**Lighting**

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**Course News**

**Quiz 1**
- Discussed in labs this week

**Reading**
- Chapter 9, 3

**Out of Town this Friday**
- For grant review meeting
- Anika will fill in for me

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**The Rendering Pipeline**

Geometry Database → Model/View Transform → Lighting → Perspective Transform → Clipping → Scan Conversion → Texturing → Depth Test → Blending → Frame-buffer

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**Light Sources and Materials**

**Goal**
- Model the interaction of light with surfaces to render realistic images

**Contributing Factors**
- Light sources
  - Shape and color
- Surface materials
  - How surfaces reflect light
- Transport of light
  - How light moves in a scene (global illumination, later in the course)

**Appearance depends on**
- Light sources, locations, properties
- Material (surface) properties
- Viewer position

**Local illumination**
- Compute at material, from light to viewer

**Global illumination (later in course)**
- Ray tracing: from viewer into scene
- Radiosity: between surface patches
**Materials**

**Analyzing surface reflectance**
- Illuminate surface point with a ray of light from different directions
- Observe how much light is reflected in all possible directions

**Light is linear**
- If two rays illuminate the surface point the result is just the sum of the individual reflections for each ray
- For N directions the reflection is the sum of the individual N reflections
- For light arriving from a *continuum* of directions, the reflection is the integral over the reflections caused by the individual directions
  
  *More on this when we talk about global illumination at the end of the term*

**Experiment**

**Goal:**
- Visualize reflected light distribution for a given illuminating ray

**Physical setup:**
- Laser illumination
- Water tank with fluorescent dye
  
  *Makes laser light visible as it travels through “empty” space*

**Material Examples**

**Diffuse Material**
BRDF

Model for all these effects:
- Bi-directional
- i.e. dependent on 2 directions: incident, exitant
- Reflectance
- A model for surface reflection (not transmission)
- Distribution
- Light is distributed over different exitant directions
- Function
### BRDF lobes and appearance

- **Diffuse**: Light scattered in all directions.
- **Glossy**: Light reflected in a specific direction.
- **Mirror**: Light reflected perfectly in one direction.

### Limitations of the BRDF Model

**BRDFs cannot describe**
- Light of one wavelength that gets absorbed and re-emitted at a different wavelength
  - (fluorescence)
- Light that gets absorbed and emitted much later
  - (phosphorescence)
- Light that penetrates the object surface, scatters in the interior of the object, and exits at a different point from where it entered
  - (subsurface scattering)

### Materials

**Practical Considerations**
- In practice, we often simplify the BRDF model further.
- Derive specific formulas that describe different reflectance behaviors.
  - E.g. diffuse, glossy, specular
- Computational efficiency is also a concern

### Types of Reflection

- **Specular (a.k.a. mirror or regular)** reflection causes light to propagate without scattering.
- **Diffuse** reflection sends light in all directions with equal energy.
- **Mixed** reflection is a weighted combination of specular and diffuse.

### Reflectance Distribution Model

**Most surfaces exhibit complex reflectances**
- Vary with incident and reflected directions.
- Model with combination

\[
\text{specular} + \text{glossy} + \text{diffuse} = \text{reflectance distribution}
\]
Specular Reflection

**Geometry of specular (mirror) reflection**

\[ r = -2(n \cdot l)n \]

Intuitively: cross-sectional area of the “beam” intersecting an element of surface area is smaller for greater angles with the normal.

Fresnel Reflection

Physics of Mirrors

Lambert’s “Law”

Intuitively: cross-sectional area of the “beam” intersecting an element of surface area is smaller for greater angles with the normal.

### Physics of Diffuse Reflection

**Ideal diffuse reflection**

- Very rough surface at the microscopic level
  - Real-world example: chalk
- Microscopic variations mean incoming ray of light equally likely to be reflected in any direction over the hemisphere
- Reflected intensity only depends on light direction!

### Computing Diffuse Reflection

- Depends on **angle of incidence**: angle between surface normal and incoming light
  - \( I_{\text{diffuse}} = k_d I_{\text{inc}} \cos \theta \)
  - In practice use vector arithmetic
  - \( I_{\text{diffuse}} = k_d I_{\text{inc}} (n \cdot l) \)
- Always normalize vectors used in lighting
  - \( n, I \) should be unit vectors
- Scalar (B/W intensity) or 3-tuple or 4-tuple (color)
- \( k_d \): diffuse coefficient, surface color
- \( I_{\text{inc}} \): incoming light intensity
- \( I_{\text{diffuse}} \): outgoing light intensity (for diffuse reflection)

### Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

  ![Diffuse Lighting Examples](image)

- need only consider angles from 0° to 90°
Physics of Glossy Reflection

- At the microscopic level a glossy reflecting surface is very smooth
- Thus rays of light are likely to bounce off the microgeometry in a mirror-like fashion
- The smoother the surface, the closer it becomes to a perfect mirror

Glossy Reflectance

- Snell's law applies to perfect mirror-like surfaces, but aside from mirrors (and chrome) few surfaces exhibit perfect specularity
- How can we capture the "softer" reflections of surface that are glossy, not mirror-like?
- One option: model the microgeometry of the surface and explicitly bounce rays off of it

or...

Empirical Approximation

- We expect most reflected light to travel in direction predicted by Snell's Law
- But because of microscopic surface variations, some light may be reflected in a direction slightly off the ideal reflected ray
- As angle from ideal reflected ray increases, we expect less light to be reflected

Empirical Approximation

- Angular falloff

how might we model this falloff?

Phong Lighting

Most common lighting model in computer graphics (Phong, 1975)

\[ I_{\text{specular}} = k_s I_{\text{light}} \left( \cos \phi \right)^n \]

- \( n_s \): purely empirical constant, varies rate of falloff
- \( k_s \): specular coefficient, highlight color
- No physical basis, works ok in practice

Phong Lighting: The \( n_s \) Term

- Phong reflectance term drops off with divergence of viewing angle from ideal reflected ray

Viewing angle – reflected angle
Calculating Phong Lighting

Compute cosine term of Phong lighting with vectors

\[ I_{\text{specular}} = k_s I_{\text{light}} (v \cdot r)^n, \]

- \( v \): unit vector towards viewer/eye
- \( r \): ideal reflectance direction (unit vector)
- \( k_s \): specular component
- \( I_{\text{light}} \): highlight color
- \( I_{\text{specular}} \): incoming light intensity

Phong Lighting: Intensity Plots

Phong

\[ \begin{array}{c|cccc}
\text{Degree} & \text{10°} & \text{20°} & \text{30°} & \text{45°} \\
\hline
\text{10°} & \text{Lightening} & \text{Point} & \text{Lightening} & \text{Lightening} \\
\text{20°} & \text{Lightening} & \text{Point} & \text{Point} & \text{Lightening} \\
\text{30°} & \text{Lightening} & \text{Lightening} & \text{Point} & \text{Lightening} \\
\text{45°} & \text{Lightening} & \text{Lightening} & \text{Lightening} & \text{Lightening} \\
\end{array} \]

Alternative Model

Blinn-Phong model (Jim Blinn, 1977)

- Variation with better physical interpretation
- \( h \): halfway vector; \( r \): roughness

\[ I_{\text{diff}}(x) = k_d \cdot (h \cdot n)^\gamma \cdot I_o(x) \text{; with } h = (I + v) / 2 \]

Simple Light Sources

Types of light sources

- Directional/parallel lights
  - E.g. sun
  - Homogeneous vector
  - Same intensity in all directions
  - Homogeneous point
- Point lights
  - Limited set of directions
  - Point + direction + cutoff angle

Light Sources

Area lights:

- Light sources with a finite area
- Can be considered a continuum of point lights
- Not available in many rendering systems
Light Source Falloff

**Quadratic falloff (point- and spot lights)**
- Brightness of objects depends on power per unit area that hits the object
- The power per unit area for a point or spot light decreases quadratically with distance

\[
I_\text{lin}(x) = \frac{1}{ar^2 + br + c} \cdot I_0
\]

**Non-quadratic falloff**
- Many systems allow for other falloffs
- Allows for faking effect of area light sources
- OpenGL / graphics hardware
  - \( I_c \): intensity of light source
  - \( x \): object point
  - \( r \): distance of light from \( x \)
  - \( I_\text{lin}(x) \)
  - \( I_0 \)

Light Sources

**Ambient lights**
- No identifiable source or direction
- Hack for replacing true global illumination
  - (light bouncing off from other objects)

Ambient Light Sources

- Scene lit only with an ambient light source

Directional Light Sources

- Scene lit with directional and ambient light

Point Light Sources

- Scene lit with ambient and point light source
**Light Sources & Transformations**

*Geometry: positions and directions*
- Standard: world coordinate system
  - *Effect*: lights fixed wrt world geometry
- Alternative: camera coordinate system
  - *Effect*: lights attached to camera (car headlights)
- Points and directions undergo normal model/view transformation

*Illumination calculations: camera coords*

**Lighting Review**

*Lighting models*
- Ambient
  - *Normals don't matter*
- Lambert/diffuse
  - *Angle between surface normal and light*
- Phong/specular
  - *Surface normal, light, and viewpoint*

**Lighting in OpenGL**

*Light source: amount of RGB light emitted*
- Value represents percentage of full intensity
  - 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 (1.0,0.0) x green surface (0.1,0) = black (0.0,0)

**Coming Up:**

*Wednesday*
- Shading

*Friday*
- Clipping; scan conversion