Illumination Models & Shading

- **Local model** – direct and local interaction of each object with the light.
- **Global model** – interactions and exchange of light energy between different objects.

Ambient Light
- Assume non-directional light in the environment
- Object illuminated with same light everywhere
- Looks like silhouette
- The Illumination equation: \( I = I_a k_u \)
- \( I_a \) - ambient light intensity
- \( k_u \) - fraction of ambient light reflected from surface.
- Also defines object color

Light Sources
- **Point source** (A): All light originates at a point
- Rays hit planar surface at different incidence angles
- **Parallel source** (B): All light rays are parallel
- Rays hit planar surface at identical incidence angles
- May be modeled as point source at infinity
- **Area source** (C): Light originates at finite area in space.
  - In between the point and parallel sources
  - Also called distributed source

Diffuse Light
- Diffuse surfaces such as solid matte plastic reflects incoming light uniformly in all directions. Called **diffuse** or **Lambertian** reflection
- Understand **intensity** as the number of photons per inch². If a flow of photos passing an inch² window is hitting a red surface, how many photons hit an inch² of the surface?
- Let \( \theta \) is the angle between the direction of incoming light and normal to surface, and let \( L, N \) be corresponding unit vectors.
- The length of the segment \( x \) is \( 1/\cos \theta \).
- The amount of incident light per unit surface area (thus reflected light) is proportional to \( \cos \theta \times N \cdot L \).
Shading

Diffused Reflection
- Illumination equation is now:
  \[ I = I_p + I_d k_a (N \cdot L) = I_p + I_d k_a \cos \theta \]
- \( I_p \) - point light source’s intensity
- \( k_a \) - surface diffuse reflection coefficient

Question: Can we locate the light source from a shaded image?

Specular Reflection
- Shiny objects (e.g. metallic) reflect light in preferred direction \( R \) determined by surface normal \( N \).
- Most objects are not ideal mirrors – also reflect in the immediate vicinity of \( R \).
- Phong Model – approximate attenuation by the form of \( \cos^n \) (no real physical basis).

Specular Reflection (Phong Model)
- Illumination equation:
  \[ I = I_p + I_d k_a (N \cdot L) + I_s k_s (R \cdot V)^n \]
- \( k_s \) - Specular reflection coefficient
- \( n \) - Specularity exponent

Specular Reflection (cont’d)
- Exponent \( n \) of cosine controls decay factor of attenuation function.
- No physical basis but looks good.
More on Illumination Equation

- For multiple light sources:
  \[ I = I_0 k_a + \sum_{p} I_p (k_o (N \cdot L_p) + k_i (R_p \cdot V)^\tau) \]

  - \( I_0 \) of all light sources are added together
  - Precautions should be taken from overflows

Even More on Illumination Equation

- For distance/atmospheric attenuation sources:
  \[ I = I_0 k_a + \sum_{p} \frac{I_p}{d_p^2} (k_o (N \cdot L_p) + k_i (R_p \cdot V)^\tau) \]

  - \( d_p \) - distance between surface and light source and/or distance between surface and viewer (heuristic atmospheric attenuation)

Flat Shading

- Applied to piecewise linear polygonal models
- Simple surface lighting approximated over polygons
- Illumination value depends only on polygon normal, i.e., each polygon is colored with a uniform intensity
- Looks non-smooth (worsened by Mach band effect)

Normal per Vertex

- If a polyhedron is an approximation of a smooth surface:
  - Assign to each vertex the normal of the original surface at that point
- If surface is not available, use estimated normal (e.g., average of neighboring faces)

Gouraud Shading

- Compute illumination intensity at vertices using those normals
- Interpolate intensity over polygon interior

Gouraud Shading

- Linearly interpolate lighting intensities at the vertices over interior pixels of the polygon, in the image plane

Question: Can Gouraud shading support specular lighting?
Shading

Phong Shading

- Interpolate (at the vertices in image space) normal vectors instead of illumination intensities
- Apply the illumination equation for each interior pixel with its own (interpolated) normal

$I(x, y) = L(n(x, y))$

Comments on Shading

- Phong shading is more expensive (why?) but well worth the effort
- Can achieve good looking specular highlight effects
- Both the Gouraud and Phong shading schemes are performed in the image plane and fit well into a polygonal scan-conversion fill scheme
- Both the Gouraud and Phong are view dependent
- Can cause artifacts during animation as they are transformation dependent

Comparison

Flat, Gouraud, Phong