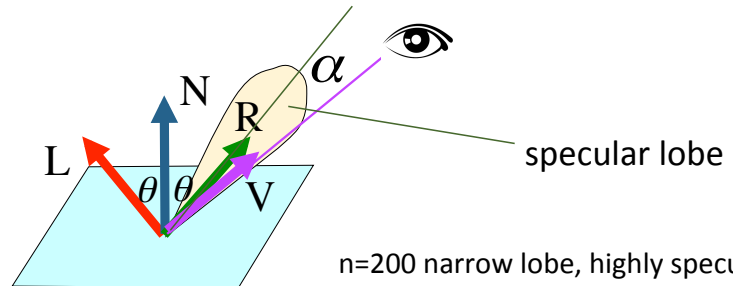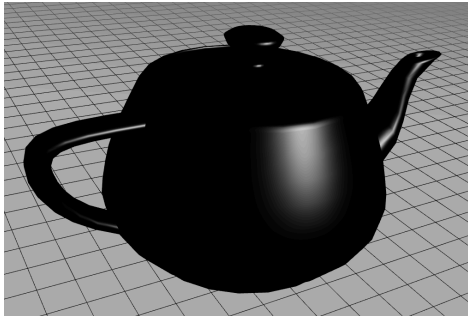
specular lobe

n=200 narrow lobe, highly specular
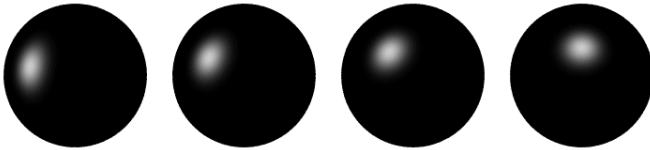n=10   wide lobe

SPECULAR TERM: COMPUTATIONS

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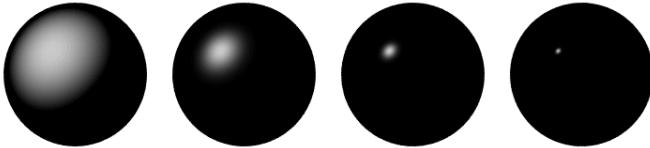 - In GLSL: use *reflect(-l,n)*
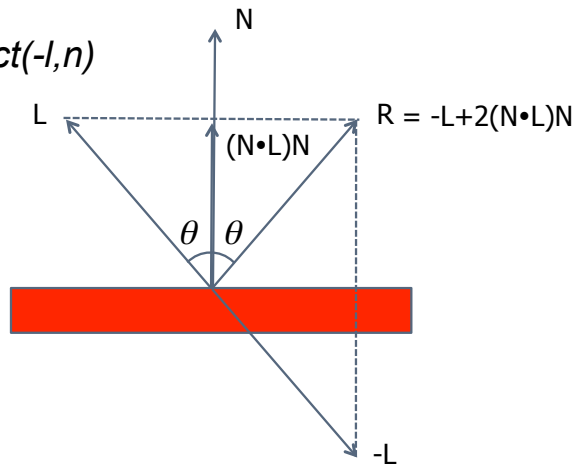
PHONG EXAMPLES

varying light position

varying n_s

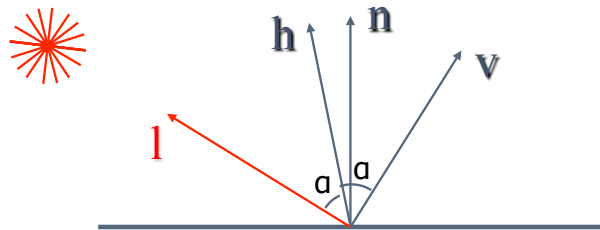The Phong specular term is an emperical model, i.e., not physics-based.

It generally produces a "plastic" appearance.

ALTERNATIVE: BLINN-PHONG MODEL

(Jim Blinn, 1977)

- Variation with better physical interpretation
 - **h**: halfway vector; r: roughness

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

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

$\vec{L}$ is constant

multiply by $\frac{1}{r^2}$

Area $4\pi r^2$

Area $4\pi(2r)^2$
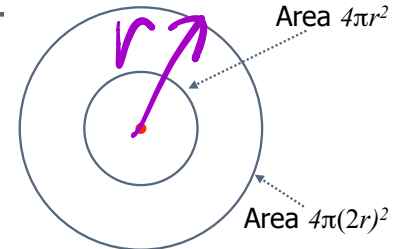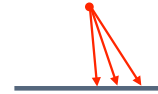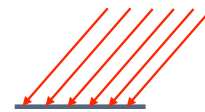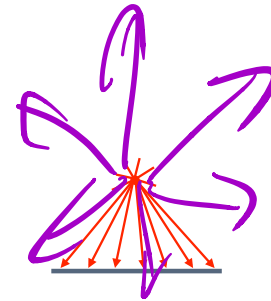
WHICH LIGHTS/MATERIALS ARE USED HERE?
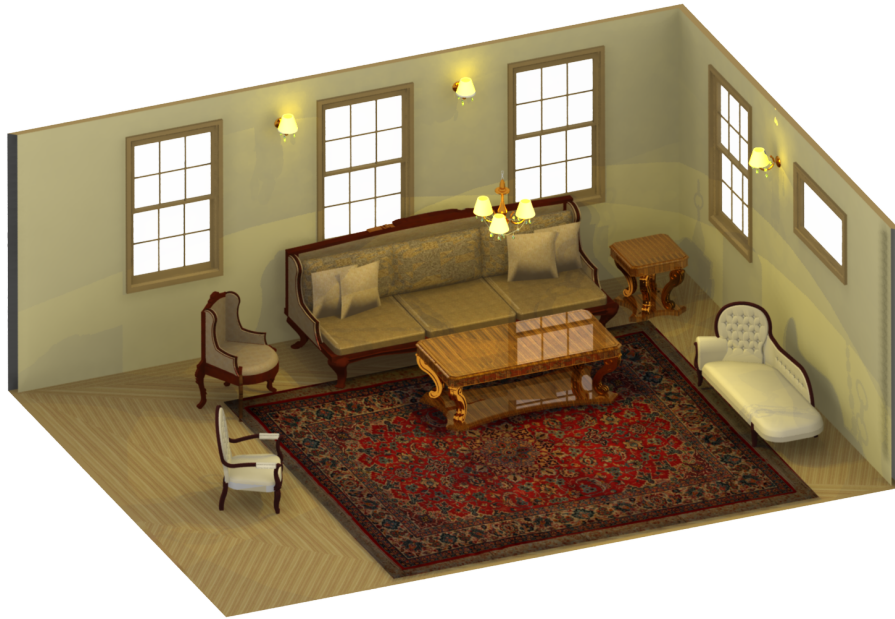
LIGHT AND MATERIAL SPECIFICATION

- 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?
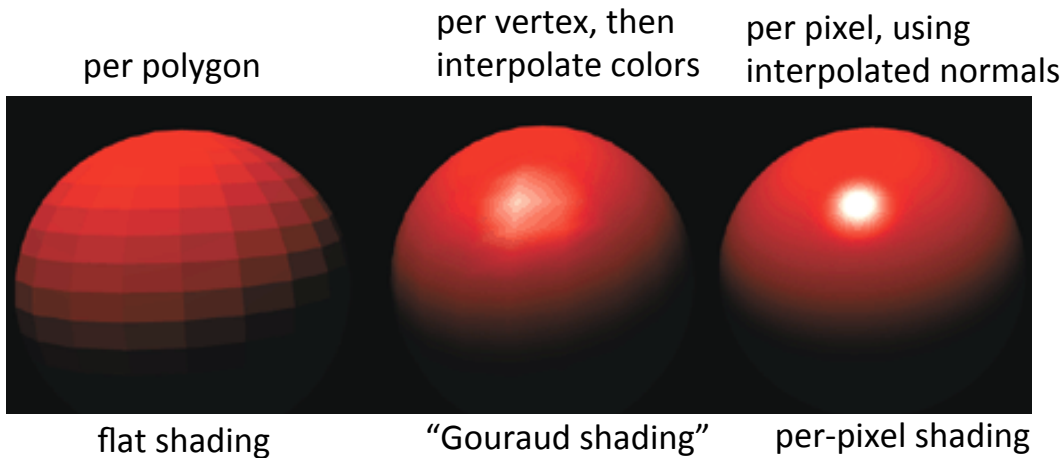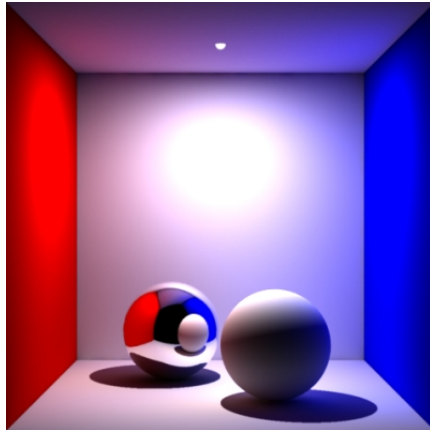
per polygon   per vertex, then interpolate colors   per pixel, using interpolated normals

flat shading   "Gouraud shading"   per-pixel shading

Image © Intergraph
Computer Systems

GLOBAL ILLUMINATION

SUBSURFACE SCATTERING

$$I = I_L k$$

Surface Color. ↗

(r,g,b)   RGB colors

(0,0,0)   black
(1,0,0)   red
(0,1,0)   green
(0,0,1)   blue
(1,1,0)   yellow.
(1,0,1)   magenta
(0,1,1)   cyan
(1,1,1)   white

QUESTIONS

- What do we see when a yellow surface is lit with:
  (a) white light?   (1,1,1) × (1,1,0) = (1,1,0)
  (b) blue light?   (0,0,1) × (1,1,0) = (0,0,0) black
  (c) red light?
  (d) yellow light?
  (e) green light?

- ~~Do specular highlights have the colour of the light or the surface?~~

Surface lit with a cyan light (0.6,1,1)

Surf colors
$$\begin{bmatrix} \text{yellow } (1,1,0.7) \Rightarrow (0.6,1,0.7) \text{ green (!)} \\ \text{red } (1,0.6,0.6) \Rightarrow (0.6,0.6,0.6) \text{ gray} \end{bmatrix}$$

QUESTIONS

- Give the Phong equation parameters that are needed to render a shiny yellow material with a single white light.

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

- What is the colour of the darkest pixel this model can produce?

- What is the colour of the brightest pixel this model can produce?