Picking Select/Hit recap

- assign (hierarchical) integer key/name(s)
- small region around cursor as new viewport
- redraw in selection mode
  - equivalent to casting pick “tube”
  - store keys, depth for drawn objects in hit list
- examine hit list
  - usually use frontmost, but up to application

Light Sources recap

- directional/parallel lights
  - point at infinity: $(x,y,z,0)^T$
- point lights
  - finite position: $(x,y,z,1)^T$
- spotlights
  - position, direction, angle
- ambient lights

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 Position Important
Viewer Position Important
Surface Angle Important

Illumination as Radiative Transfer

• radiative heat transfer approximation
  – substitute light for heat
  – light as packets of energy (photons)
    • particles not waves
  – model light transport as packet flow

Light Transport Assumptions

• geometrical optics (light is photons not waves)
  – no diffraction
  – no polarization (some sunglasses)
  – no interference (packets don’t interact)
    • interference demo: http://www.falstad.com/ripple
    • which visual effects does this preclude?

Light Transport Assumptions II

• color approximated by discrete wavelengths
  – quantized approx of dispersion (rainbows)
  – quantized approx of fluorescence (cycling vests)

• no propagation media (surfaces in vacuum)
  – no atmospheric scattering (fog, clouds)
    • some tricks to simulate explicitly
  – no refraction (mirages)

Light Transport Assumptions III

• light travels in straight line
  – no gravity lenses

• superposition (lights can be added)
  – no nonlinear reflection models
    • nonlinearity handled separately

Illumination

• transport of energy from light sources to surfaces & points
  – includes direct and indirect illumination
Components of Illumination

- two components: light sources and surface properties
- light sources (or emitters)
  - spectrum of emittance (i.e., color of the light)
  - geometric attributes
    - position
    - direction
    - shape
    - directional attenuation
    - polarization

Components of Illumination

- surface properties
  - reflectance spectrum (i.e., color of the surface)
  - subsurface reflectance
  - geometric attributes
    - position
    - orientation
    - micro-structure

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.

Types of Reflection

- retro-reflection occurs when incident energy reflects in directions close to the incident direction, for a wide range of incident directions.
- gloss is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.

Reflectance Distribution Model

- most surfaces exhibit complex reflectances
  - vary with incident and reflected directions.
  - model with combination

specular + glossy + diffuse = reflectance distribution

Surface Roughness

- at a microscopic scale, all real surfaces are rough
- cast shadows on themselves
- "mask" reflected light:
Surface Roughness

• notice another effect of roughness:
  – each “microfacet” is treated as a perfect mirror.
  – incident light reflected in different directions by different facets.
  – end result is mixed reflectance.
• smoother surfaces are more specular or glossy.
• random distribution of facet normals results in diffuse reflectance.

Physics of 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

• what does the reflected intensity depend on?

Lambert’s Cosine Law

• ideal diffuse surface reflection
  the energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal
• reflected intensity
  – independent of viewing direction
  – depends on surface orientation wrt light
• often called Lambertian surfaces

Lambert’s Law

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

Computing Diffuse Reflection

• angle between surface normal and incoming light is angle of incidence:

\[ I_{\text{diffuse}} = k_d \cdot I_{\text{light}} \cdot \cos \theta \]

• in practice use vector arithmetic:

\[ I_{\text{diffuse}} = k_d \cdot I_{\text{light}} \cdot (n \cdot l) \]

Diffuse Lighting Examples

• Lambertian sphere from several lighting angles:

• need only consider angles from 0° to 90°
  – why?
  – demo: Brown exploratory on reflection
Specular Reflection

- shiny surfaces exhibit **specular reflection**
  - polished metal
  - glossy car finish

- **specular highlight**
  - bright spot from light shining on a specular surface

- **view dependent**
  - highlight position is function of the viewer's position

Physics of Reflection

- at the microscopic level a specular 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

Optics of Reflection

- reflection follows **Snell's Law**:
  - incoming ray and reflected ray lie in a plane with the surface normal
  - angle the reflected ray forms with surface normal equals angle formed by incoming ray and surface normal

\[ \theta_{\text{light}} = \theta_{\text{reflection}} \]

Non-Ideal Specular 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 rather than 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**

\[ \theta_{\text{light}} = \theta_{\text{reflection}} \]

- how might we model this falloff?
Phong Lighting

- most common lighting model in computer graphics
- \( I_{\text{specular}} = k_s I_{\text{light}} (\cos \varphi)^{n_{\text{shiny}}} \)
- \( n_{\text{shiny}} \): purely empirical constant, varies the rate of falloff
- no physical basis, works ok in practice

Phong Lighting: The \( n_{\text{shiny}} \) Term

- Phong reflectance term drops off with divergence of viewing angle from ideal reflected ray
- what does this term control, visually?

Phong Examples

- varying light intensity
- varying \( n_{\text{shiny}} \)

Calculating Phong Lighting

- compute cosine term of Phong lighting with vectors
- \( I_{\text{specular}} = k_s I_{\text{light}} (v \cdot r)^{n_{\text{shiny}}} \)
  - \( v \): unit vector towards viewer
  - \( r \): ideal reflectance direction
  - \( k_s \): specular component
    * highlight color
- how to efficiently calculate \( r \)?

Calculating The \( R \) Vector

\[
\begin{align*}
P &= \mathbf{N} \cos \theta = \text{projection of } \mathbf{L} \text{ onto } \mathbf{N} \\
P + S &= R \\
\mathbf{N} \cos \theta + S &= R \\
2 (\mathbf{N} \cos \theta) - L &= R \\
\cos \theta &= \mathbf{N} \cdot \mathbf{L} \\
2 (\mathbf{N} \cdot \mathbf{L}) - L &= R \\
\mathbf{N} \text{ and } \mathbf{R} \text{ are unit length!} \\
2 (\mathbf{N} \cdot \mathbf{L}) - L &= R
\end{align*}
\]

The Phong Lighting Model

- combine ambient, diffuse, specular components
- commonly called Phong lighting
  * once per light
  * once per color component

\[
I_{\text{total}} = k_a I_{\text{ambient}} + \sum_{i=1}^{\text{#lights}} I_i \left( k_d (\mathbf{n} \cdot \mathbf{l}_i) + k_a (\mathbf{v} \times \mathbf{r}_i)^{n_{\text{diffuse}}} \right)
\]
**Phong Lighting: Intensity Plots**

<table>
<thead>
<tr>
<th>Phong</th>
<th>Oblique</th>
<th>Vertical</th>
<th>Specular</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.2</td>
<td>0.8</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>20°</td>
<td>0.1</td>
<td>0.7</td>
<td>0.9</td>
<td>1.9</td>
</tr>
<tr>
<td>40°</td>
<td>0.08</td>
<td>0.6</td>
<td>0.7</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Blinn-Phong Model**

- variation with better physical interpretation
  - Jim Blinn, 1977
  - $h$: halfway vector
  - highlight occurs when $h$ near $n$
  \[ I_{\text{out}}(x) = k_r \cdot (h \cdot n)^n_{\text{shiny}} \cdot I_{\text{in}}(x); \text{ with } h = (l + v) / 2 \]

**Lighting Review**

- lighting models
  - ambient
    - normals don’t matter
  - Lambert/diffuse
    - angle between surface normal and light
  - Phong/specular
    - surface normal, light, and viewpoint

**Anisotropy**

- so far we’ve been considering isotropic materials.
  - reflection and refraction invariant with respect to rotation of the surface about the surface normal vector.
  - for many materials, reflectance and transmission are dependent on this azimuth angle: anisotropic reflectance/transmission.
  - examples?

**BRDF**

- Bidirectional Reflectance Distribution Function
  \[ \rho(x, \omega_i, \omega_o) \]
  - $x$ is the position.
  - $\omega_i = (\theta_i, \phi_i)$ represents the incoming direction (elevation, azimuth)
  - $\omega_o = (\theta_o, \phi_o)$ represents the outgoing direction (elevation, azimuth)

**Properties of the BRDF**

- dependent on both incoming and outgoing directions: bidirectional.
- always positive: distribution function.
- invariant to exchange of incoming/outgoing directions: reciprocity principal.
- in general, BRDFs are anisotropic.
Dimensionality of BRDF

- function of position (3D), incoming, outgoing directions (4 angles), wavelength, and polarization.
  - thus, a 9D function!
  - usually simplify:
    - ignore polarization (geometric optics!).
    - sometimes ignore wavelength.
    - assume uniform material (ignore position).
    - isotropic reflectance makes one angle go away.