University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2005

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Lighting and Shading

Week 5, Mon Jan 31

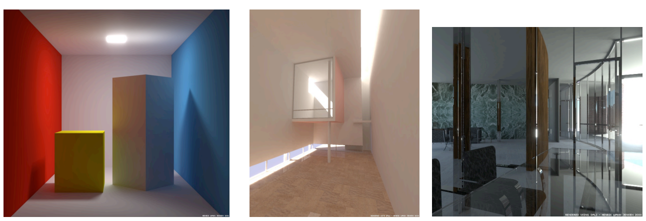
http://www.ugrad.cs.ubc.ca/~cs314/Vjan2005

News

- homework correction: questions 13-16 should use:
  - unit square has points A=(0,0,0,1), B=(0,1,0,1), C=(0,1,1,1), D=(0,0,1,1) in world coordinates

Review: Illumination

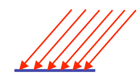
- transport of energy from light sources to surfaces & points
  - includes *direct* and *indirect illumination*



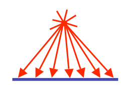
Images by Henrik Wann Jensen

Review: Light Sources

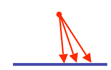
- directional/parallel lights
  - point at infinity: $(x,y,z,0)^T$



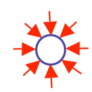
- point lights
  - finite position: $(x,y,z,1)^T$



- spotlights
  - position, direction, angle



- ambient lights

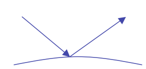


Review: Light Source Placement

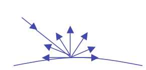
- geometry: positions and directions
  - standard: world coordinate system
    - effect: lights fixed wrt world geometry
  - alternative: camera coordinate system
    - effect: lights attached to camera (car headlights)

Types of Reflection

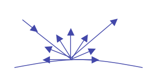
- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



- *diffuse* reflection sends light in all directions with equal energy.

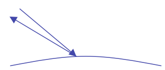


- *mixed* reflection is a weighted combination of specular and diffuse.

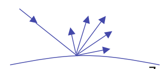


Types of Reflection

- *retro-reflection* occurs when incident energy reflects in directions close to the incident direction, for a wide range of incident directions.

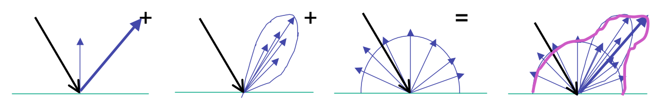


- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.



Reflectance Distribution Model

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

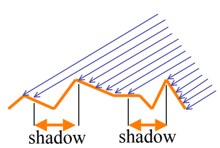


specular + glossy + diffuse =
reflectance distribution

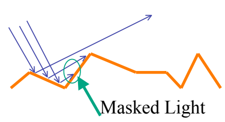
Surface Roughness

- at a microscopic scale, all real surfaces are rough

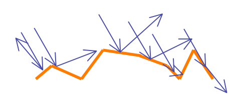
- cast shadows on themselves



- “mask” reflected light:



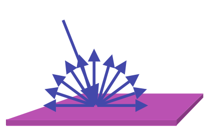
Surface Roughness

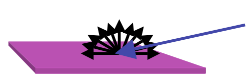


- notice another effect of roughness:
  - each “microfacet” is treated as a perfect mirror.
  - incident light reflected in different directions by different facets.
  - end result is mixed reflectance.
    - smoother surfaces are more specular or glossy.
    - random distribution of facet normals results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

Physics of 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
  - what does the reflected intensity depend on?





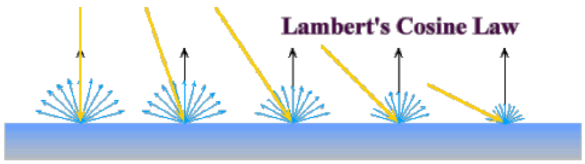
Lambert’s Cosine Law

- ideal diffuse surface reflection

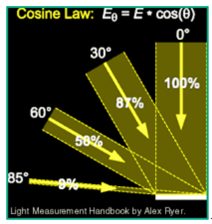
  the energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal

- reflected intensity
  - independent of viewing direction
  - depends on surface orientation wrt light
- often called Lambertian surfaces

Lambert's Law

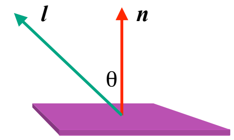


intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

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



k_d :
diffuse component
"surface color"

$$I_{diffuse} = k_d\, I_{light} \cos\theta$$

- in practice use vector arithmetic

$$I_{diffuse} = k_d\, I_{light}\, (\mathbf{n} \bullet \mathbf{l})$$

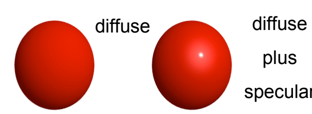
Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°
  - *why?*
  - *demo: Brown exploratory on reflection*
  - http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/reflection2D/reflection_2d_java_browser.html

Specular Reflection

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



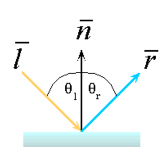
- specular highlight
  - bright spot from light shining on a specular surface
- view dependent
  - highlight position is function of the viewer's position

Physics of Specular 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

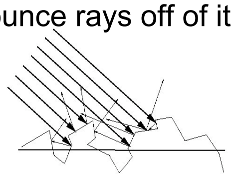
- reflection follows *Snell's Law:*
  - incoming ray and reflected ray lie in a plane with the surface normal
  - angle the reflected ray forms with surface normal equals angle formed by incoming ray and surface normal



$$\theta_{(l)ight} = \theta_{(r)eflection}$$

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, not mirror-like?
- one option: model the microgeometry of the surface and explicitly bounce rays off of it
- or…

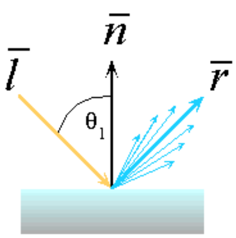


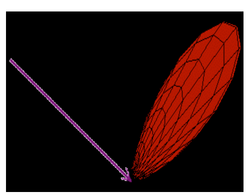
Empirical Approximation

- 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





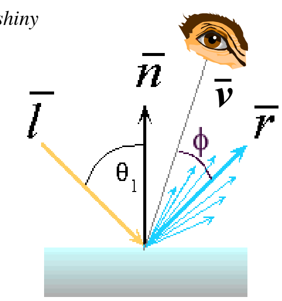
- how might we model this falloff?

Phong Lighting

- most common lighting model in computer graphics
  - (Phong Bui-Tuong, 1975)

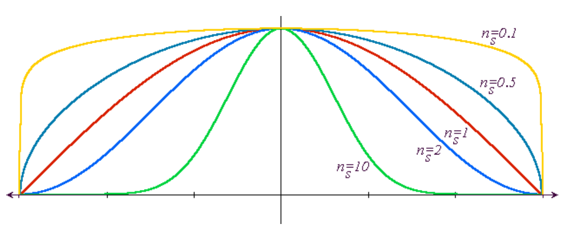
$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\cos\phi)^{n_{shiny}}$$

- n_{shiny} : purely empirical constant, varies the rate of falloff
- no physical basis, works ok in practice



Phong Lighting: The n_{shiny} Term

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

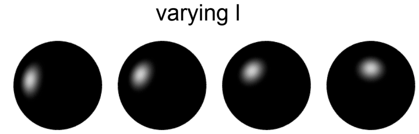


- *what does this term control, visually?*

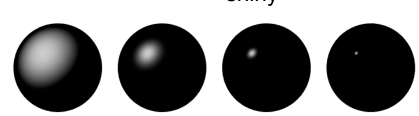
Viewing angle – reflected angle

Phong Examples

varying l



varying n_{shiny}

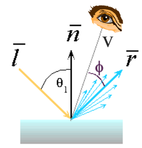


Calculating Phong Lighting

- compute **cosine** term of Phong lighting with vectors

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_s \mathbf{I}_{\mathbf{light}} (\mathbf{v} \bullet \mathbf{r})^{n_{shiny}}$$

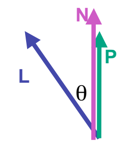
- v: unit vector towards viewer
- r: ideal reflectance direction
- k_S: specular component
  - highlight color



- how to efficiently calculate **r** ?

Calculating The R Vector

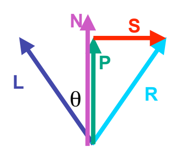
P = **N** cos θ = projection of **L** onto **N**



Calculating The R Vector

P + **S** = **R**

P = **N** cos θ = projection of **L** onto **N**

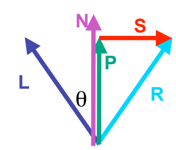


Calculating The R Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**



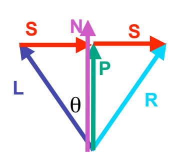
Calculating The R Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**

S = **P** – **L** = **N** cos θ - **L**



Calculating The R Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**

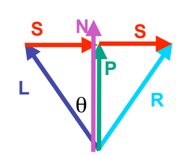
S = **P** – **L** = **N** cos θ - **L**

N cos θ + (**N** cos θ – **L**) = **R**

2 (**N** cos θ) – **L** = **R**

cos θ = **N** · **L**

2 (**N** (**N** · **L**)) – **L** = **R**



Calculating The *R* Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**

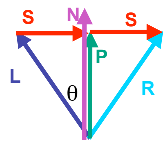
S = **P** – **L** = **N** cos θ - **L**

N cos θ + (**N** cos θ – **L**) = **R**

2 (**N** cos θ) – **L** = **R**

cos θ = **N** · **L**

2 (**N** (**N** · **L**)) – **L** = **R**



- **N** and **R** are unit length!

Calculating The *R* Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**

S = **P** – **L** = **N** cos θ - **L**

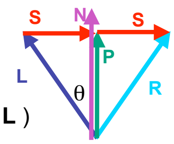
N cos θ + (**N** cos θ – **L**) = **R**

2 (**N** cos θ) – **L** = **R**

cos θ = **N** · **L**

2 (**N** (**N** · **L**)) – **L** = **R**

P = **N** (**N** · **L**)



- **N** and **R** are unit length!

Calculating The *R* Vector

P = **N** cos θ = projection of **L** onto **N**

P + **S** = **R**

N cos θ + **S** = **R**

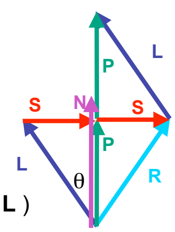
S = **P** – **L** = **N** cos θ - **L**

N cos θ + (**N** cos θ – **L**) = **R**

2 (**N** cos θ) – **L** = **R**

cos θ = **N** · **L**

2 (**N** (**N** · **L**)) – **L** = **R**



P = **N** (**N** · **L**)

2 **P** = **R** + **L**

2 **P** – **L** = **R**

2 (**N** (**N** · **L**)) - **L** = **R**

- **N** and **R** are unit length!

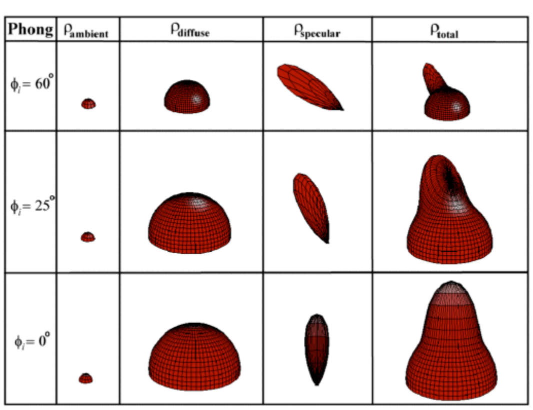
Phong Lighting Model

- combine ambient, diffuse, specular components

$$\mathbf{I}_{\text{total}} = \mathbf{k}_s \mathbf{I}_{\text{ambient}} + \sum_{i=1}^{\#\,lights} \mathbf{I}_i (\mathbf{k}_d (\mathbf{n} \bullet \mathbf{l}_i) + \mathbf{k}_s (\mathbf{v} \bullet \mathbf{r}_i)^{n_{shiny}})$$

- commonly called *Phong lighting*
  - once per light
  - once per color component

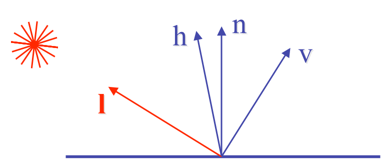
Phong Lighting: Intensity Plots



Blinn-Phong Model

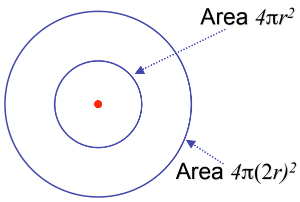
- variation with better physical interpretation
  - Jim Blinn, 1977
- ***h***: halfway vector
- highlight occurs when h near n

$$I_{out}(\mathbf{x}) = \mathbf{k}_s (\mathbf{h} \bullet \mathbf{n})^{n_{shiny}} \bullet I_{in}(\mathbf{x}); \text{with } \mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$



Light Source Falloff

- quadratic falloff
  - 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



Light Source Falloff

- non-quadratic falloff
  - many systems allow for other falloffs
  - allows for faking effect of area light sources
  - OpenGL / graphics hardware
    - I_o: intensity of light source
    - $\boldsymbol{x}$: object point
    - r: distance of light from $\boldsymbol{x}$

$$I_{in}(\mathbf{x}) = \frac{1}{ar^2 + br + c} \cdot I_0$$

Lighting Review

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