Why do we need Lighting & shading?

- Sphere without lighting & shading

- We want (sphere with shading):
  - Has **visual cues** for humans (shape, light position, viewer position, surface orientation, material properties, etc)
What Causes Shading?

- Shading caused by different angles with light, camera at different points
**Lighting?**

- **Problem:** Model light-surface interaction at vertices to determine vertex color and brightness
- Calculate lighting based on angle that surface makes with light, viewer
- Per vertex calculation? Usually done in vertex shader
Shading?

- After triangle is rasterized (drawn in 2D)
  - Triangle converted to pixels
  - Per-vertex lighting calculation means we know color of pixels coinciding with vertices (red dots)
- Shading: figure out color of interior pixels
- How? Assume linear change => interpolate
Lighting (or Illumination) Model?

- Equation for computing illumination
- Usually includes:

1. **Light attributes:**
   - intensity, color, position, direction, shape

2. **Surface attributes**
   - color, reflectivity, transparency, etc

3. **Interaction**
   - between lights and objects
Light Bounces at Surfaces

- Light strikes A
  - Some reflected
  - Some absorbed
- Some reflected light from A strikes B
  - Some reflected
  - Some absorbed
- Some of this reflected light strikes A and so on
- The infinite reflection, scattering and absorption of light is described by the *rendering equation*
Render Equation

- Introduced by James Kajiya in 86 Siggraph paper.
- Mathematical basis for all global illumination algorithms

\[ Lo = Le(x, \tilde{\omega}) + \int_{\Omega} fr(x, \tilde{\omega}', \tilde{\omega}) Li(x, \tilde{\omega}')(\tilde{\omega}' \cdot \tilde{n}) d\tilde{\omega}' \]

- \( Lo \) is outgoing radiance
- \( Li \) incident radiance
- \( Le \) emitted radiance,
- \( fr \) is bidirectional reflectance distribution function (BRDF)
  - Describes how a surface reflects light energy
  - Fraction of incident light reflected
Rendering Equation

\[ L_o = L_e(x, \bar{\omega}) + \int_\Omega f r(x, \bar{\omega}', \bar{\omega}) L_i(x, \bar{\omega}')(\bar{\omega}' \cdot \bar{n}) d \bar{\omega}' \]

- Rendering equation includes many effects
  - Reflection
  - Shadows
  - Multiple scattering from object to object
- **Rendering equation** cannot be solved in general
- Rendering algorithms solve approximately. E.g. by sampling discretely
Global Illumination (Lighting) Model

- **Global illumination**: model interaction of light from all surfaces in scene (track multiple bounces)

![Diagram showing light interaction and effects](image)

- Shadow
- Multiple reflection
- Translucent surface
Local Illumination (Lighting) Model

- One bounce!
  - Doesn’t track inter-reflections, transmissions

- Simple! Only considers
  - Light
  - Viewer position
  - Surface Material properties
Local vs Global Rendering

- Global Illumination is accurate, looks real
  - But raster graphics pipeline (like OpenGL) renders each polygon independently (local rendering)

- OpenGL cannot render full global illumination
- However, we can use techniques exist for approximating (faking) global effects
Light-Material Interaction

- Light strikes object, some absorbed, some reflected
- Fraction reflected determines object color and brightness
  - Example: A surface looks red under white light because red component of light is reflected, other wavelengths absorbed
- Reflected light depends on surface smoothness and orientation
Light Sources

- General light sources are difficult to model because we must compute effect of light coming from all points on light source.
Basic Light Sources

- We generally use simpler light sources
- Abstractions that are easier to model

Point light

Directional light

Spot light

Area light

Light intensity can be **independent** or **dependent** of the distance between object and the light source.
Phong Model

- Simple lighting model that can be computed quickly
- 3 components
  - Diffuse
  - Specular
  - Ambient
- Compute each component separately
- Vertex Illumination = ambient + diffuse + specular
- Materials reflect each component differently
  - Material reflection coefficients control reflection
Phong Model

- Compute lighting (components) at each vertex (P)
- Uses 4 vectors, from vertex
  - To light source (l)
  - To viewer (v)
  - Normal (n)
  - Mirror direction (r)
Mirror Direction?

- Angle of reflection = angle of incidence
- Normal is determined by surface orientation
- The three vectors must be coplanar

\[ \mathbf{r} = 2 (\mathbf{l} \cdot \mathbf{n}) \mathbf{n} - \mathbf{l} \]
Surface Roughness

- **Smooth surfaces:** more reflected light concentrated in mirror direction
- **Rough surfaces:** reflects light in all directions
Diffuse Lighting Example
Diffuse Light Reflected

- Illumination surface receives from a light source and reflects equally in all directions

Eye position does not matter
Diffuse Light Calculation

- How much light received from light source?
- Based on Lambert’s Law

Receive more light

Receive less light
Lambert’s law: radiant energy $D$ a small surface patch receives from a light source is:

$$D = I \times k_D \cos(\theta)$$

- $I$: light intensity
- $\theta$: angle between light vector and surface normal
- $k_D$: Diffuse reflection coefficient.
  Controls how much diffuse light surface reflects
Specular light example

Specular? Bright spot on object
Specular light contribution

- Incoming light reflected out in small surface area
- Specular bright in mirror direction
- Drops off away from mirror direction
- Depends on viewer position relative to mirror direction
Specular light calculation

- Perfect reflection surface: all specular seen in mirror direction
- Non-perfect (real) surface: some specular still seen away from mirror direction
- $\phi$ is deviation of view angle from mirror direction
- Small $\phi = $ more specular
Modeling Specular Relections

\[ I_s = k_s I \cos^\alpha \phi \]

- incoming intensity
- reflected intensity
- shininess coef
- Absorption coef
- Mirror direction
The Shininess Coefficient, $\alpha$

- $\alpha$ controls falloff sharpness
- High $\alpha = $ sharper falloff = small, bright highlight
- Low $\alpha = $ slow falloff = large, dull highlight
  - $\alpha$ between 100 and 200 = metals
  - $\alpha$ between 5 and 10 = plastic look

\[
\cos^\alpha \phi
\]
Specular light: Effect of ‘α’

$$I_s = k_s I \cos^\alpha \phi$$

α = 10

α = 90

α = 30

α = 270
Ambient Light Contribution

- Very simple approximation of global illumination (Lump 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, .... etc bounce into single term)
- Assume to be a constant
- No direction!
  - Independent of light position, object orientation, observer’s position or orientation

\[
\text{Ambient} = I_a \times K_a
\]
Ambient Light Example

**Ambient:** background light, scattered by environment
Light Attenuation with Distance

- Light reaching a surface **inversely proportional** to square of distance
- We can multiply by factor of form $1/(ad + bd + cd^2)$ to **diffuse** and **specular** terms
Adding up the Components

- Adding all components (no attenuation term), phong model for each light source can be written as

\[
I = k_d I_d \cos \theta + k_s I_s \cos \phi^\alpha + k_a I_a
\]

= \[k_d I_d (l \cdot n) + k_s I_s (v \cdot r)^\alpha + k_a I_a \]

- Note:
  - \( \cos \theta = l \cdot n \)
  - \( \cos \phi = v \cdot r \)
Separate RGB Components

- We can separate red, green and blue components
- Instead of 3 light components $I_d, I_s, I_a$,
  - E.g. $I_d = I_{dr}, I_{dg}, I_{db}$
  - 9 coefficients for each point source
    - $I_{dr}, I_{dg}, I_{db}, I_{sr}, I_{sg}, I_{sb}, I_{ar}, I_{ag}, I_{ab}$
- Instead of 3 material components $k_d, k_s, k_a$,
  - E.g. $k_d = k_{dr}, k_{dg}, k_{db}$
  - 9 material absorption coefficients
    - $k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb}, k_{ar}, k_{ag}, k_{ab}$
Put it all together

- Can separate red, green and blue components. Instead of:

\[ I = k_d I_d (l \cdot n) + k_s I_s (v \cdot r)^\alpha + k_a I_a \]

- We computing lighting for RGB colors separately

\[
\begin{align*}
I_r &= k_{dr} I_{dr} l \cdot n + k_{sr} I_{sr} (v \cdot r)^\alpha + k_{ar} I_{ar} \quad \text{Red} \\
I_g &= k_{dg} I_{dg} l \cdot n + k_{sg} I_{sg} (v \cdot r)^\alpha + k_{ag} I_{ag} \quad \text{Green} \\
I_b &= k_{db} I_{db} l \cdot n + k_{sb} I_{sb} (v \cdot r)^\alpha + k_{ab} I_{ab} \quad \text{Blue}
\end{align*}
\]

- Above equation is just for one light source!!

- For N lights, repeat calculation for each light

Total illumination for a point \( P = \Sigma \) (Lighting for all lights)
# Coefficients for Real Materials

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<th>Material</th>
<th>Ambient Kar, Kag, kab</th>
<th>Diffuse Kdr, Kdg, kdb</th>
<th>Specular Ksr, Ksg, ksb</th>
<th>Exponent, $\alpha$</th>
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Figure 8.17, Hill, courtesy of McReynolds and Blythe
References