Computer Graphics

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Outline

1. Lighting Models: §10 (contd.)
   - Illumination Models: §10-3

Outline

Reflections

- From the types of light sources seen, what is the effect of the three different types of light reflection (**ambient**, **diffuse**, **specular**) off a surface?
- As surfaces vary so do the amounts of light that they reflect
- For a given surface we denote the fraction of light that is reflected **diffusely** by k_d and **specularly** by k_s
- Although some models permit a separate $\boxed{}$ light reflectivity component k_a **usually**, not coming from a particular source, $\boxed{}$ light gets reflected diffusely and the intensity of the reflected light is

$$k_d I_a$$

  - Since $\boxed{}$ light is "all around" the intensity of light due to ambient light, I_a, is constant at all points in space

Diffuse Reflection

- When a surface is illuminated by a light source the **intensity** of the light falling on it, I_l, is the amount of light that falls per unit area of the surface; this depends on orientation of surface

- The amount depends on the **cosine** of the angle between the incident path and the normal to the surface, N

$$I_{l,\text{incident}} = I_l \cos\theta$$

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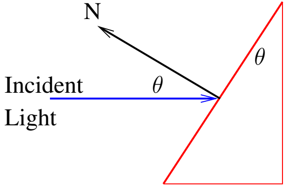

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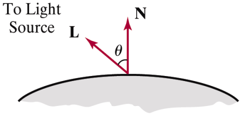
Diffuse Reflection (contd.)

- In general

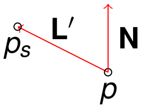


and, by using normalised vectors for **L** and **N**, $\cos\theta$ is easily computed as the $\boxed{\phantom{\text{dot product}}}$ so that

$$I_{l,\text{diff}} = \begin{cases} k_d I_l(\mathbf{N}\cdot\mathbf{L}) & \text{if } \mathbf{N}\cdot\mathbf{L} > 0 \\ 0.0 & \text{if } \mathbf{N}\cdot\mathbf{L} \leq 0 \end{cases}$$

- We can calculate the vector **L**, as the (normalised) difference of the light source p_s and the point on the surface p; see picture over

Diffuse Reflection (contd.)



- Since $p + \mathbf{L}' = p_s$, $\mathbf{L}' = p_s - p$ and

$$\mathbf{L} = \frac{\mathbf{L}'}{|\mathbf{L}'|} = \frac{p_s - p}{|p_s - p|}$$

- If we allow for a different reflectivity coefficient for ambient light, k_a, then the intensity of diffuse reflection due to ambient light and diffuse reflection from a light source is given by

$$I_{\text{diff}} = \begin{cases} k_a I_a + k_d I_l(\mathbf{N} \cdot \mathbf{L}) & \text{if } \mathbf{N} \cdot \mathbf{L} > 0 \\ k_a I_a & \text{if } \mathbf{N} \cdot \mathbf{L} \leq 0 \end{cases}$$

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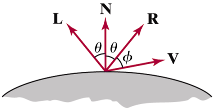
Specular Reflection

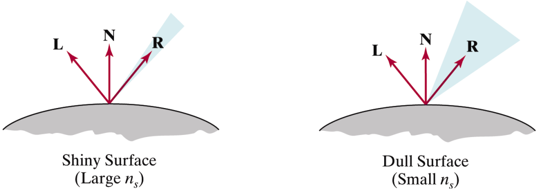
- Specular reflection is the result of total, or near total, reflection of the light in a region around the **specular-reflection angle**



- Light from the direction **L** falling on a surface will be specularly reflected in the direction **R**
- The "outgoing" angle θ will be the same as the "incoming" angle θ
- For an ideal reflector (a perfect mirror) incident light is reflected in the **specular direction** only ($\phi = 0$ above)

Specular Reflection (contd.)

- With the viewer situated at angle ϕ to **R** some light may be visible depending on the surface



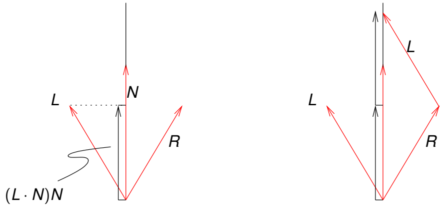
- According to the **Phong specular-reflection model** the intensity of light at angle ϕ is given by $\cos^{n_s}\phi$ where n_s is particular to a material (wood, metal, glass, etc.)
- Shiny surfaces have larger n_s so, for a given ϕ, intensity will be *smaller*

Specular Reflection (contd.)

- The intensity of the specular reflection due to a point light source of intensity I_l at a surface point is

$$I_{l,\mathrm{spec}} = \begin{cases} k_s I_l (\mathbf{V} \cdot \mathbf{R})^{n_s} & \text{if } \mathbf{V} \cdot \mathbf{R} > 0 \text{ and } \mathbf{N} \cdot \mathbf{L} > 0 \\ 0.0 & \text{if } \mathbf{V} \cdot \mathbf{R} < 0 \text{ and } \mathbf{N} \cdot \mathbf{L} \leq 0 \end{cases}$$

- How to calculate **R** above?



Specular Reflection (contd.)

- From the scalar product operator definition $\mathbf{L} \cdot \mathbf{N} = \mathbf{R} \cdot \mathbf{N} =$ projection of $\mathbf{L}$ onto $\mathbf{N}$
- But from adding vectors $\mathbf{L}$ and $\mathbf{R}$, $\mathbf{L} + \mathbf{R}$ is twice projection of $\mathbf{L}$ onto $\mathbf{N}$ and in the direction $\mathbf{N}$
- So

$$\begin{aligned}\mathbf{R} + \mathbf{L} &= (2\mathbf{L} \cdot \mathbf{N})\mathbf{N} \\ \mathbf{R} &= (2\mathbf{L} \cdot \mathbf{N})\mathbf{N} - \mathbf{L}\end{aligned}$$

$\mathbf{L}, \mathbf{N}, \mathbf{V}$ are all unit-length so $\mathbf{R}$ will be automatically. (Why?)

Specular Reflection (contd.)

- Because it is different at every point on the surface calculating **R** can be expensive; although **N**, **V** and **L** are also unique to each point on surface **N** will be known in advance and, **if the light and viewer are far enough away**, **V** and **L** can be taken to be the same everywhere
- An alternative strategy that gives almost as good results and that avoids the additional computational burden is the **halfway vector H**
- **H** is the bisector (average) of the angle between **L** and **V** and can be computed by

$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{V}}{|\mathbf{L} + \mathbf{V}|}$$

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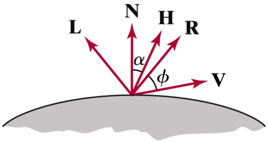

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Specular Reflection (contd.)

- **Fun fact:** if all of this is taking place in a 2-D world (or if all vectors are co-planar) then $\alpha = \phi/2$
- In effect, we replace the empirically-based parameter, $\cos\phi = \mathbf{V} \cdot \mathbf{R}$, by another empirically-based value, $\cos\alpha = \mathbf{N} \cdot \mathbf{H}$, that is cheaper to compute
- When computing lighting in a scene it is important to remember that, generally, the light source(s) and the viewer position are fixed; if they're far enough away we can say that at every point in the scene the vectors **V** and **L** are more-or-less constant. Rabhadh: this is a simplification and may lead to poor results.
- We may then (independently) choose to work with the halfway vector

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Combined Diffuse and Specular Reflections

- We can model the combined ambient, diffuse and specular reflections from a point on an surface illuminated by a single point light as

$$= k_a I_a + k_d I_l(\mathbf{N} \cdot \mathbf{L}) + k_s I_l(\mathbf{V} \cdot \mathbf{R})^{n_s}$$

- The surface is illuminated only with ambient light if the light source is behind the surface; there are no specular effects if **V** and **L** are on the same side of **N**
- For multiple light sources (n of them)

$$\begin{aligned} I &= I_{\text{ambdiff}} + \sum_{l=1}^{n} \left(I_{l,\text{diff}} + I_{l,\text{spec}} \right) \\ &= k_a I_a + \sum_{l=1}^{n} I_l \left(k_d(\mathbf{N} \cdot \mathbf{L}) + k_s(\mathbf{V} \cdot \mathbf{R})^{n_s} \right) \end{aligned}$$