University of British Columbia

CPSC 414 Computer Graphics

Lighting

Week 5, Mon 29 Sep 2003

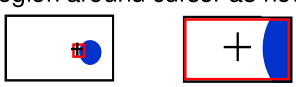
- recap: picking, light sources
- lighting

News

- continue signup for project 1 demo slots
- extra TA hours in labs
  - Monday 10-2, 4-5:30
  - Tuesday 11-1
  - Wednesday 10-1, 4-5:30
  - Thursday 11-1
- normal lab hours
  - Wed 1-3

Picking Select/Hit recap

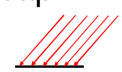
- assign (hierarchical) integer key/name(s)
- small region around cursor as new viewport



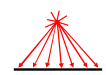
- redraw in selection mode
  - equivalent to casting pick “tube”
  - store keys, depth for drawn objects in hit list
- examine hit list
  - usually use frontmost, but up to application

Light Sources recap

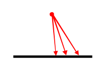
- directional/parallel lights
  - point at infinity: $(x,y,z,0)^T$



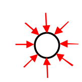
- point lights
  - finite position: $(x,y,z,1)^T$



- spotlights
  - position, direction, angle

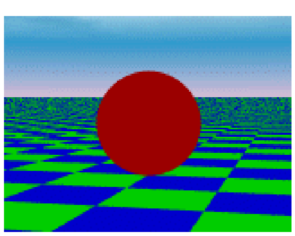


- ambient lights



Ambient Light Sources

- scene lit only with an ambient light source



Light Position Not Important

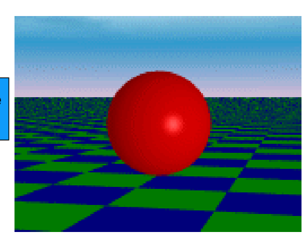
Viewer Position Not Important

Surface Angle Not Important

Directional Light Sources

- scene lit with directional and ambient light

Surface Angle Important



Light Position Not Important

Viewer Position Not Important

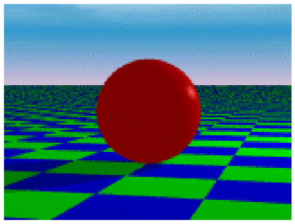
Point Light Sources

- scene lit with ambient and point light source

Light Position Important

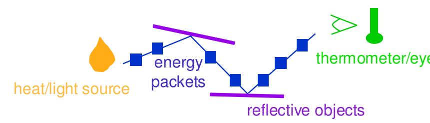
Viewer Position Important

Surface Angle Important



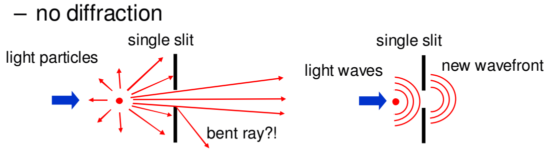
Illumination as Radiative Transfer

- 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)
    - light of all orientations gets through
  - 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*

Images by Henrik Wann Jensen

Components of Illumination

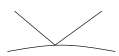
- two components: light sources and surface properties
- light sources (or *emitters*)
  - spectrum of emittance (i.e., color of the light)
  - geometric attributes
    - position
    - direction
    - shape
  - directional attenuation
  - polarization

Components of Illumination

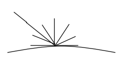
- surface properties
  - reflectance spectrum (i.e., color of the surface)
  - subsurface reflectance
  - geometric attributes
    - position
    - orientation
    - micro-structure

Types of Reflection

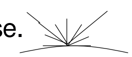
- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



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

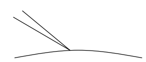


- *mixed* reflection is a weighted combination of specular and diffuse.

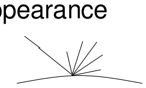


Types of Reflection

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

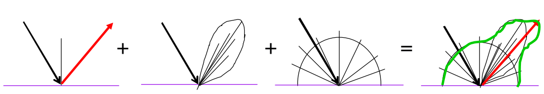


- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.



Reflectance Distribution Model

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

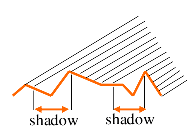


specular + glossy + diffuse =
reflectance distribution

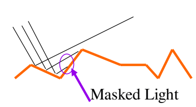
Surface Roughness

- at a microscopic scale, all real surfaces are rough

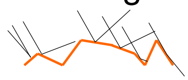
- cast shadows on themselves



- “mask” reflected light:



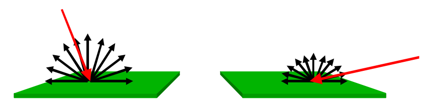
Surface Roughness



- 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



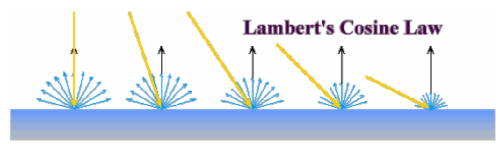
- *what does the reflected intensity depend on?*

Lambert's Cosine Law

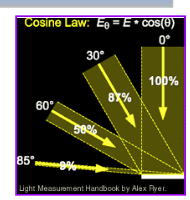
- ideal diffuse surface reflection

  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

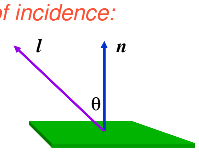


intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

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



k_d :
diffuse component
"surface color"

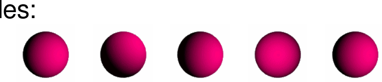
$$I_{diffuse} = k_d \, I_{light} \cos \theta$$

- in practice use vector arithmetic

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

Diffuse Lighting Examples

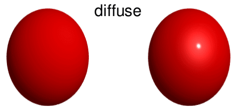
- Lambertian sphere from several lighting angles:



- need only consider angles from 0° to 90°
  - *why?*
  - *demo: Brown exploratory on reflection*

Specular Reflection

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



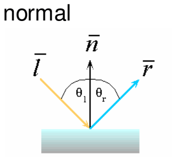
- *specular highlight*
  - bright spot from light shining on a specular surface
- view dependent
  - highlight position is function of the viewer's position

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

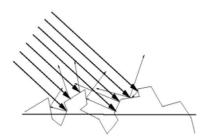
- reflection follows *Snell's Law:*
  - incoming ray and reflected ray lie in a plane with the surface normal
  - angle the reflected ray forms with surface normal equals angle formed by incoming ray and surface normal



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

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 rather than mirror-like?



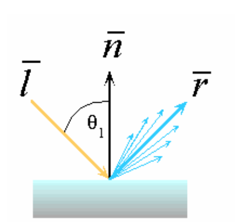
- one option: model the microgeometry of the surface and explicitly bounce rays off of it
- or…

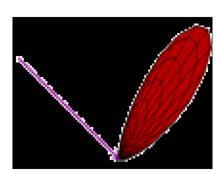
Empirical Approximation

- 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





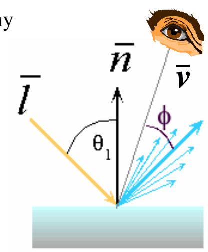
- how might we model this falloff?

Phong Lighting

- most common lighting model in computer graphics

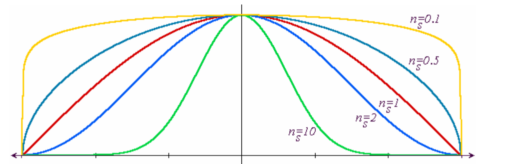
$$I_{specular} = k_s I_{light} (\cos \varphi)^{n_{shiny}}$$

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



Phong Lighting: The n_{shiny} Term

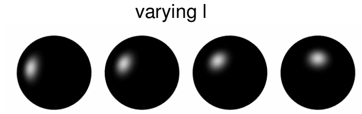
- Phong reflectance term drops off with divergence of viewing angle from ideal reflected ray



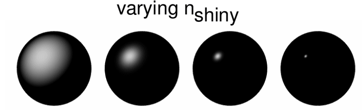
- *what does this term control, visually?*

Phong Examples

varying l



varying n_{shiny}

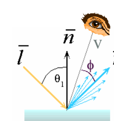


Calculating Phong Lighting

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

$$I_{specular} = k_s I_{light} (\mathbf{v} \bullet \mathbf{r})^{n_{shiny}}$$

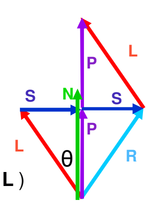
- v: unit vector towards viewer
- r: ideal reflectance direction
- k_s: specular component
  - highlight color



- how to efficiently calculate **r** ?

Calculating The *R* Vector

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

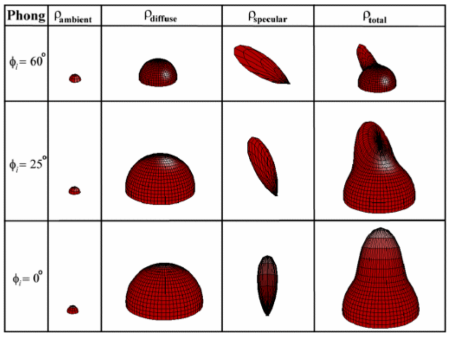
The Phong Lighting Model

- combine ambient, diffuse, specular components

$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{\#lights} I_i \left(k_d (\mathbf{n} \times \mathbf{l_i}) + k_s (\mathbf{v} \times \mathbf{r_i})^{n_{shiny}} \right)$$

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

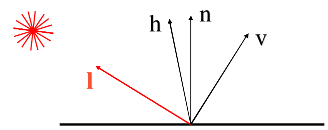
Phong Lighting: Intensity Plots



Blinn-Phong Model

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

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



Lighting Review

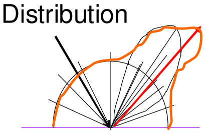
- lighting models
  - – ambient
    - normals don't matter
  - – Lambert/diffuse
    - angle between surface normal and light
  - – Phong/specular
    - surface normal, light, and viewpoint

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.