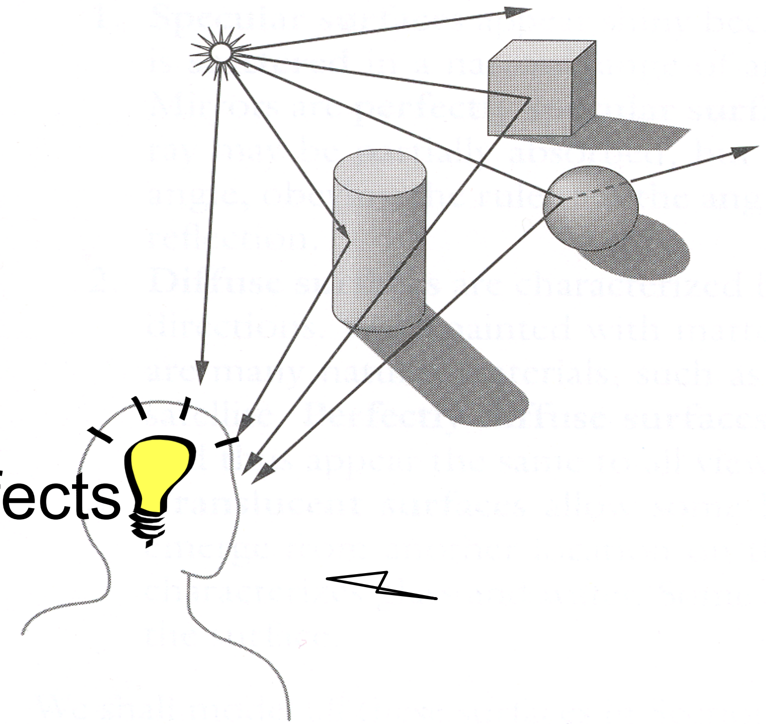
Illumination and Shading

Illumination Model (Lighting Model)

- Calculating the light intensity at a point on the surface of objects
- Surface rendering (or shading) is the use of illumination models on objects to calculate projected pixel values

physical simulation



Psychophysical effects

Angel Figure 6.2

Factors for desirable illumination model

- Physical accuracy (realism)
- Efficiency of calculation
- Control
  - What parameters are given to the user to generate desirable effects?
- Models used in graphics are approximations that balance these factors

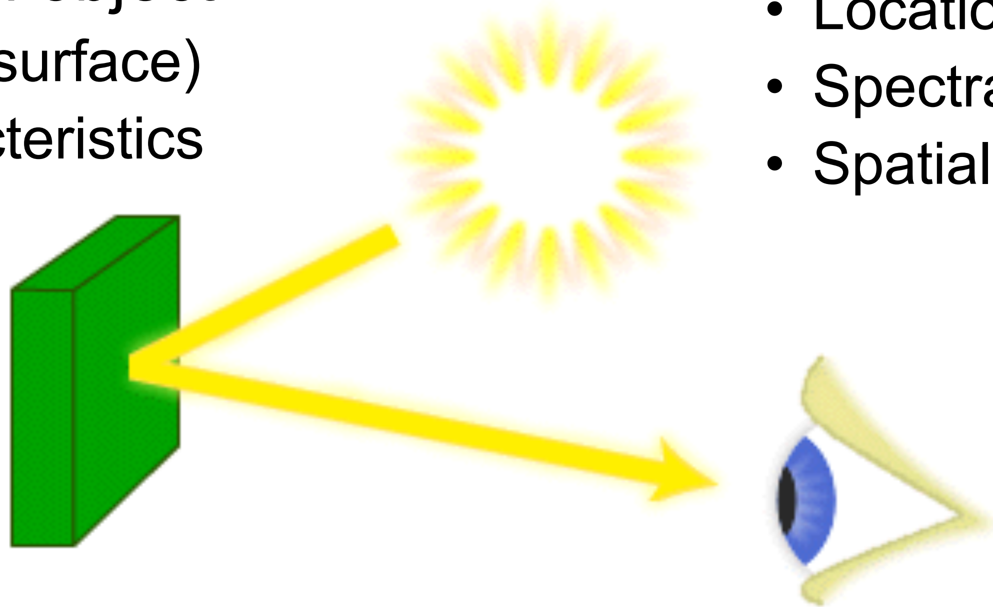
Local illumination model

Light interaction with object

- Location (on the surface)
- Reflection characteristics

Light source

- Location (in space)
- Spectral distribution
- Spatial distribution

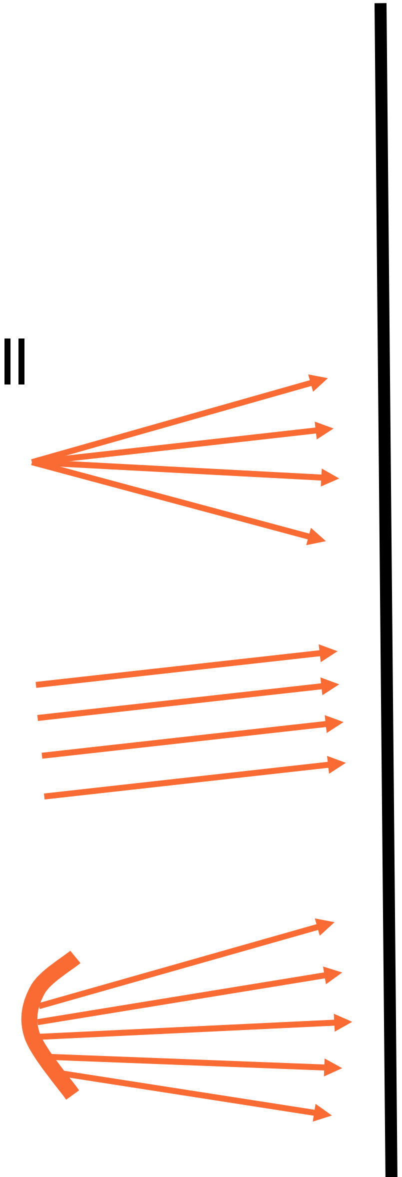


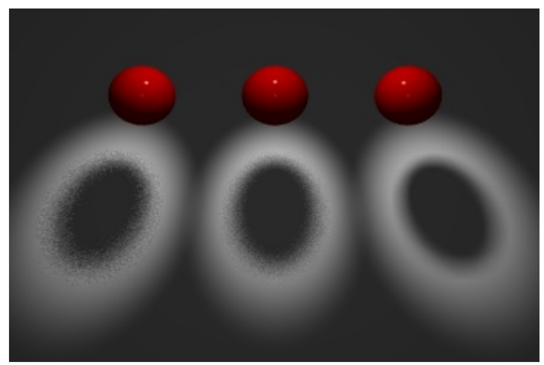
Light perception by the “camera”

- Location (of camera)
- Spectral sensitivity

Light sources

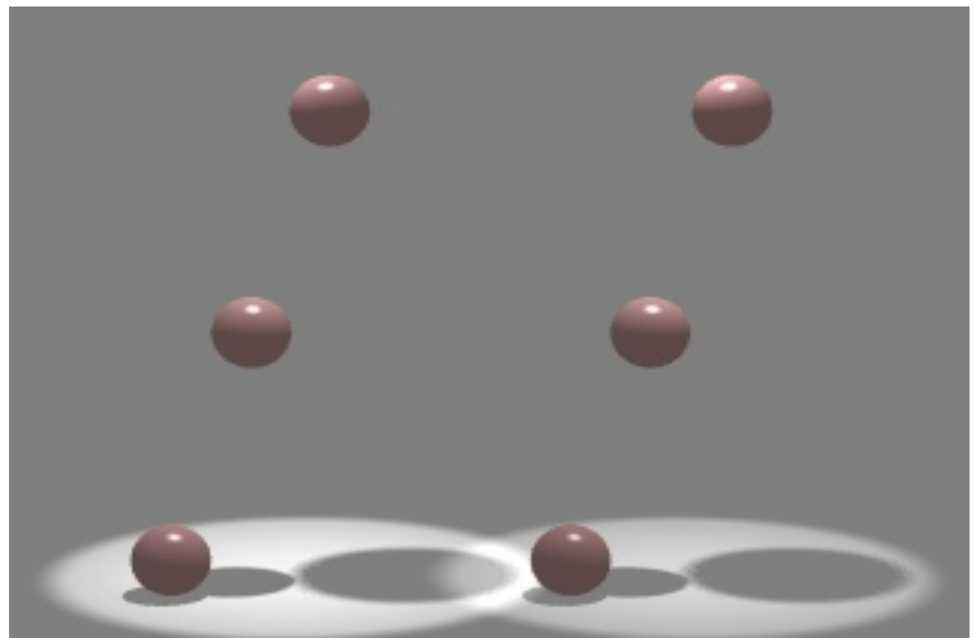
– Point
  - Approximation of light sources that are small compared to the object that it is illuminating
- – Infinite distance
  - Light source is far away so that the light arrives with parallel rays
- – Area light





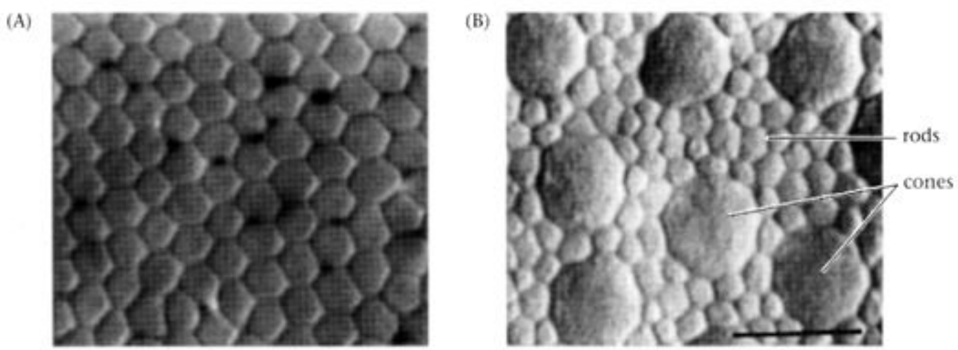
Attenuation of Light

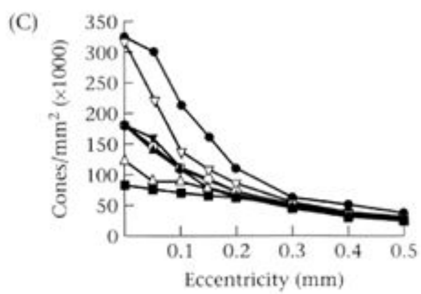
- Due to distance to light source
  - Light intensity falls off as $1/r^2$ from the light source
  - Often not modeled
- Due to angular distance from light direction
  - For directional lights
- Due to medium (e.g. fog)
- Due to occlusion
  - Shadows



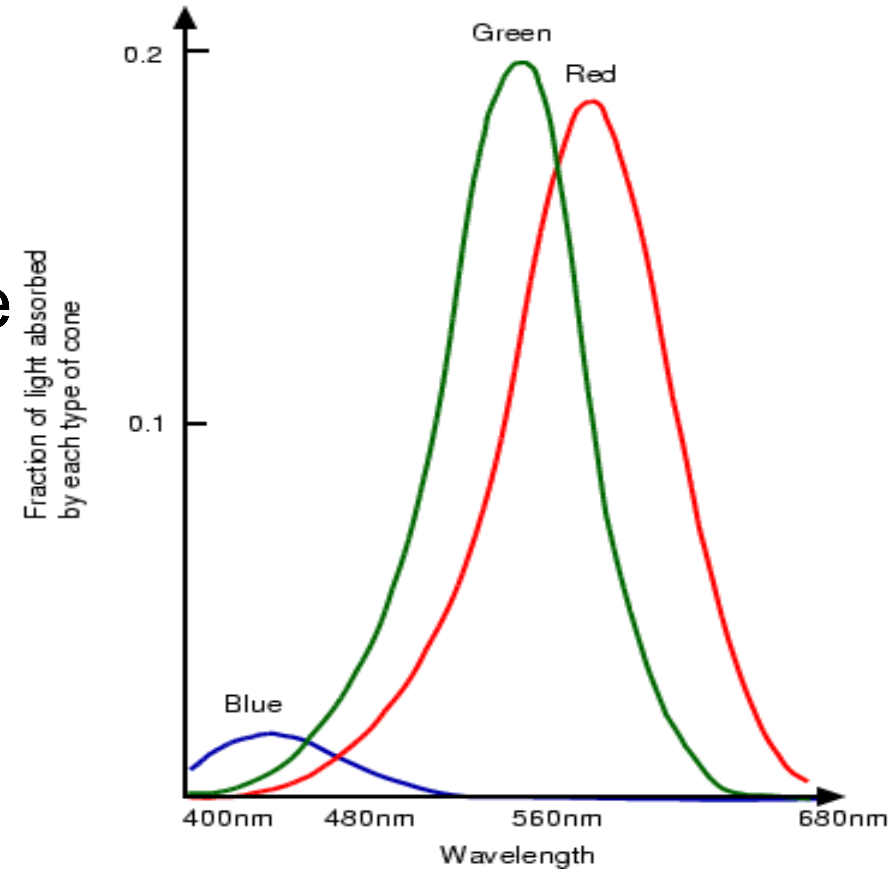
Tristimulus Theory

- Retina have three kinds of color receptors (cones)
- Perception of the entire spectrum recreated from the three frequencies





3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.



Source: http://www.cis.rit.edu/people/faculty/montag/vandplite/pages/chap_9/ch9p1.html

Frequency of light

- Light usually has continuous spectrum
- In computer graphics, calculate and store only three frequencies (R, G, B)
  - Sampling the spectrum at three frequencies
  - Do all calculations in three frequencies
  - Represent an image using only three frequencies

Basic Illumination Model

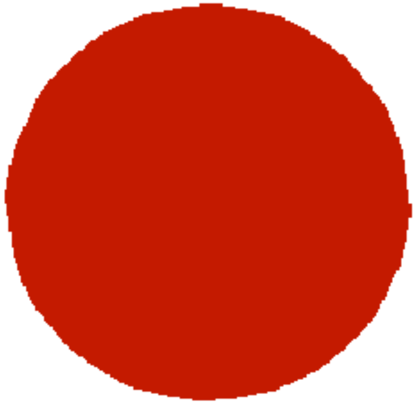
- Assume three separate contributions
- Ambient
  - Effect due to other surfaces in the environment
  - A very rough hack - uniform for all objects, no source or direction
- Diffuse
  - Effect due to roughness of surface
- Specular
  - Effect due to specularity (shininess) of surface
- This is an artificial separation - not real light

Ambient

- Assume there is a non-directional source of light that is uniform everywhere with intensity I_a
- Reflectivity of a surface is given by k_a
  - Composed of three terms for the R, G, B components
  - Objects reflect different frequencies of light differently
  - Scale from 0..1
- Reflected ambient light:
  - $I_{reflected} = k_a I_a$

Ambient Illumination

- No given location of light
- Surface position or orientation unimportant
- Location of camera unimportant
- A red sphere lit with “white” ambient light =>
- This is total hack used to model “global illumination” or illumination from the environment without expensive calculations



Diffuse

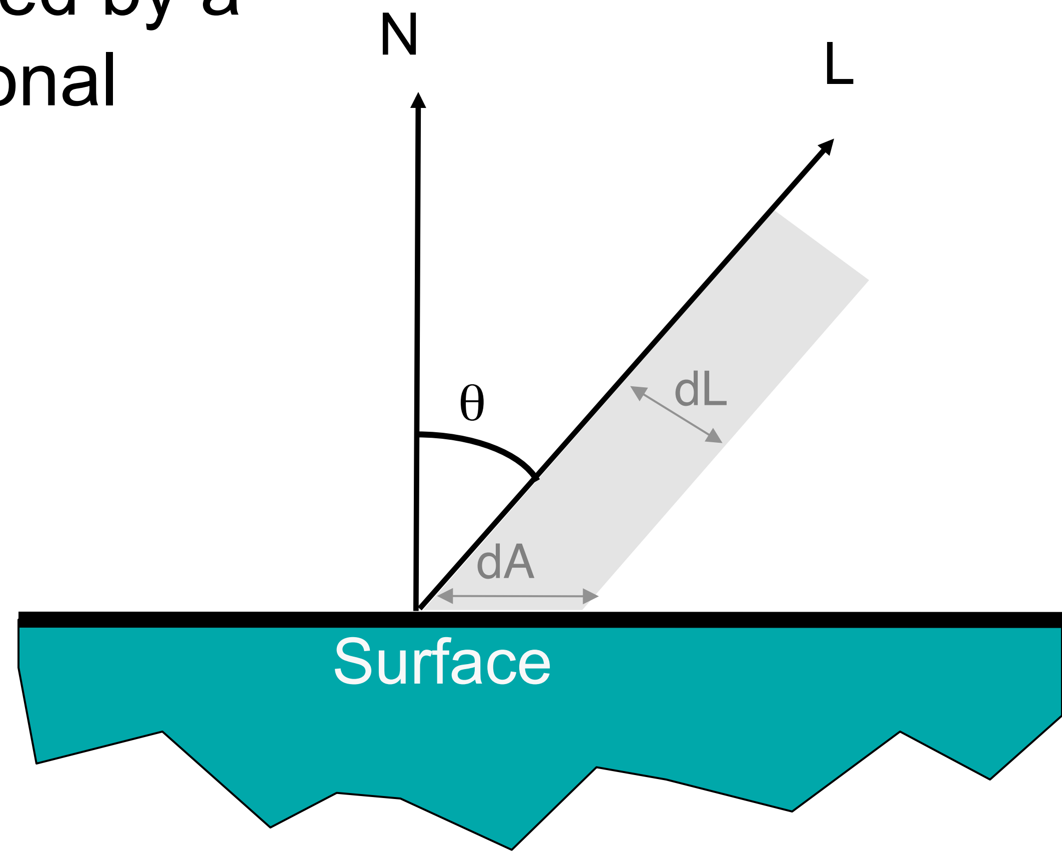
- Model the effect of rough surface (like chalk, fabric, etc.)
  - Called Lambertian surfaces
- Light is scattered uniformly in all directions (ideal diffuse surface)

- Assume a directional light source
  - Point, area, or parallel

Lambert's Cosine Law

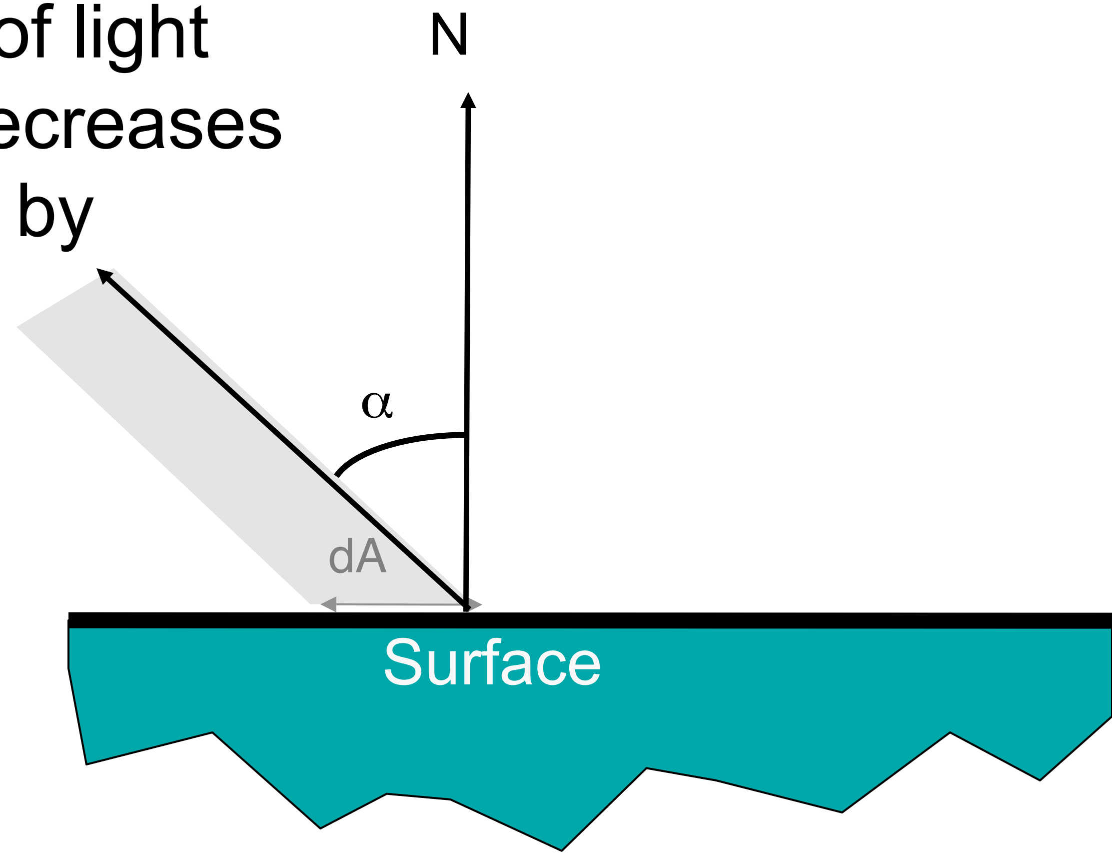
– Area subtended by dL $dA = \dfrac{dL}{\cos\Theta}$

$\therefore$ Amount of light received by a surface area is proportional to $\cos\theta$



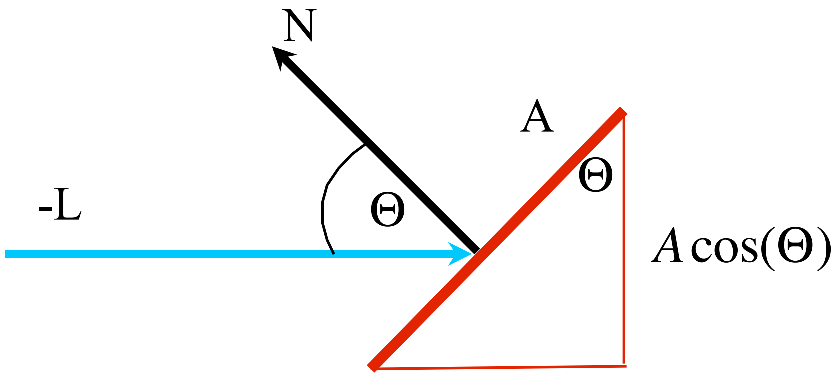
– As angle α between N and eyepoint increases, the amount of light emitted per unit area decreases by cos α but area seen by viewer increases by cos α

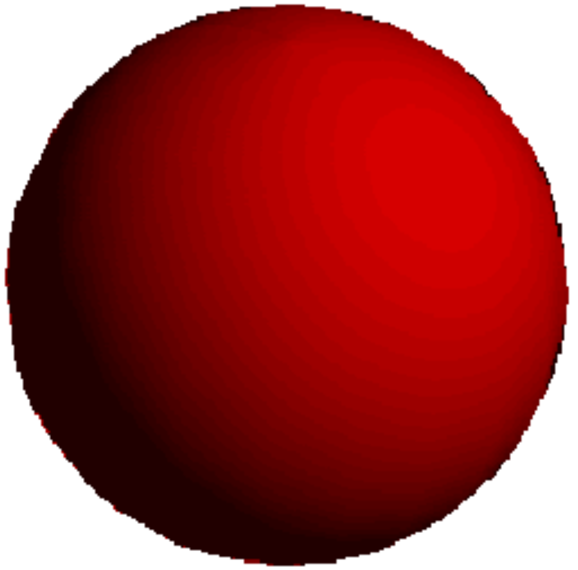
$\therefore$Reflected intensity independent of eyepoint



Diffuse Illumination

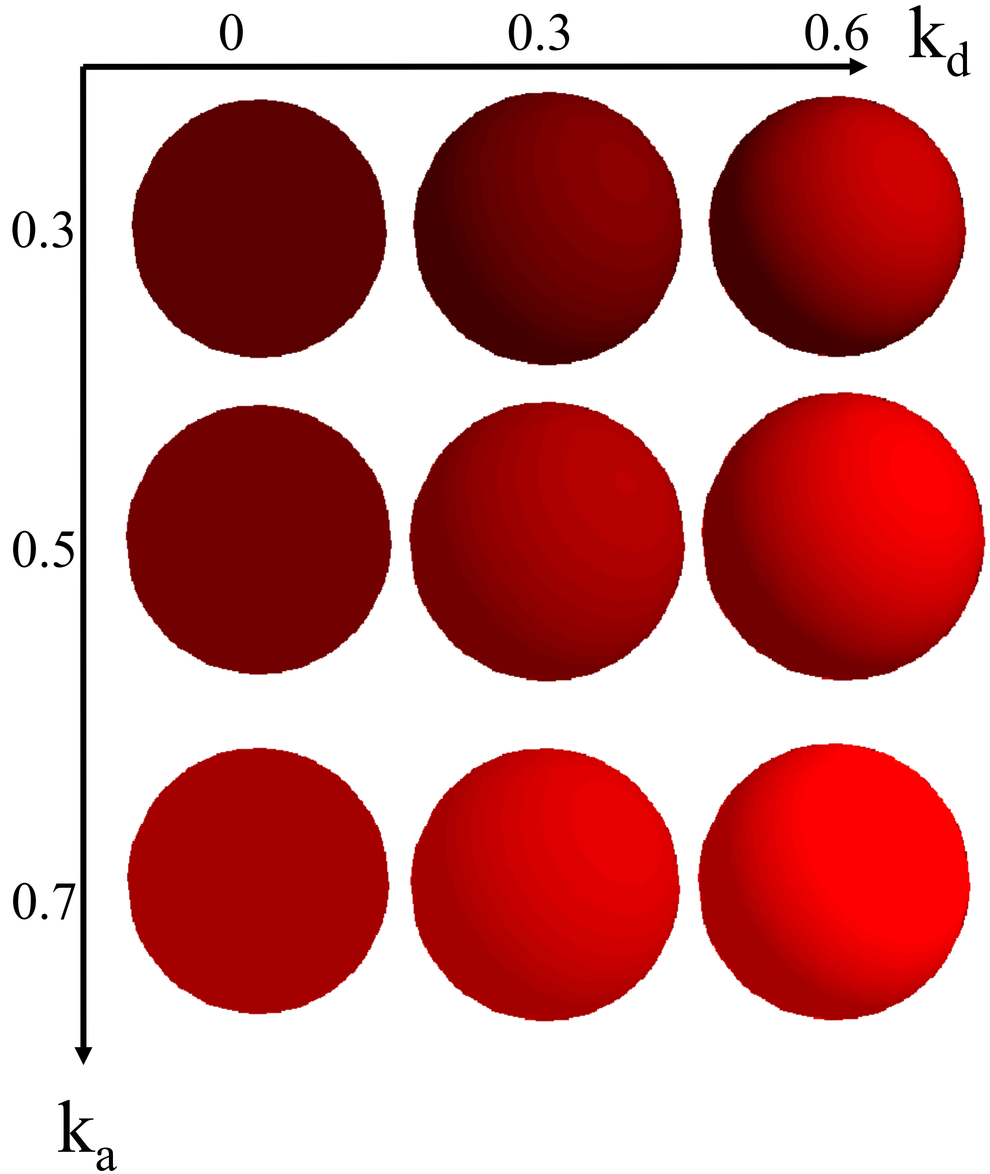
– $I_{diffuse} = k_d\, I_{light} \cos\theta = k_d\, I_{light}\, (N \bullet L)$
  - k_d diffuse reflectivity of the surface
  - I_{light} intensity of light
  - N surface normal at the point
  - L normalized vector to the light





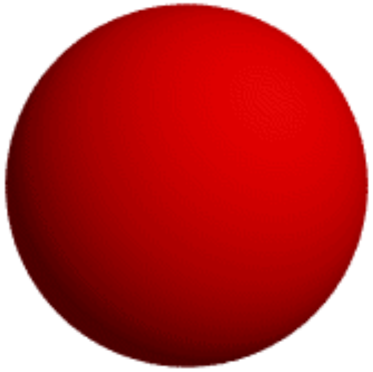
– Independent of where the camera is located
– Dependent on the direction to light
– Dependent on the surface normal at the point on the surface

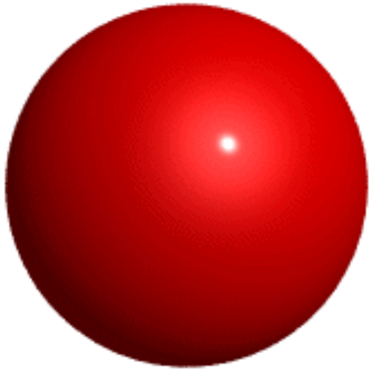
Ambient and Diffuse terms



Specular

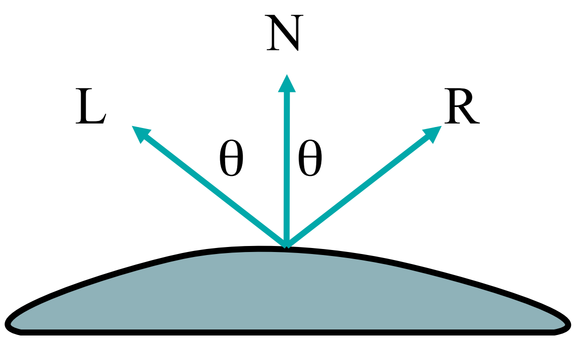
– Model the effect of polished shiny surfaces
– The bright spot is called specular highlight


Diffuse Lighting

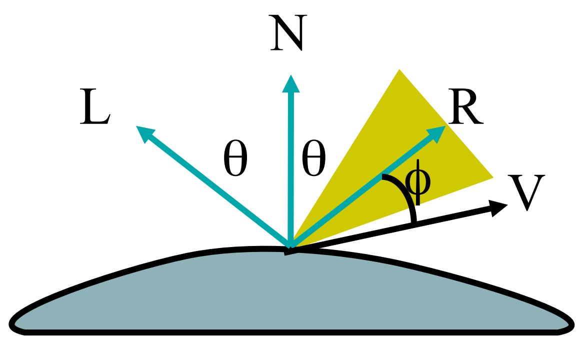

Plus Specular Highlight

– Ideal specular surface (mirror) reflects all the light coming in from L only in one direction, R

– Non-ideal specular surface (most everything else) reflects light coming in from L mostly toward R but distributed over an angle



Ideal specular surface

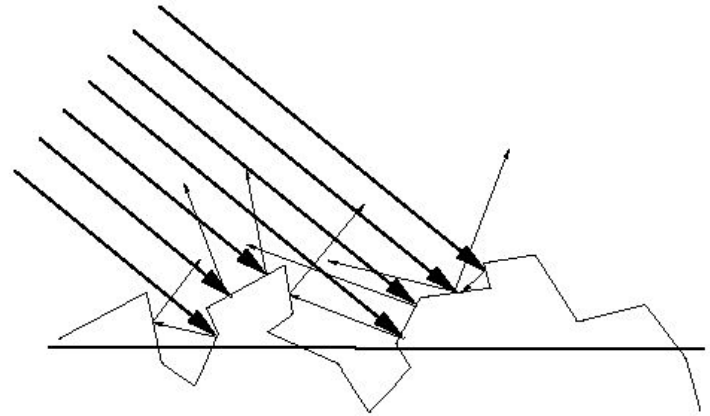


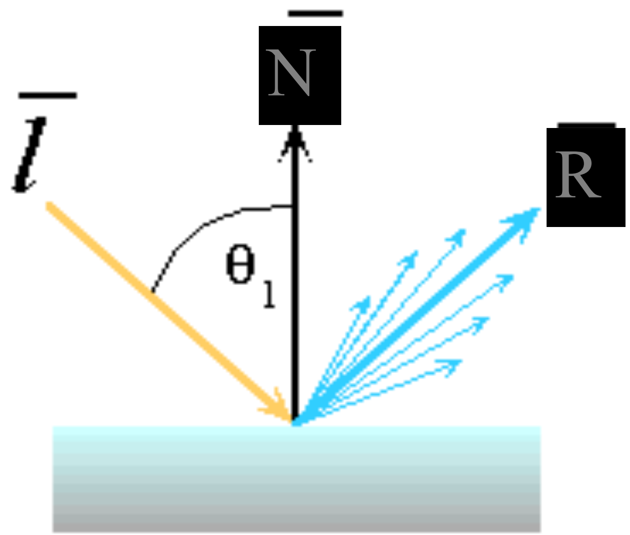
non-ideal specular surface

– Think of rough surface composed of tiny mirrors

– Normals randomly distributed but many have their normal close to N

– Distribution of normals give the falloff of specular peak from R direction



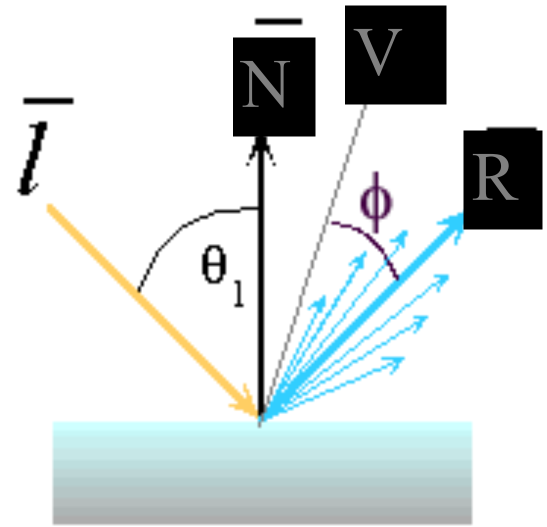


Phong illumination model

– An empirical model that uses the cosine with a shininess power as the shape of the falloff from the ideal reflection direction

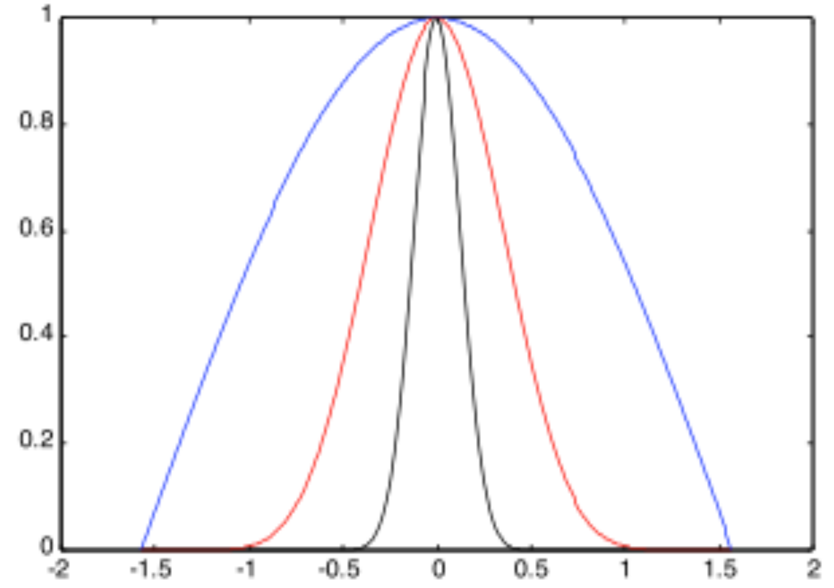
$$I_{specular} = k_s I_{light} (\cos \Phi)^n = k_s I_{light} (V \bullet R)^n$$

- R is the ideal direction
- V is the direction to the camera
- N is the surface normal
- L is the direction to the light



– Plot of $(\cos\phi)^n$ as a function of ϕ as n varies (n=1, 8, 64)

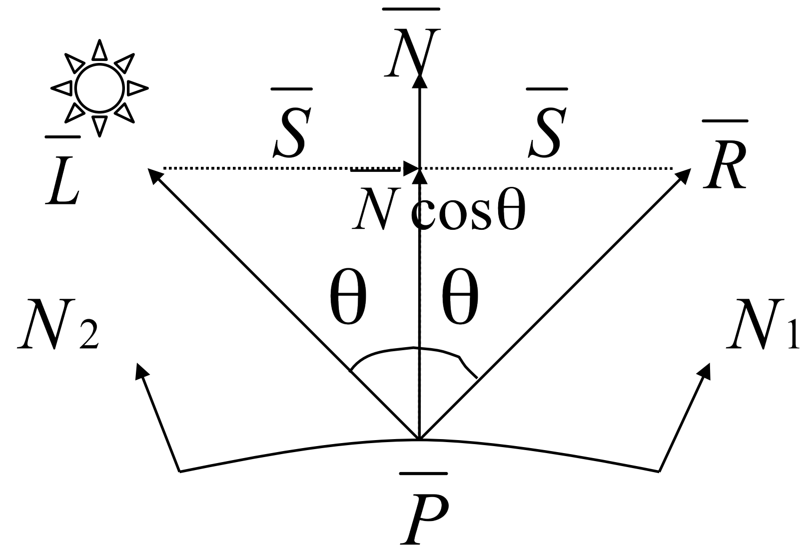
– This means as n gets large the function has a sharp peak near $\phi = 0$



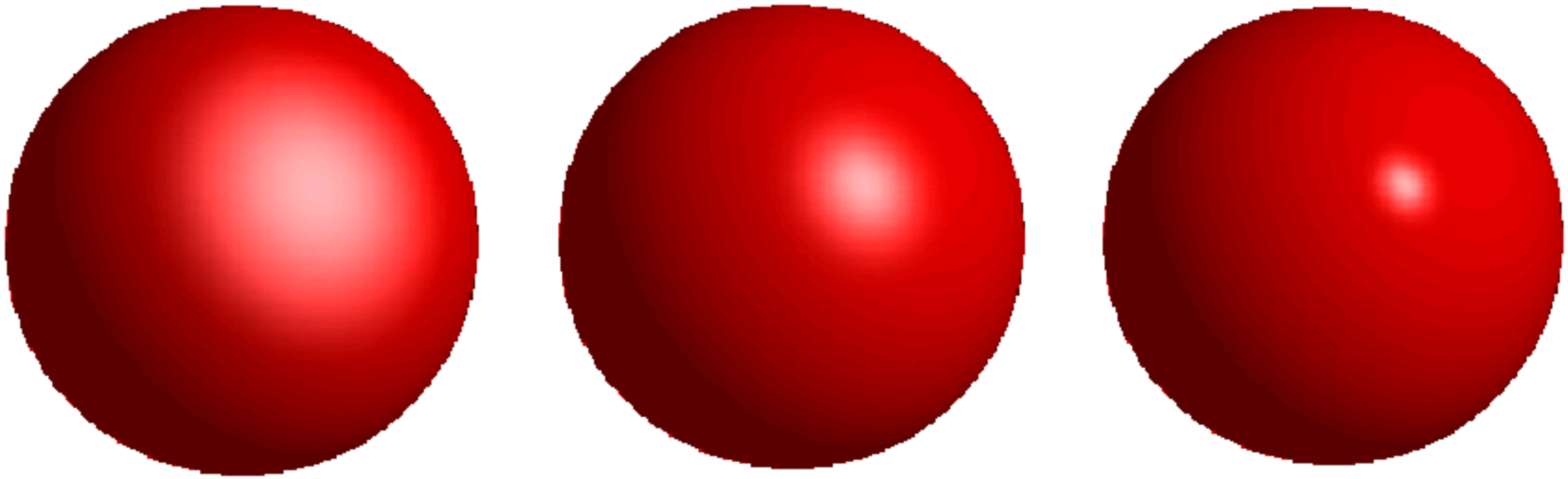
$$\overline{R} = \overline{N}\cos\theta + \overline{S}$$
$$\overline{S} = \overline{N}\cos\theta - \overline{L}$$

$$\therefore \overline{R} = 2\overline{N}\cos\theta - \overline{L}$$

$$= 2\overline{N}(\overline{N}\bullet\overline{L}) - \overline{L}$$



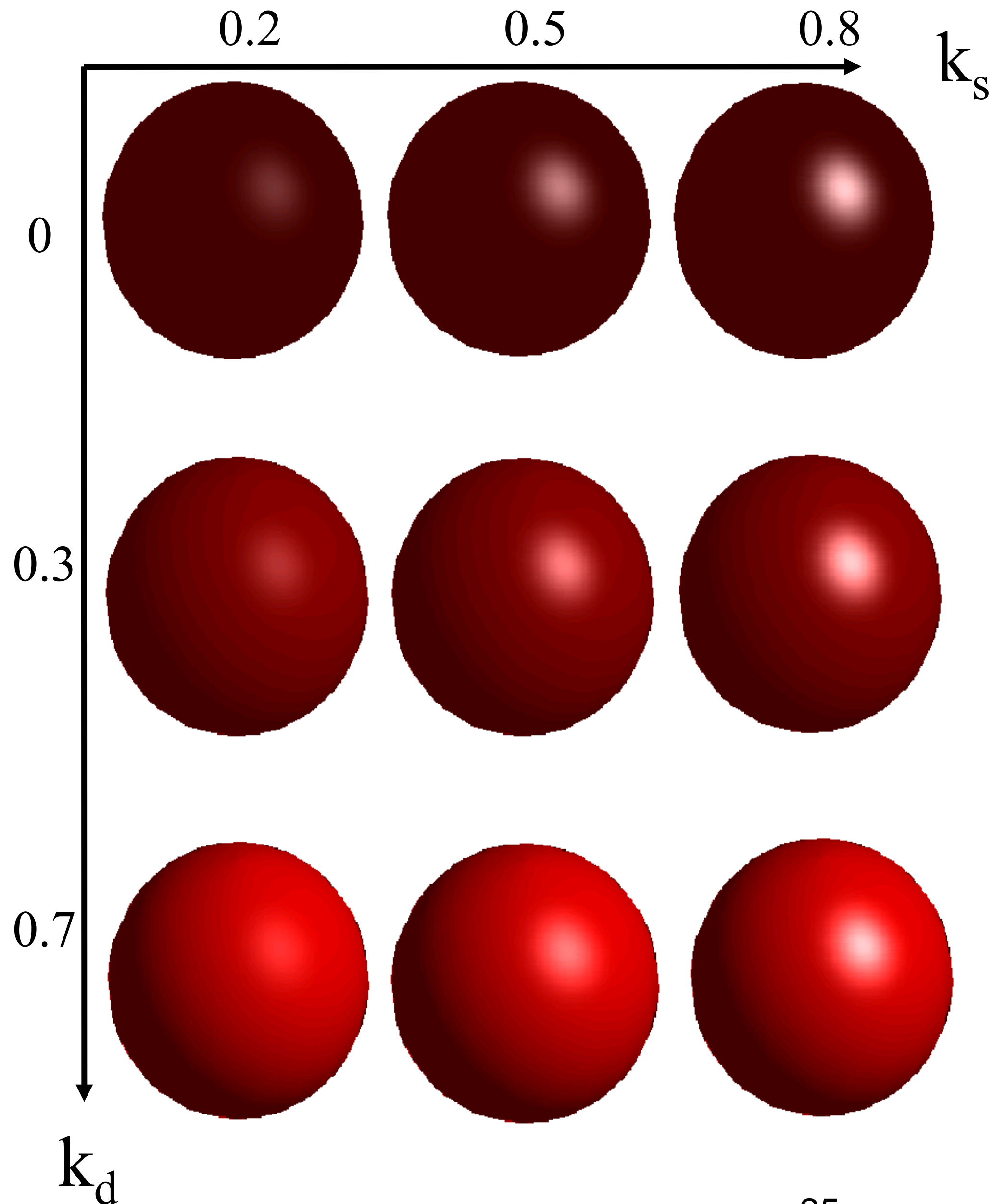
Specular and diffuse for different specular values



N=3 N=10 N=50

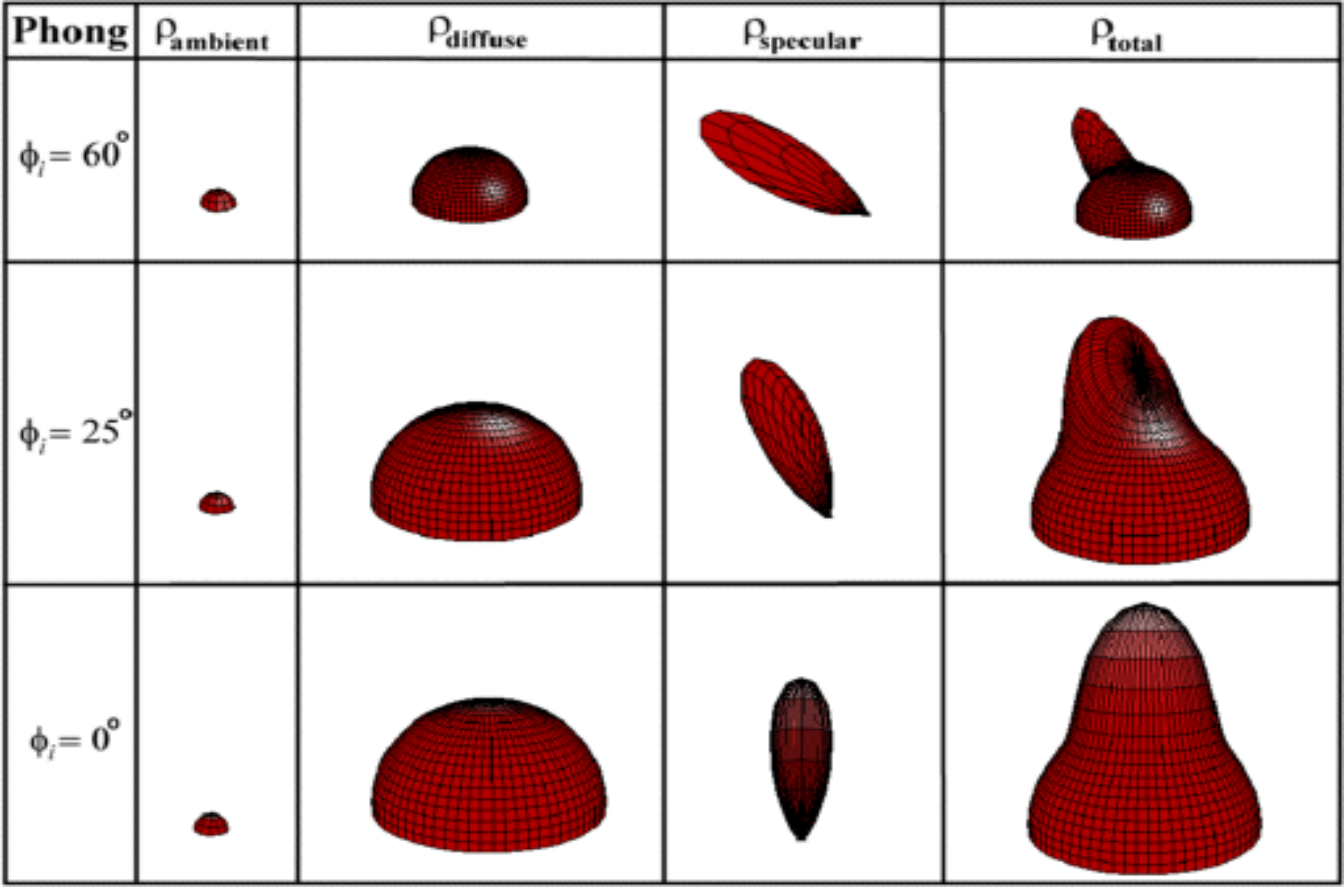
– A good simulation of hard plastic.

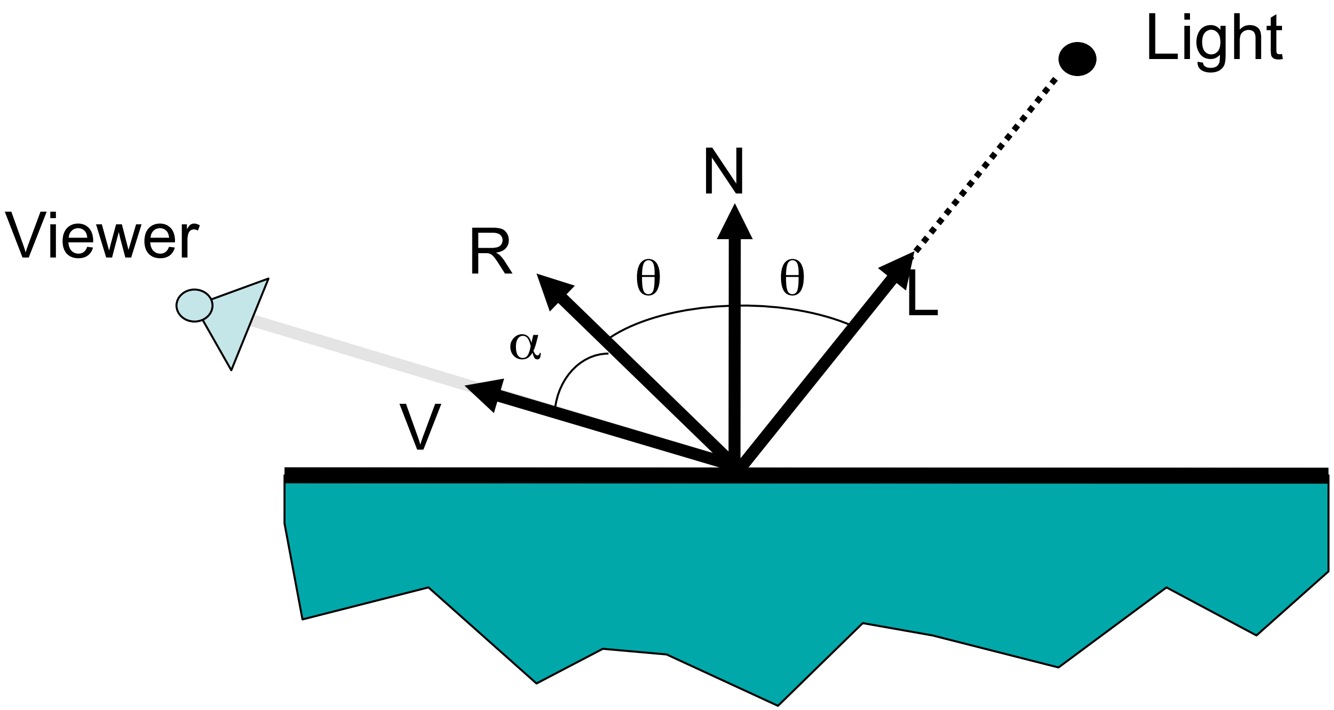
Specular and Diffuse Terms



Combined terms

– ambient + diffuse + specular
– In following slide, distance of surface from origin indicates magnitude of reflected light in that direction given a particular incoming direction Φ_i


Phong
$\rho_{ambient}$
$\rho_{diffuse}$
$\rho_{specular}$
ρ_{total}
$\phi_i = 60^\circ$
$\phi_i = 25^\circ$
$\phi_i = 0^\circ$



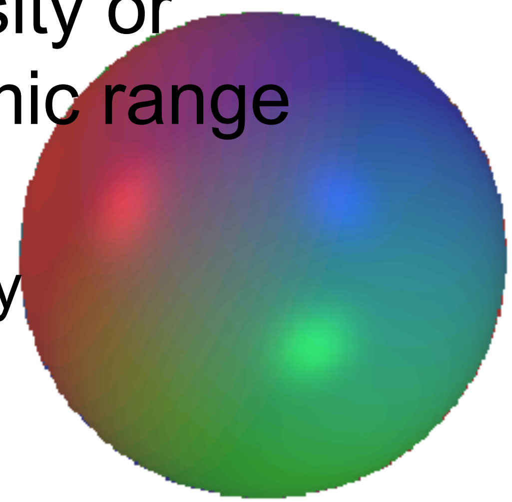
$$I = I_E + K_a I_{ambient} + K_d (N \bullet L) I_{Light} + K_S (V \bullet R)^n I_{Light}$$

For multiple light sources

- Sum the contribution of all light for diffuse and specular

$$\boxed{I = I_E + K_a I_{ambient} + \sum_i (K_d (N \bullet L) I_i + K_S (V \bullet R)^n I_i)}$$

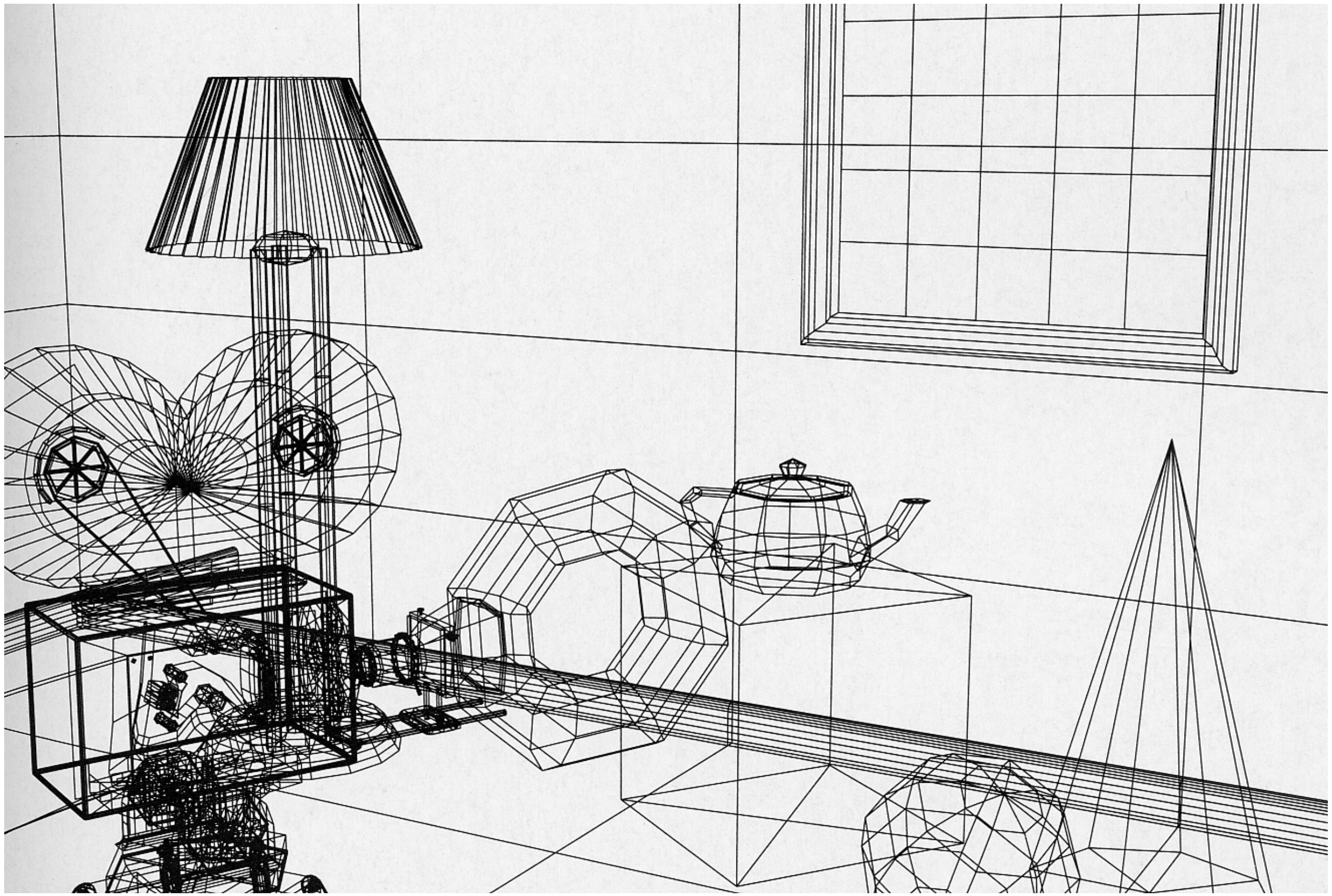
- Make sure to either clamp the intensity or to re-scale the intensity to the dynamic range of the display
  - If there are many light sources, intensity can be large



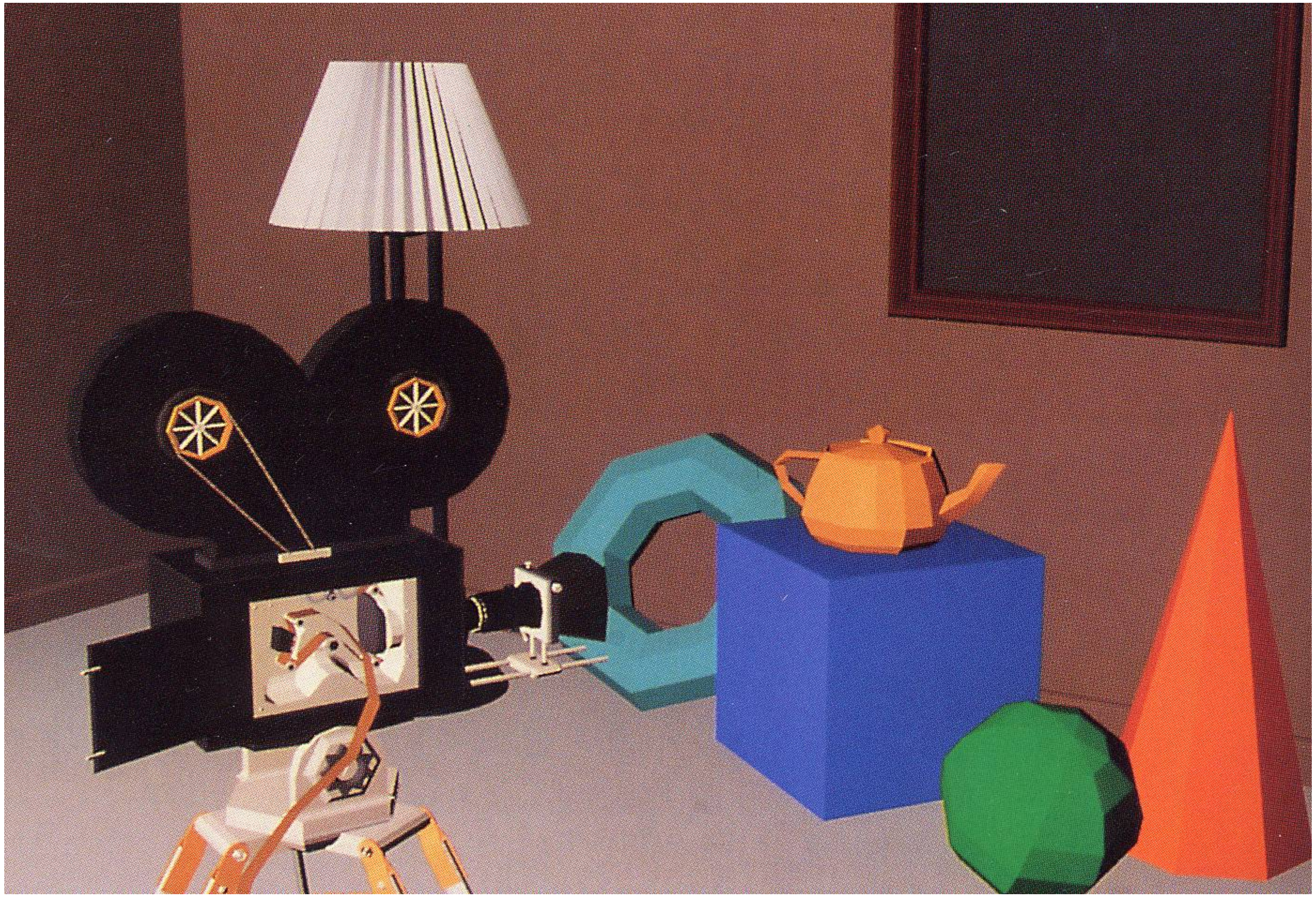
Surface Rendering (Shading)

- Determination of pixel values corresponding to points on the surfaces
- Difference between Shading and Illumination model
  - Illumination model tells you how to calculate light intensity
  - Shading model tells you when to invoke the illumination model
- Invoking illumination model at each pixel expensive
- Three methods: each treats a single polygon independent of all others
  - Constant
  - Gouraud (intensity interpolation)
  - Phong (normal -vector interpolation)

Wireframe (no surface rendering)



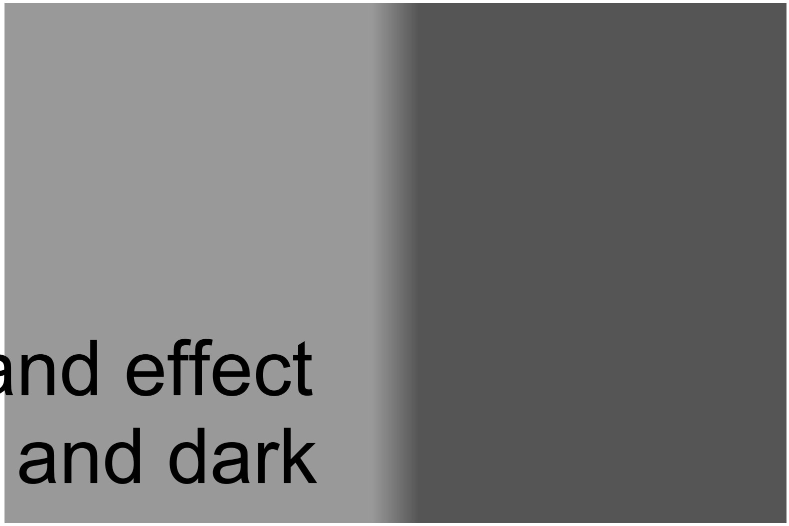
Constant Shading



Constant Shading

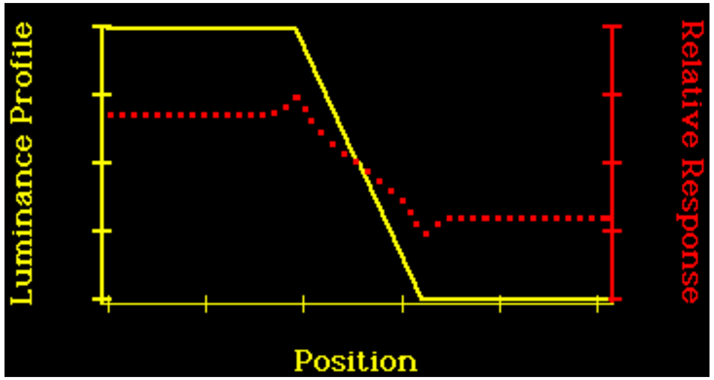
- Single intensity value per polygon
- Gives reasonable results only if
  - Object is a polyhedron: if the mesh is an approximation to curved surface, faceted look is a problem
  - Light source is far away from the surface (or light rays are parallel) so that N•L is constant over each polygon
  - Viewing position is far away from the surface so that V•R is constant over each polygon

Mach Band



- Facets exaggerated by mach band effect
- Image shows white band on left and dark band on right of the ramp
- Graph shows the actual intensity

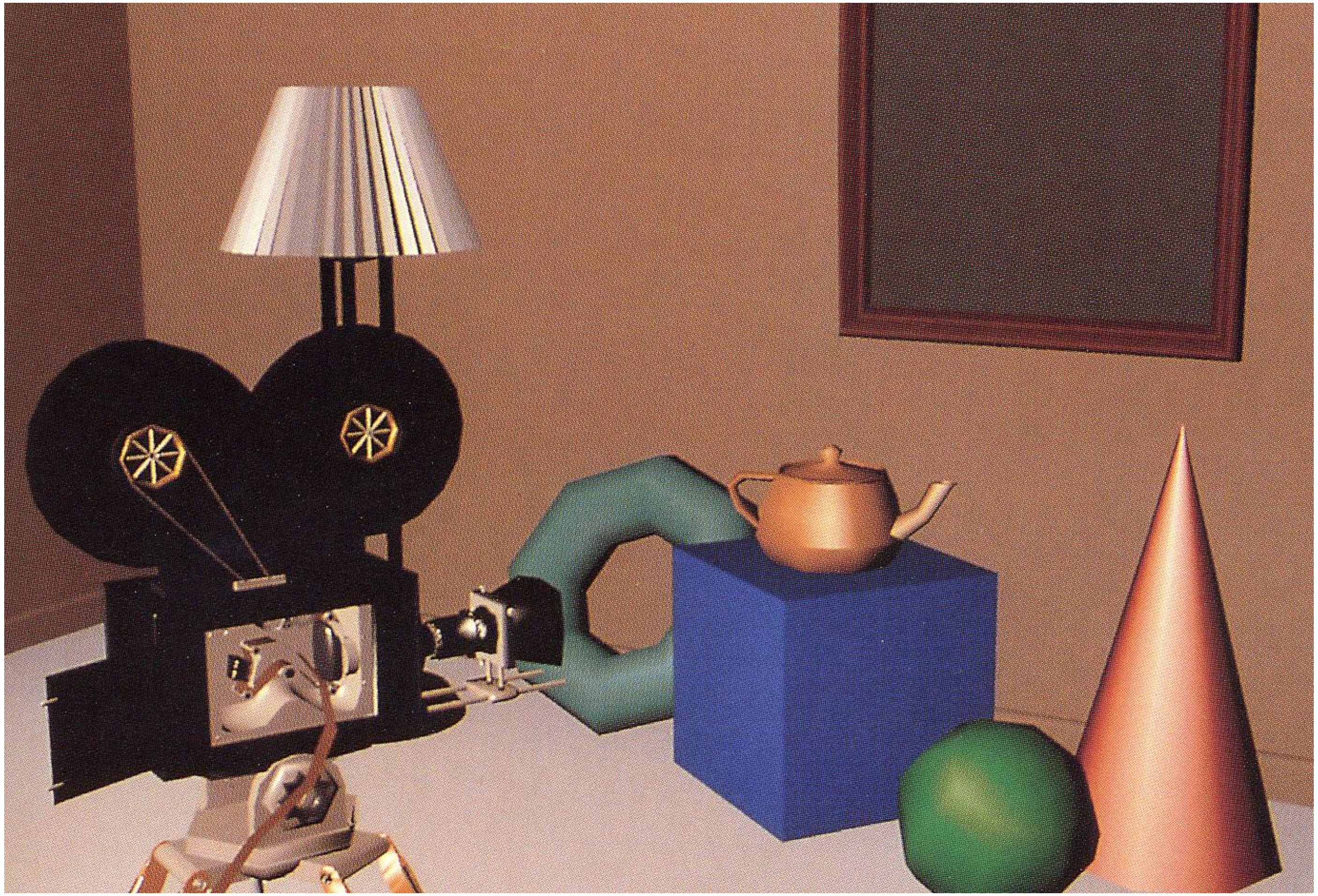
- Actual and perceived intensities



http://www.cquest.utoronto.ca/psych/psy280f/ch3/mb/mb.html

– Constant shading accentuate the facets due to Mach banding

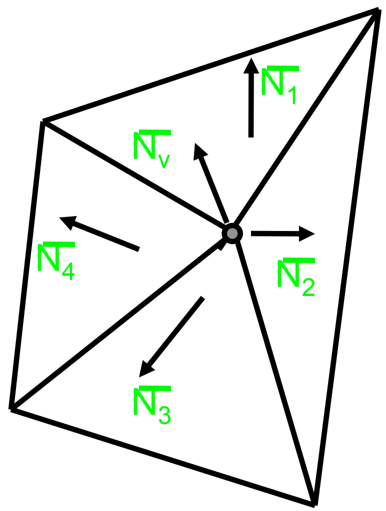
Gouraud Shading



Gouraud Shading

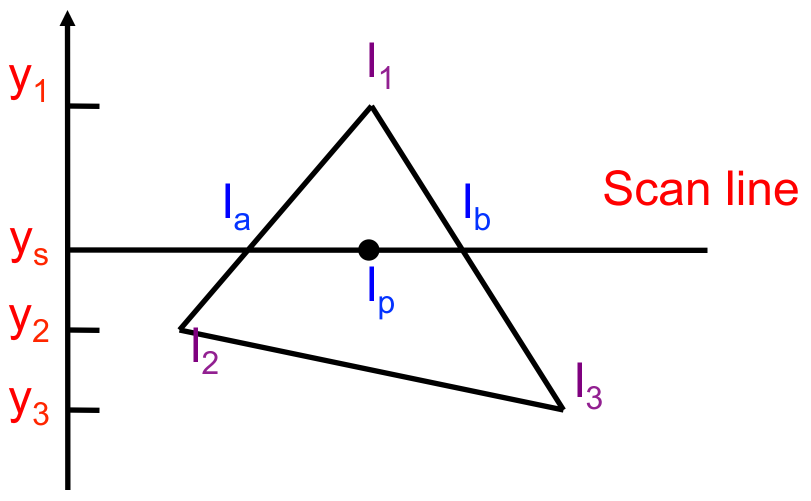
- Used for polygon approximations to curved surfaces
- Eliminates intensity discontinuities at polygon edges
- Still have gradient discontinuities, so Mach banding is improved, but not eliminated
- 1. Calculate vertex normals as average of surrounding polygons' normals
- 2. Calculate the illumination at the vertices
- 3. Interpolate intensity along polygon edges
- 4. Interpolate intensity along scan lines

– Vertex normal is average of neighboring polygon normals (for smooth objects - not boxes!)



$$N_v = \frac{(N_1 + N_2 + N_3 + N_4)}{\|(N_1 + N_2 + N_3 + N_4)\|}$$

– Only compute intensities at polygon vertices
– Linearly interpolate intensities at the vertices to get intensities inside the polygon
– Could use coherence to do the interpolation by an addition of the slope instead of the formula given

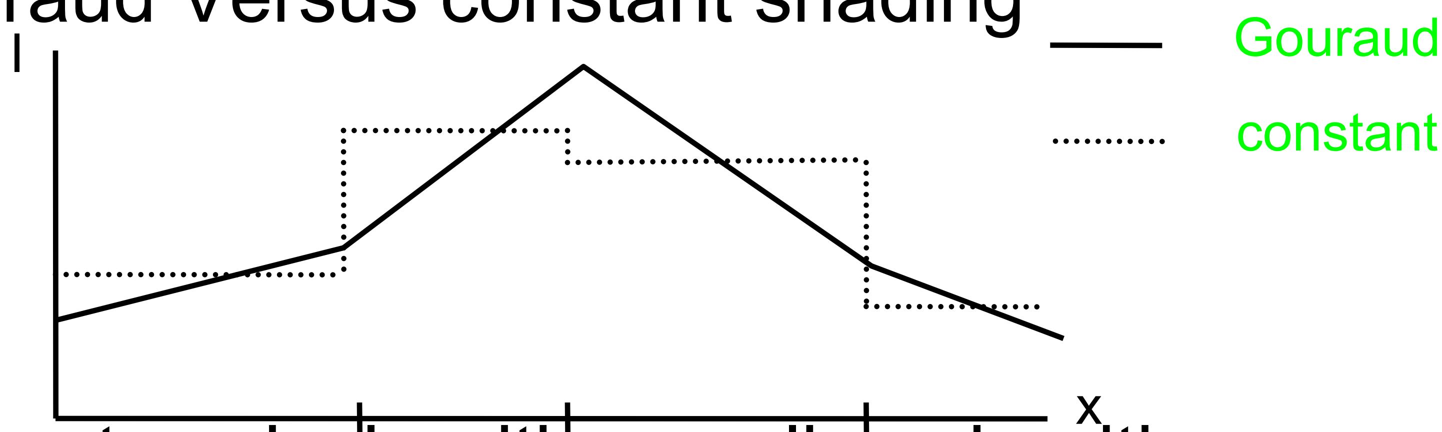


$$I_a = \frac{I_1(y_s - y_2) + I_2(y_1 - y_s)}{y_1 - y_2}$$

$$I_b = \frac{I_1(y_s - y_3) + I_3(y_1 - y_s)}{y_1 - y_3}$$

$$I_p = \frac{I_a(x_b - x_p) + I_b(x_p - x_a)}{x_b - x_a}$$

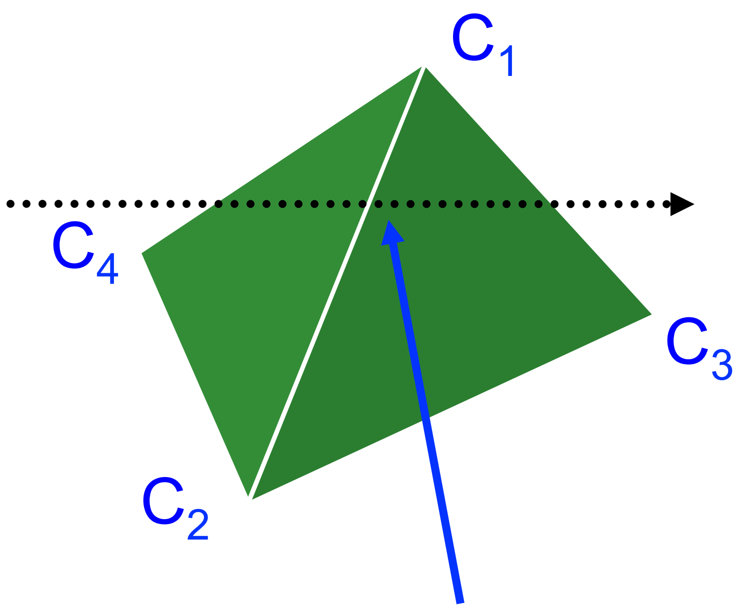
– Gouraud Versus constant shading

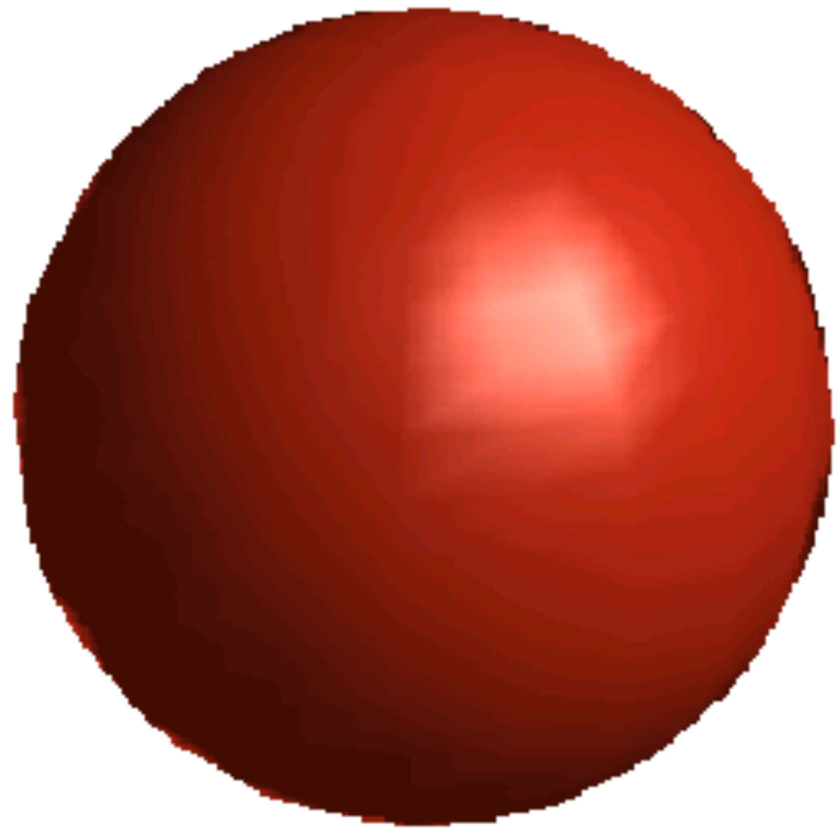


– Integrates nicely with scan line algorithm :

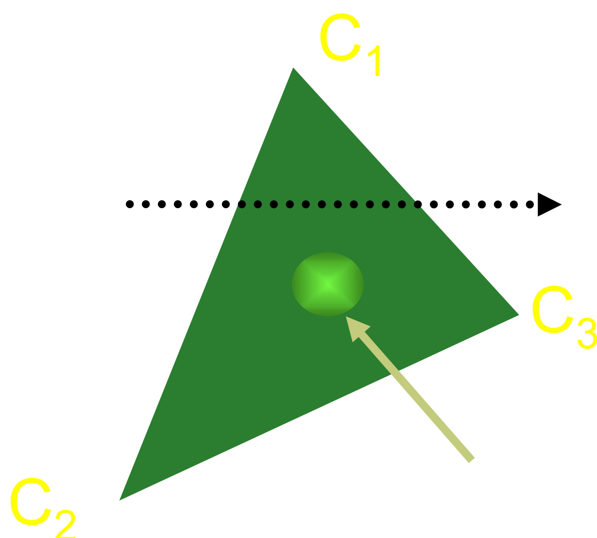
- $\frac{\Delta I}{\Delta Y}$ is constant along polygon edge

– Notice the Mach banding effects on the highlight

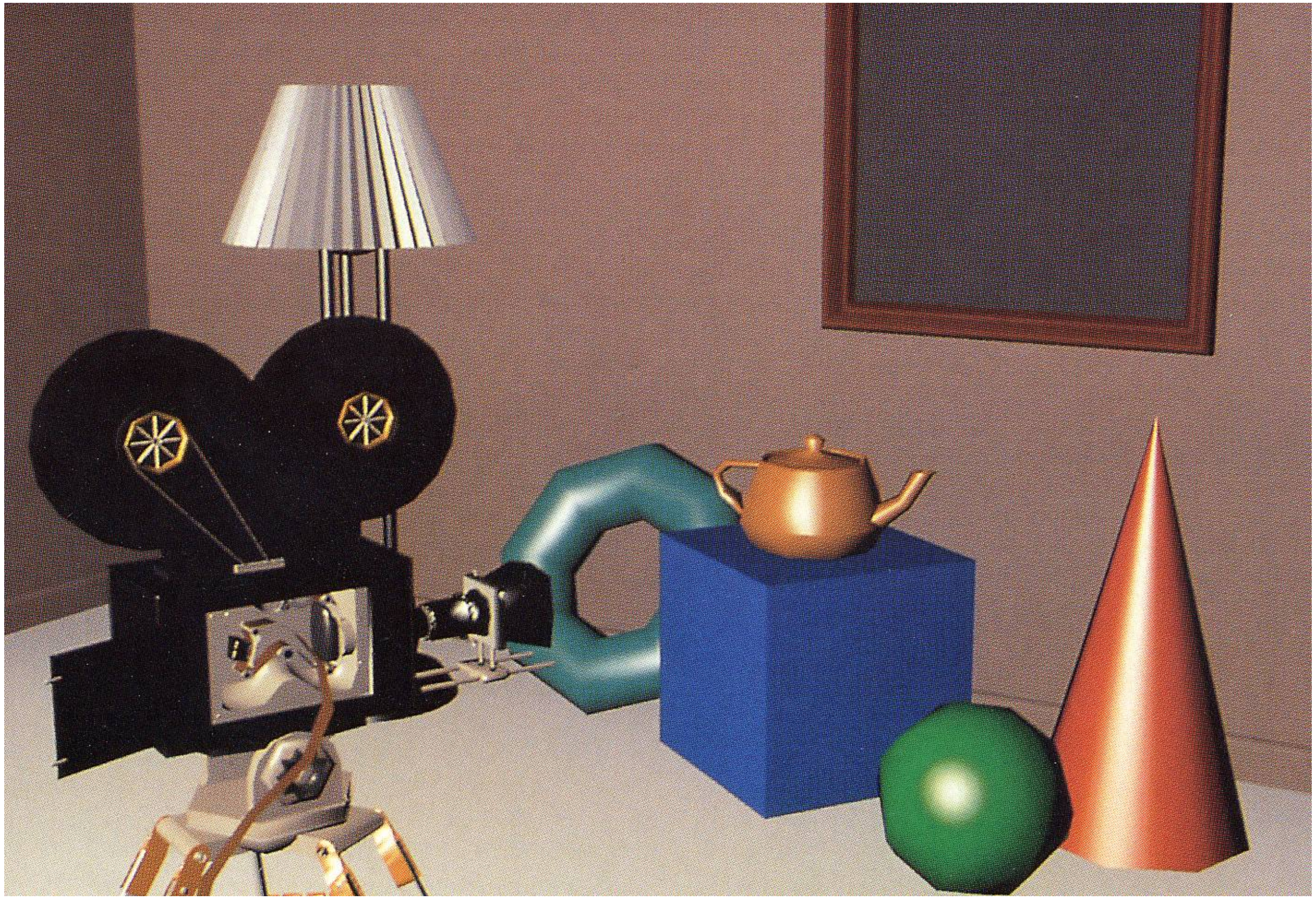




– Highlights that fall inside the polygon (and not on the vertices) are missed



Phong Shading

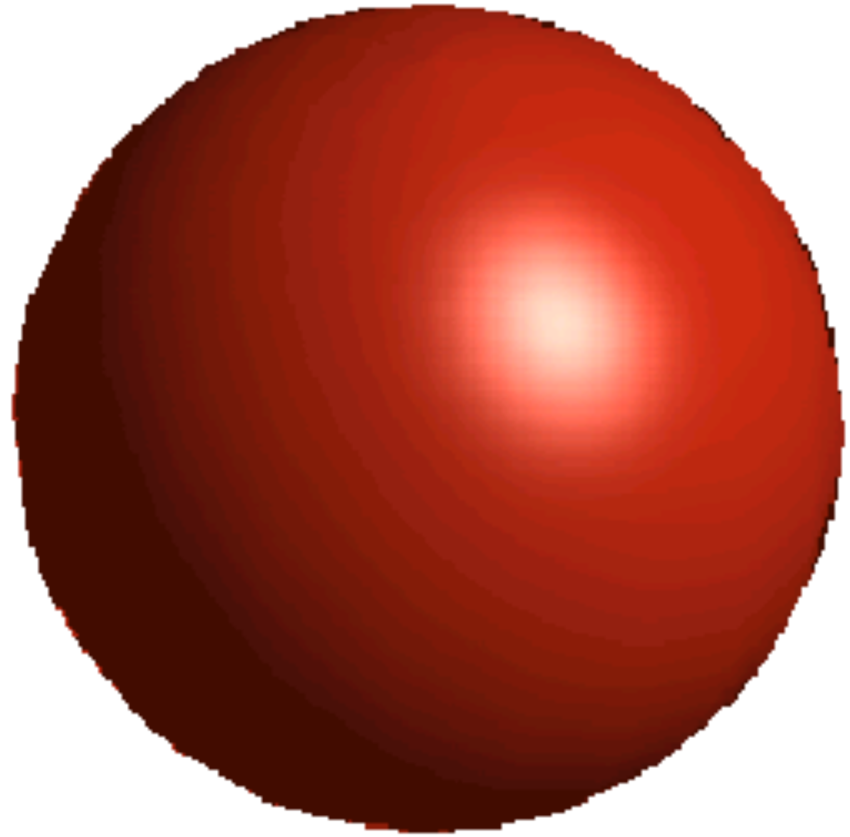


Phong Shading

- –Interpolate N rather than I
- –Especially important with specular reflection
  - •Since specular highlight may fall within a polygon
- –Computationally expensive at each pixel to
  - •Re-normalize N (expensive square root)
  - •Re-compute I (intensity) at each pixel position

- –1. Calculate vertex normals as average of surrounding polygons' normals
- –2. Interpolate normals along polygon edges
- –3. Interpolate normals along scan lines
- –4. Calculate the illumination at each pixel

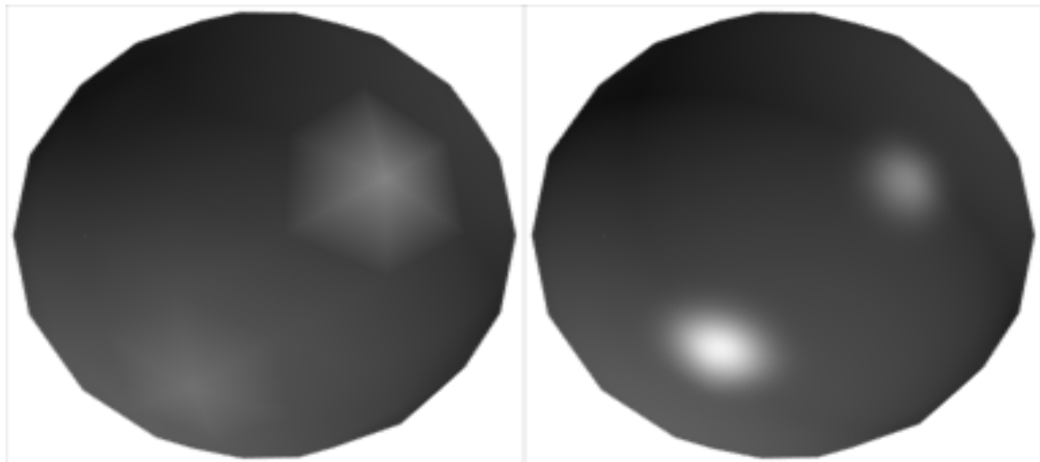
- Interior appears to be smooth surface
- Silhouette still faceted unless use large number of polygons
- Notice the color quantization error and the resulting Mach banding



Phong illumination vs Phong shading

- Phong illumination is the use of the cosine to the nth power to approximate semi-glossy surface
- Phong shading is the interpolation of normals before applying illumination equation

Compare Gouraud with Phong



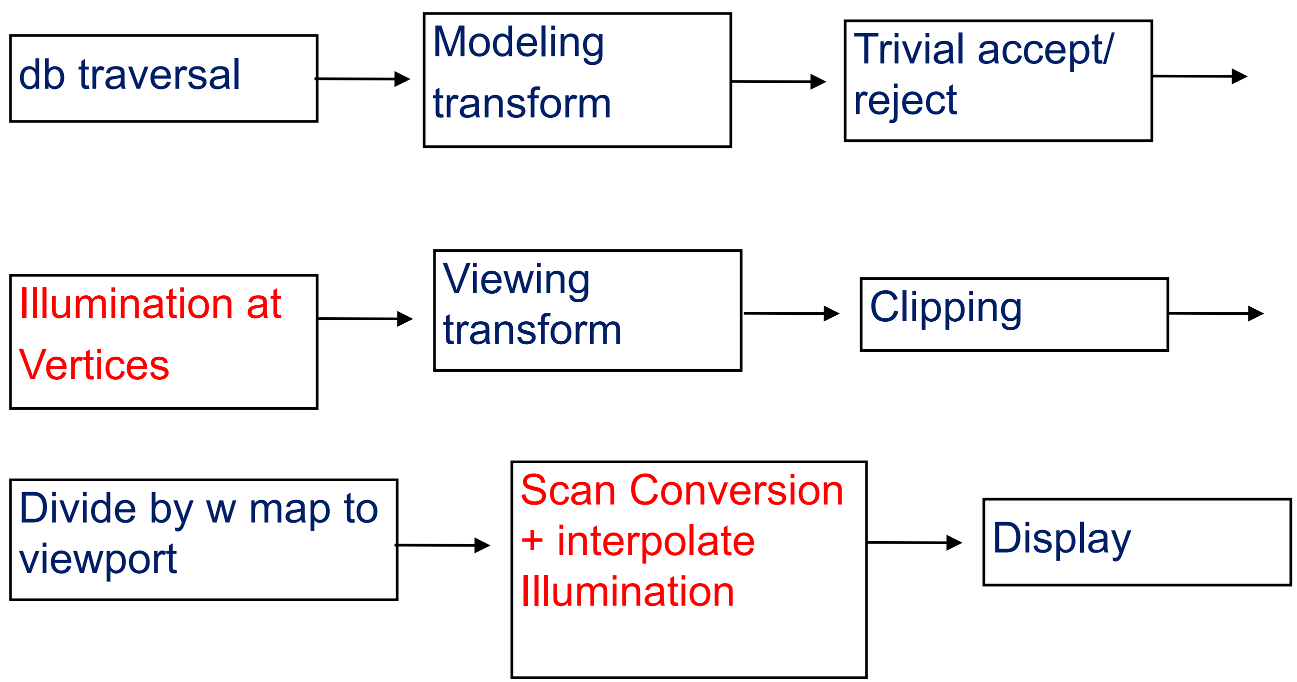
Gouraud Phong

Where is it done?

– Calculation of N, L, V and illumination calculation done in the world coordinate system before perspective transformation
  - Perspective transformation will distort the space
– Interpolation done after perspective transformation during scan conversion
  - Take advantage of scanline and pixel coherence
  - Approach similar to the use of coherence in scan conversion
– What about Phong shading?
  - Need to wait until scan conversion to do the illumination model since we don't know what the normal for a pixel is until then
  - But do the calculation in the world coordinate system

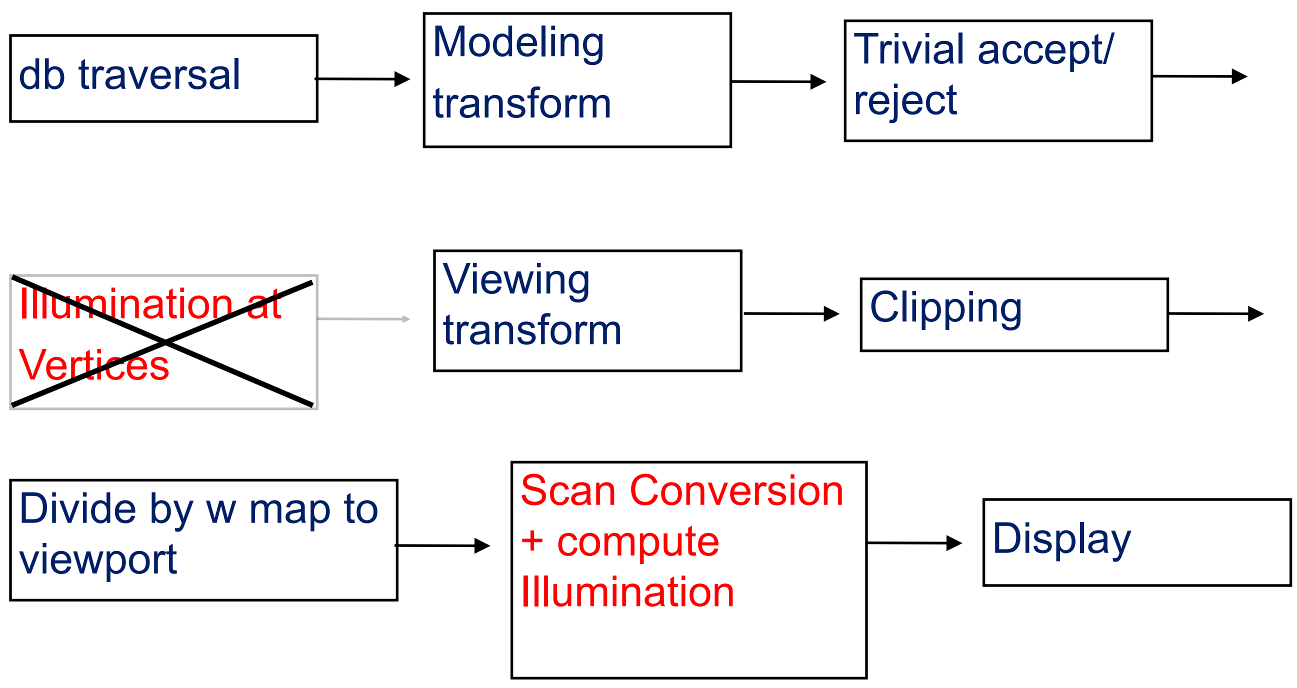
Gouraud shading

– Illumination done at vertices



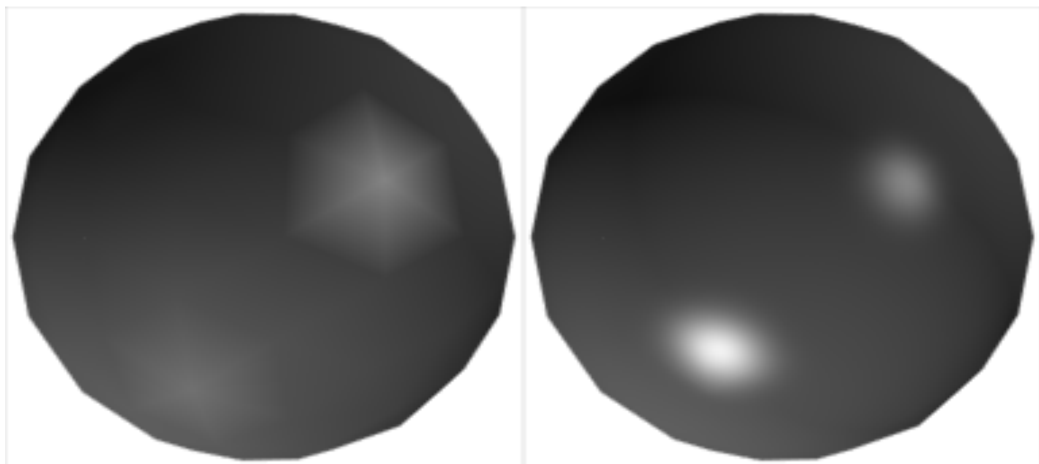
Phong shading

– Illumination calculation done during scan conversion - normally far more pixels than vertices



Problems at the Silhouette

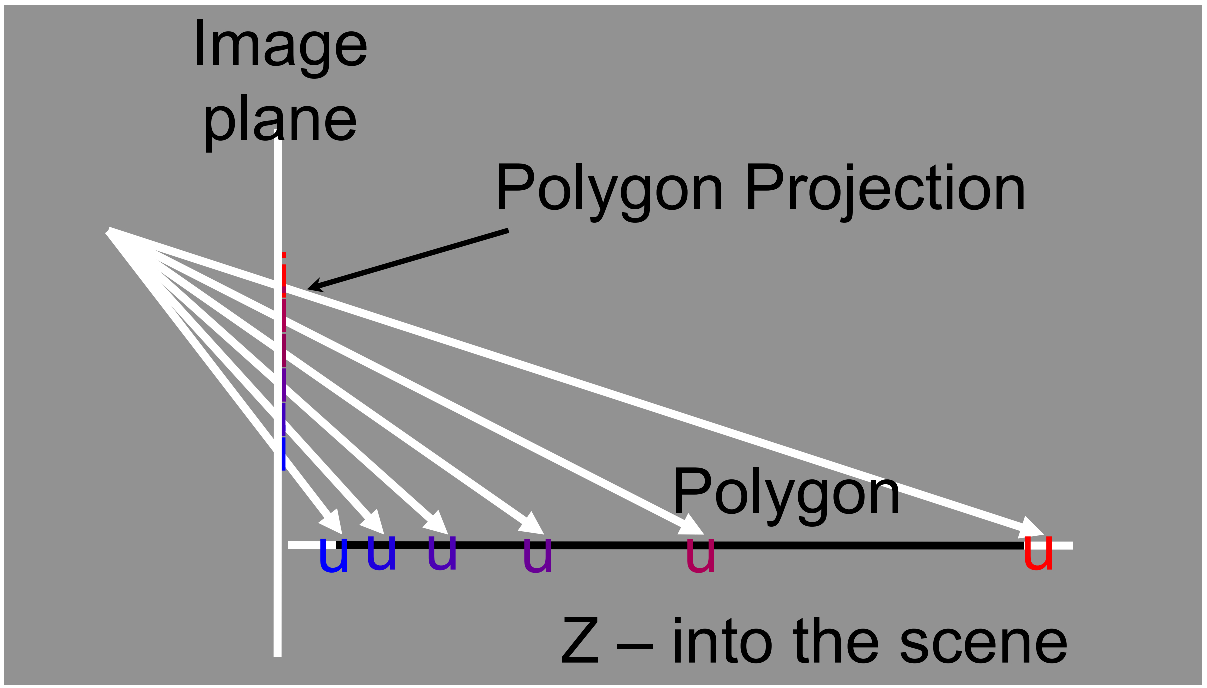
– improved by increasing polygons



Gouraud Phong

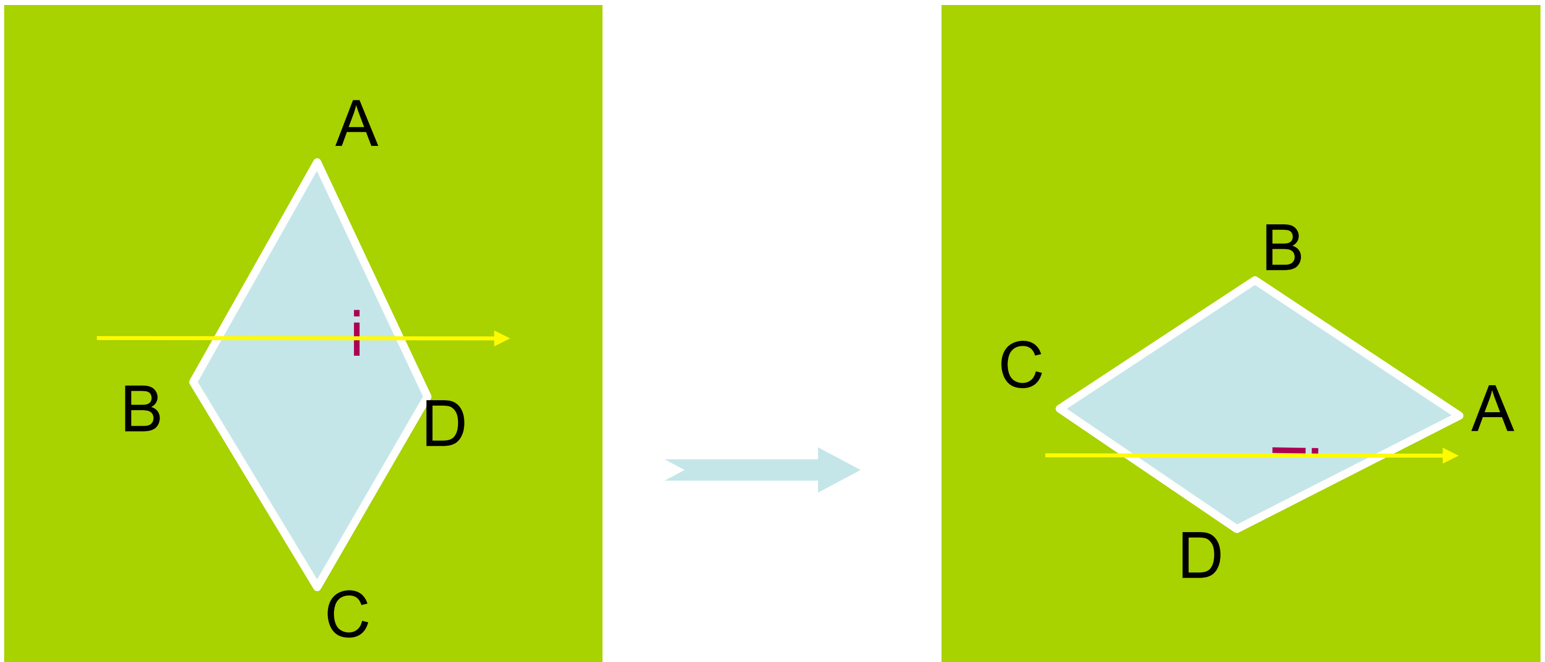
Perspective distortion

– linear interpolation across scan line (in image space) is not linear interpolation in object space



Orientation dependence

– What is interpolated changes as object is rotated

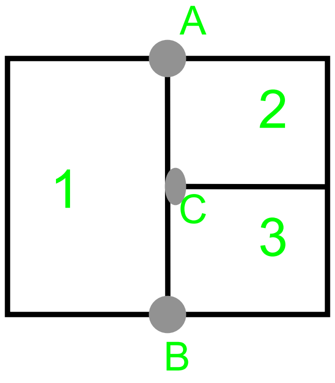


Interpolate between AB and AD

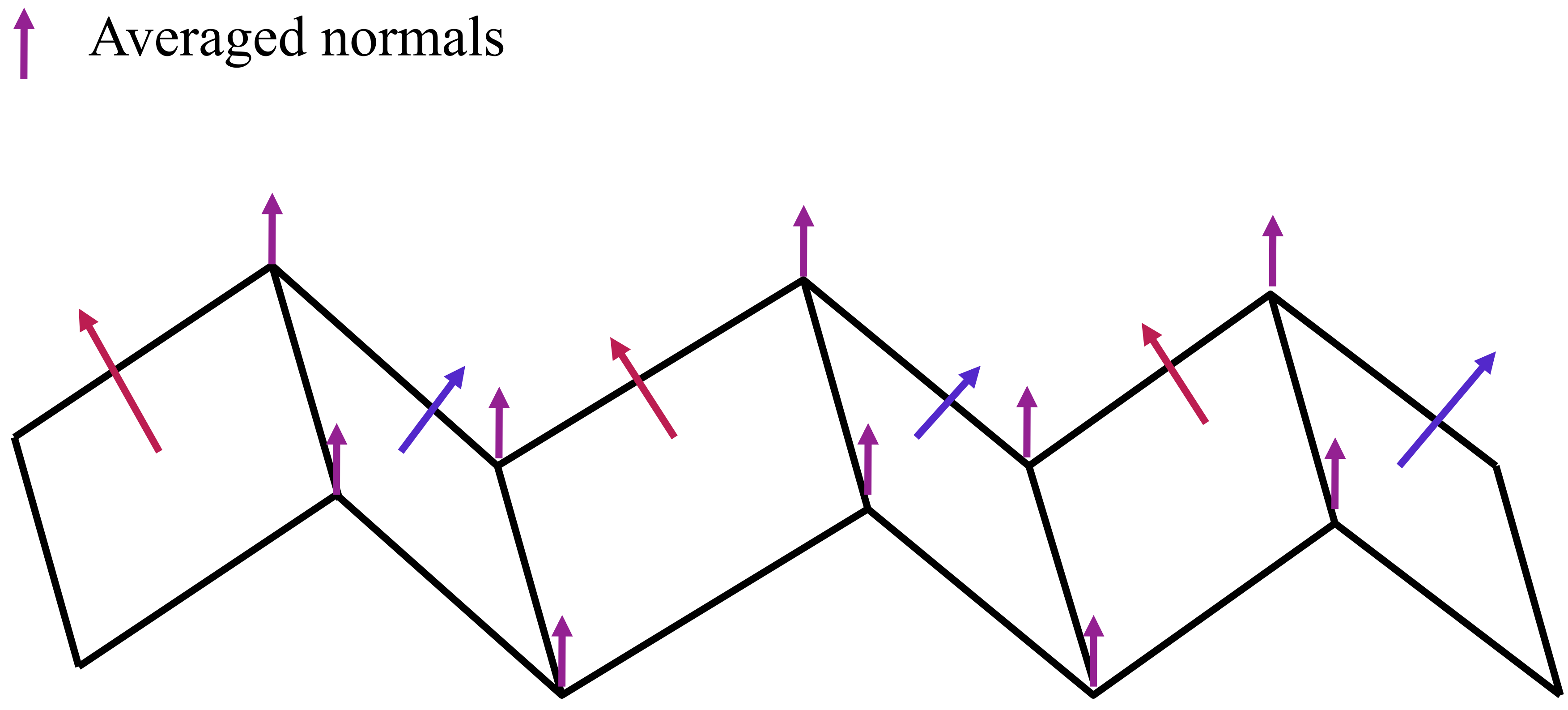
Interpolate between CD and AD

Discontinuities due to non-shared vertices

– Near vertex C
  - On polygon 1, interpolated from A and B
  - On polygon 2 and 3, from vertex C



Error due to averaging normals



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Global Illumination