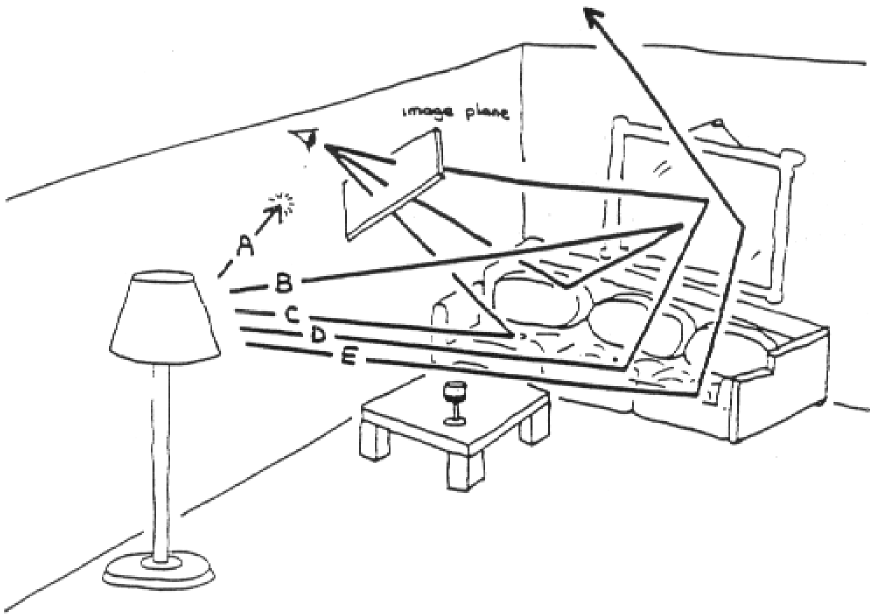
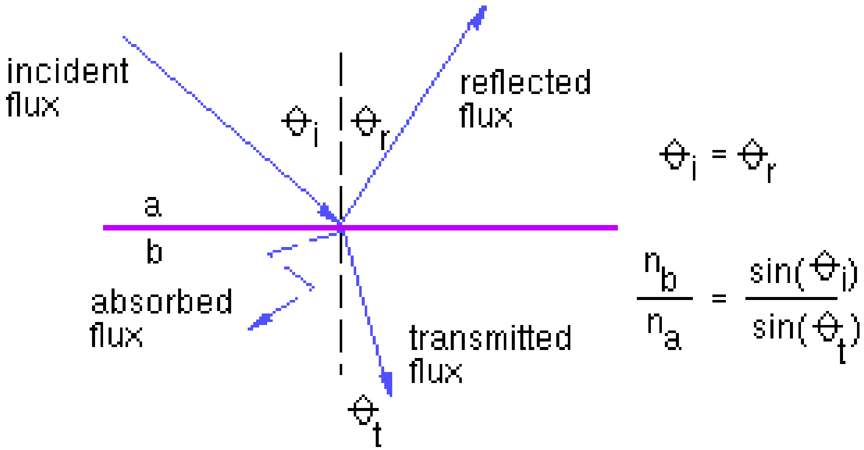
Illumination and Shading

Concepts

- Illumination - the transport of luminous flux from light sources between points via direct and indirect paths
- Lighting - the process of computing the luminous intensity reflected from a specified 3-D point
- Shading - the process of assigning a colors to a pixels





Illumination models

- Empirical : simple formulations that approximate observed phenomenon
- Physically-based : models based on the actual physics of light's interactions with matter
- Local illumination model / Global illumination model:

  - Local model deals with a single surface.

  - Global model is more general and more physically correct.

Illumination components

- Light sources:

  - Emittance Spectrum (colour)

  - Geometry (position and direction)

  - Directional Attenuation
- Surface properties:

  - Reflectance Spectrum (colour) for different aspects of illumination

  - Geometry (position, orientation, and micro-structure)

  - Absorption
- View angle

Illumination in CG

- Simplifications:

  - Only the direct illumination from the emitters to the reflectors of the scene

  - Ignore the geometry of light emitters, and consider only the geometry of reflectors

  - Most of the light from a scene results from a single bounce of a emitted ray off of a reflective surface

- Forgotten things:

  - Polarisation

  - Index of refraction of material (variation function of wavelength)

  - Diffraction

  - Surface evolution

Ambient light source

Ambient light source : no spatial or directional characteristics

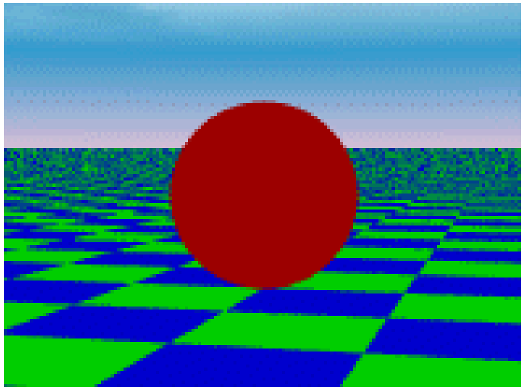
- The amount of ambient light incident on each object is a constant for all surfaces in the scene.
- An ambient light can have a color.
- The amount of ambient light that is reflected by an object is independent of the object's position or orientation.
- Surface properties are used to determine how much ambient light is reflected

Intensity: $I_{reflected} = k_{ambient} I_{ambient}$

$$k_{ambient} \approx k_{diffuse}$$

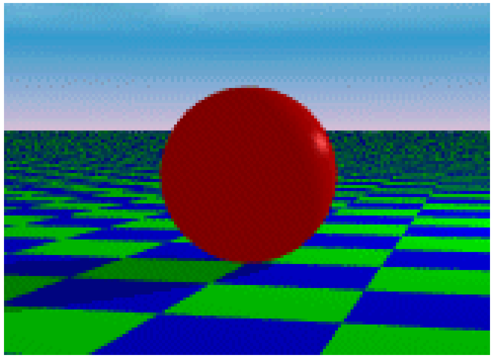
Directional light source

- All of the rays from a directional light source have the same direction, and no point of origin.
- It is as if the light source was infinitely far away from the surface that it is illuminating.
- Sunlight is an example of an infinte light source.



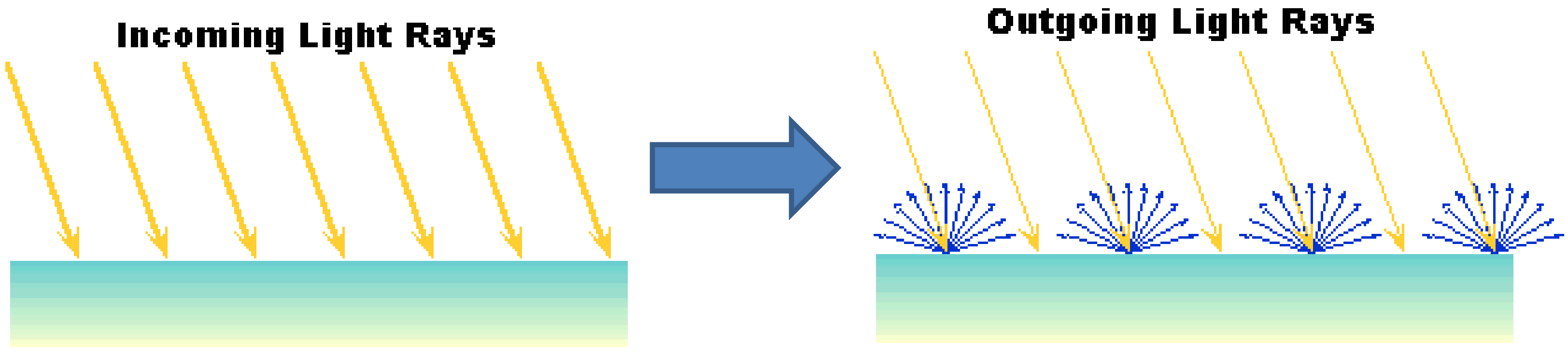
Point light source

- The rays emitted from a point light radially diverge from the source.
- A point light source is a fair approximation to a local light source such as a light bulb.
- The direction of the light to each point on a surface changes when a point light source is used.
  ⇒ A normalized vector to the light emitter must be computed for each point that is illuminated.



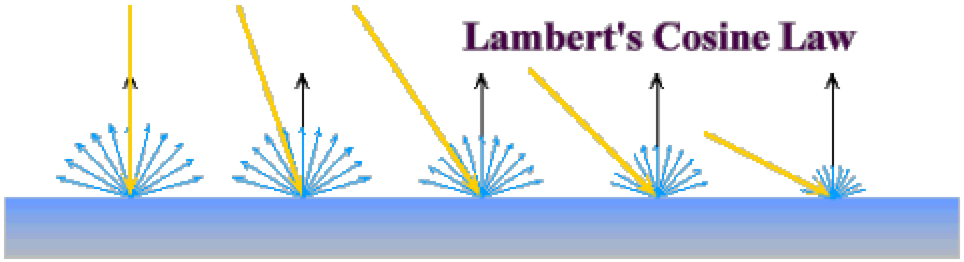
Ideal diffuse reflection

- An incoming ray of light is equally likely to be reflected in any direction over the hemisphere.



Lambertian reflector

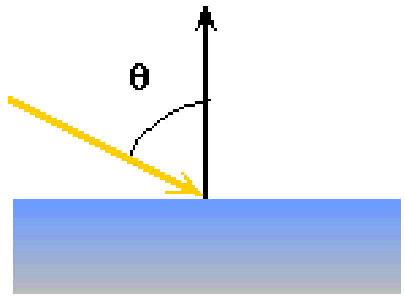
- Ideal diffuse reflector = Lambertian reflector
- Lambert's Cosine Law : reflected energy from a small surface area in a particular direction is proportional to the cosine of the angle between that direction and the surface normal.



Reflected intensity is independent of the viewing direction, but dependent of the source orientation.

Diffuse reflection calculation

$$I_{diffuse} = k_d I_{light} \cos\theta$$



- The I_{light} denotes the intensity of the incoming light; and k_d represents the diffuse *reflectivity of the surface*.
- In practice, *normal vector* and the incoming *light vector* are normalized (unit length) then diffuse shading can be computed as follows

$$I_{diffuse} = k_d I_{light} \left(\bar{n} \cdot \bar{l}\right)$$

The angle will always change from 0 to 90 degree.

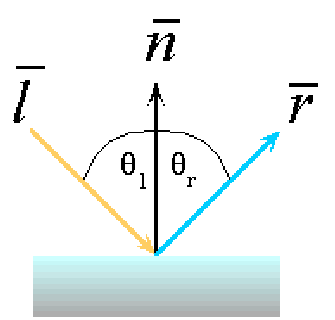
Specular reflection

- Specular reflector: At very smooth surface, we see a highlight or bright spot.
- Ideal mirror: A purely specular reflector.
- The Snell/ Descartes's law

  - The incoming ray and the reflected ray all lie in a common plane.

  - The relation between angles is set by the rule:

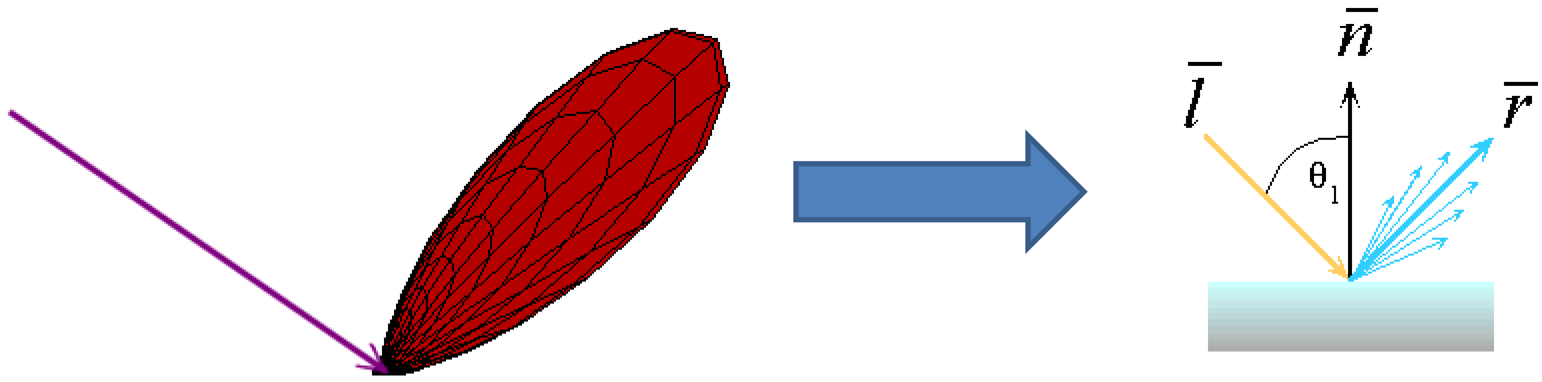
$$n_l \sin\theta_l = n_r \sin\theta_r$$



$n_{glass} = 1.52$
$n_{water} = 1.33$
$n_{air} = 1.000292$ at S.T.P.

Non-Ideal specular reflection

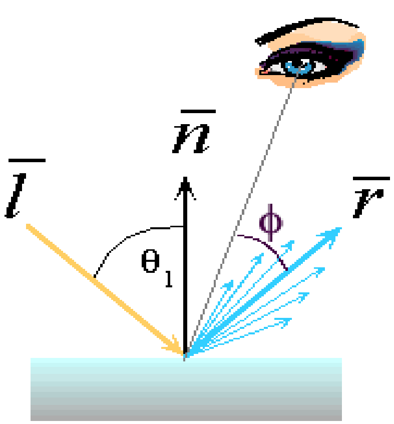
- Microscopic surface variations.
- The reflected ray trends to be less light when we move farther from the ideal ray.



Phong illumination model:

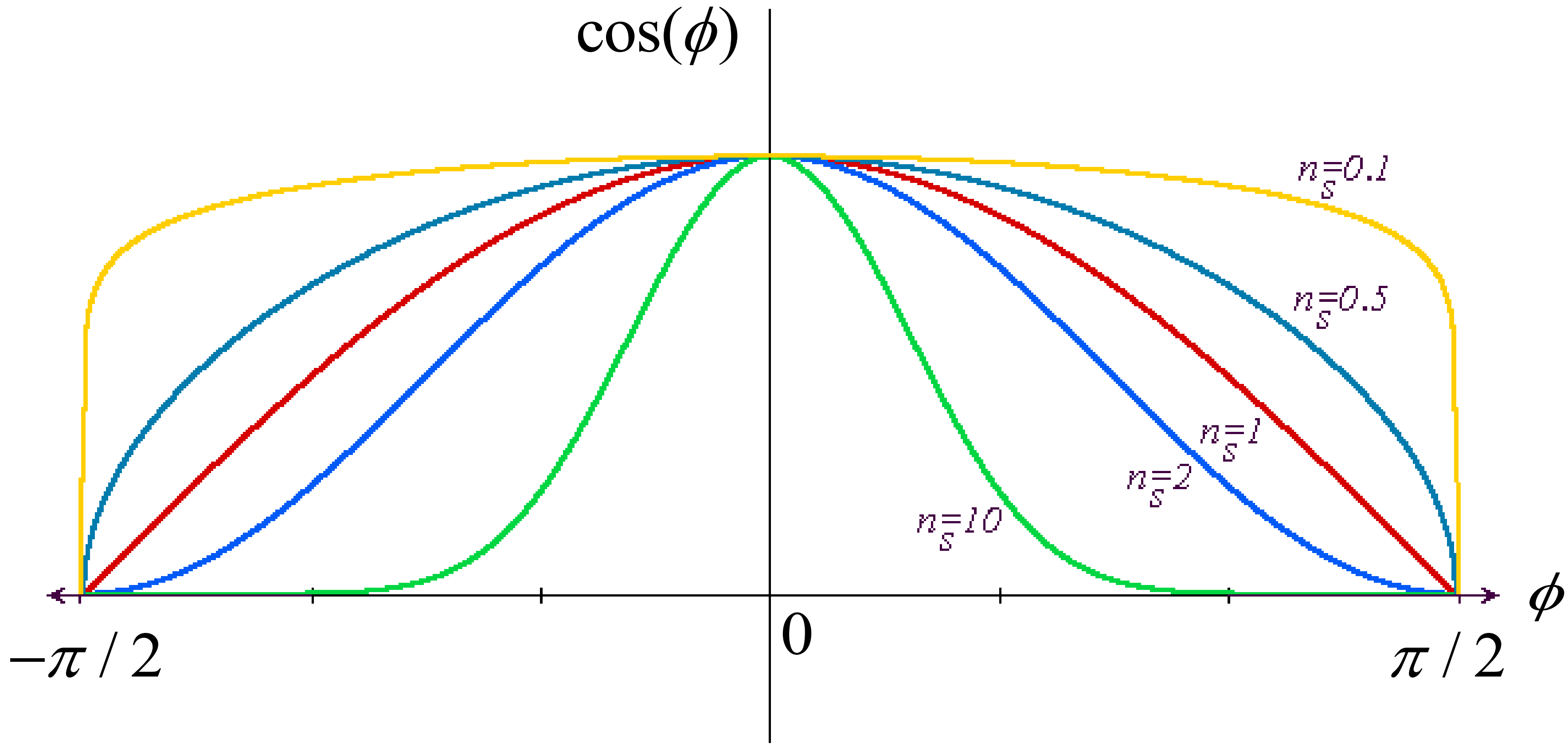
- It is the specular reflection part.
- Use one function to approximate this effect.
- Interesting point: it is not based on any physical model, but returns very successful effect.

$$I_{specular} = I_{light} (\cos\phi)^{n_{shiney}}$$



$$0 \le \phi < 90$$

Phong illumination model

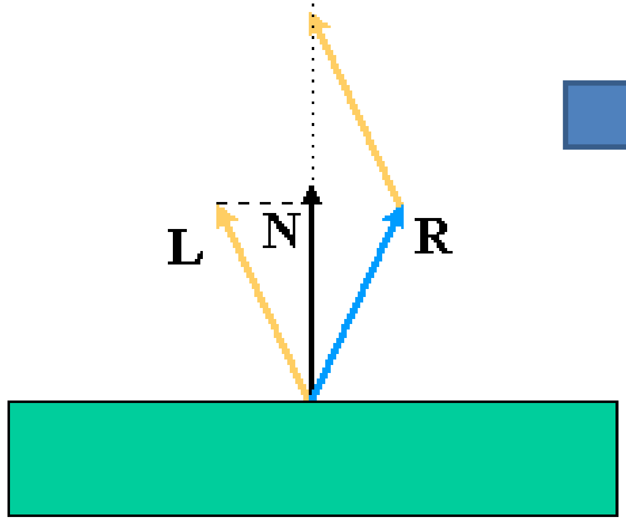


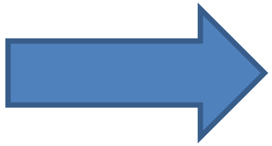
Phong illumination model

$$I_{specular} = k_s I_{light}\left(\hat{V} \cdot \hat{R}\right)^{n_{shiny}}$$

- V : Viewer unit vector
- R : mirror reflectance unit vector

$$\hat{R} + \hat{L} = \left(2\left(\hat{N} \cdot \hat{L}\right)\right)\hat{N}$$

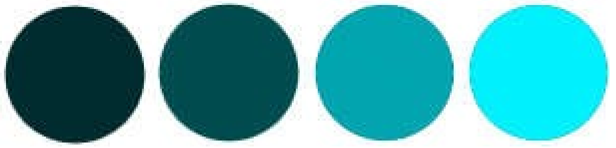




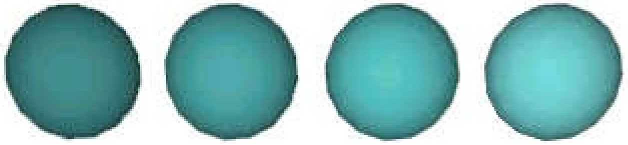
$$\hat{R} = \left(2\left(\hat{N} \cdot \hat{L}\right)\right)\hat{N} - \hat{L}$$

Examples

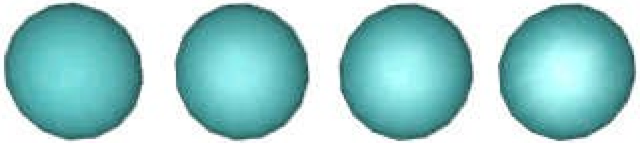
- Ambient reflection



- Diffuse reflection



- Specular reflection



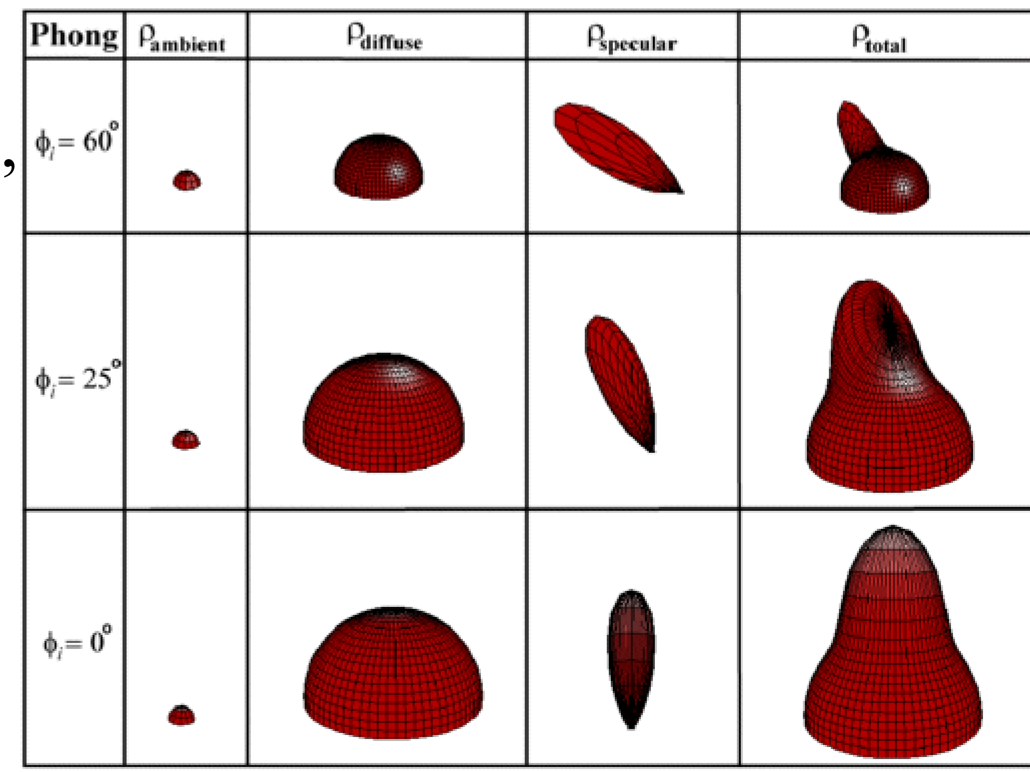
Phong lighting model

- It is a local illumination model

$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{lights} I_i \left(k_d \left(\hat{N} \cdot \hat{L} \right) + k_s \left(\hat{V} \cdot \hat{R} \right)^{n_{shiney}} \right)$$

I_i : lighting color;

k_a, k_d, k_s : ambient, difuse, and specular parameters;



Shading

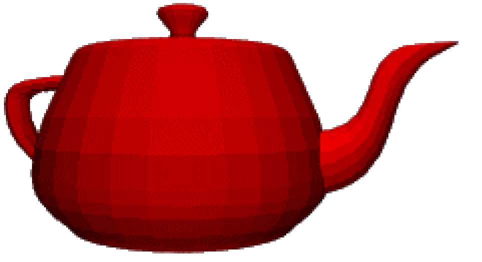
For models defined by collections of polygonal facets or triangles:

- Each facet has a common surface normal
- If the light is directional then the diffuse contribution is constant across the facet
- If the eye is infinitely far away and the light is directional then the specular contribution is constant across the facet

Flat shading

- Computation done at the centroid

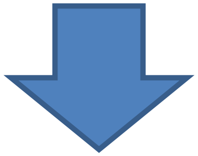
$$centroid = \frac{1}{vertices} \sum_{i=1}^{vertices} \overline{p}_i$$



- Illumination is computed for only a single point (centroid) on the facet and all points of one facet are filled by the same color.
- For point light sources, the direction to the light source varies over the facet
- For specular reflections, the direction to the eye varies over the facet

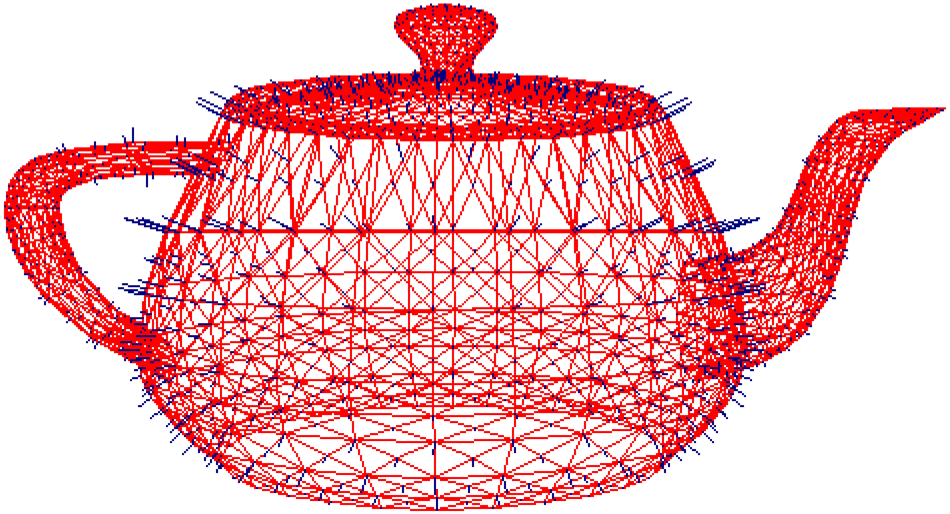
Facet shading

- Discontinuity of normal.
- Just a working hypothesis.



Normal vectors are introduced at each vertex.

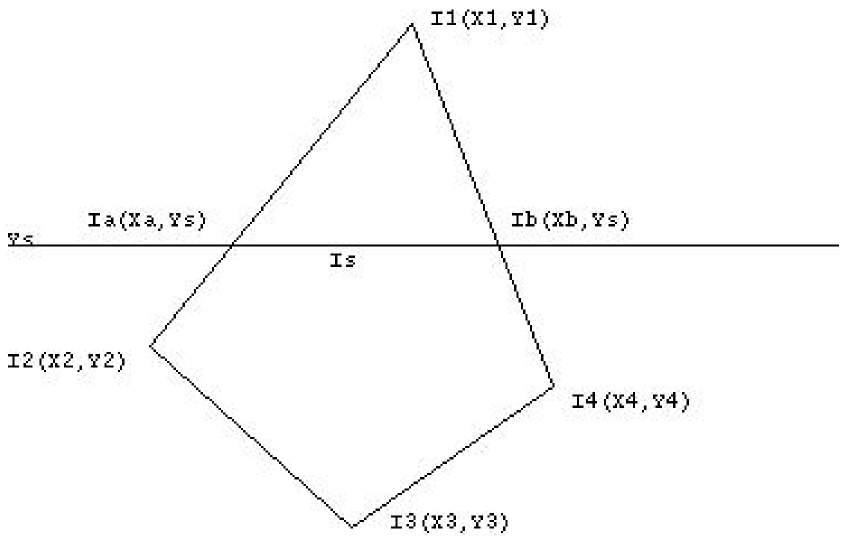
Vertex Normal



- Vertex normals are approximated by averaging the normals of the facets which share the vertex.

$$\bar{n}_v = \sum_{i=1}^{k} \frac{\bar{n}_i}{|\bar{n}_i|}$$

Gouraud shading



$$I_a = \frac{1}{y_1 - y_2}[I_1(y_s - y_2) + I_2(y_1 - y_s)]$$

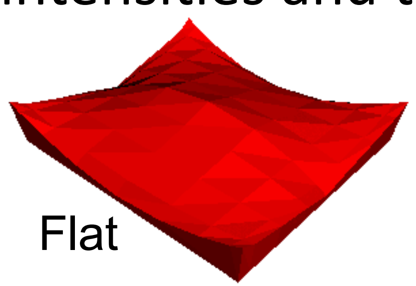
$$I_b = \frac{1}{y_1 - y_4}[I_1(y_s - y_4) + I_4(y_1 - y_s)]$$

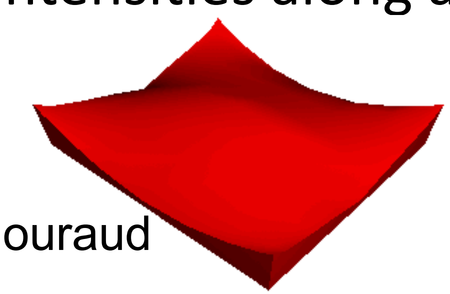
$$I_s = \frac{1}{x_b - x_a}[I_a(x_b - x_s) + I_b(x_s - x_a)]$$

$$\Delta I_s = \frac{\Delta x}{x_b - x_a}(I_b - I_a)$$

$$I_{s,n} = I_{s,n-1} + \Delta I_s$$

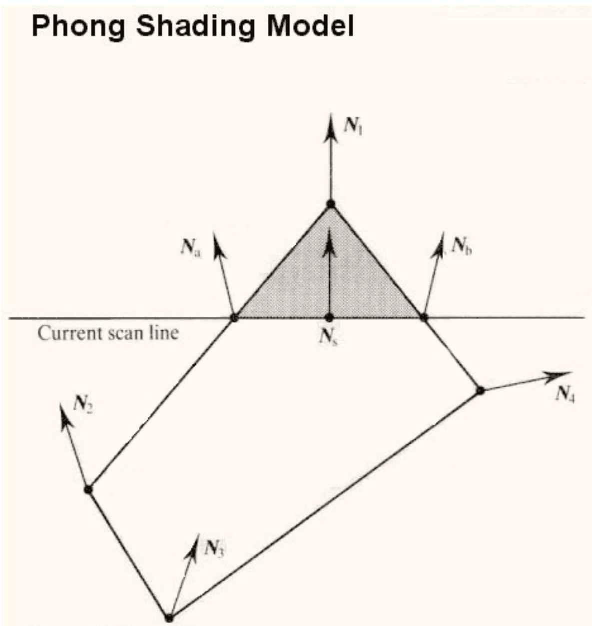
- The color of each vertex is first calculated.
- The intensities at the edge of each scan line are calculated from the vertex intensities and the intensities along a scan line from these.


Flat


Gouraud

Phong shading

- Not to be confused with Phong illumination model.
- Linear interpolation of the surface normals.
- Illumination model applied at every point.



$$N_a = \frac{1}{y_1 - y_2}[N_1(y_s - y_2) + N_2(y_1 - y_s)]$$

$$N_b = \frac{1}{y_1 - y_4}[N_1(y_s - y_4) + N_4(y_1 - y_s)]$$

$$N_s = \frac{1}{x_b - x_a}[N_a(x_b - x_s) + N_b(x_s - x_a)]$$

$$\begin{cases} N_{sx,n} = N_{sx,n-1} + \Delta N_{sx} \\ N_{sy,n} = N_{sy,n-1} + \Delta N_{sy} \\ N_{sz,n} = N_{sz,n-1} + \Delta N_{sz} \end{cases}$$

Phong shading

- Phong Shading interpolates the vertex normals.
- And the illumination model is applied at every point on the surface, where the normal at each point is the result of linearly interpolating the vertex normals defined at each vertex.
- Phong Shading overcomes some of the disadvantages of Gouraud shading.

References

[1] Pascal Vuylsteker, CG-Course Slide, Australia National University.

[2] Foley, Van Dam, Feiner, Hughes, Computer Graphics - Principles and Practices 2nd Ed. In C, Addison Wesley, 1997.