Illumination

Simple Lighting/Illumination Models

Scene rendered using direct lighting only

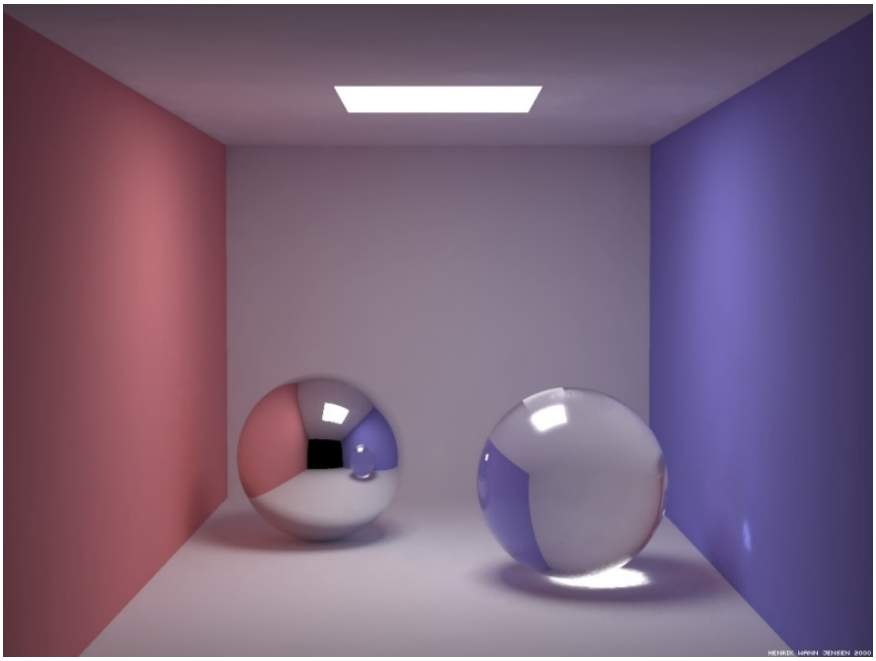
Photograph

Scene rendered using a physically-based global illumination model with manual tuning of colors

(Frederic Drago and Karol Myszkowski, ***Validation Proposal for Global Illumination and Rendering Techniques,*** http://www.mpi-sb.mpg.de/resources/atrium/)

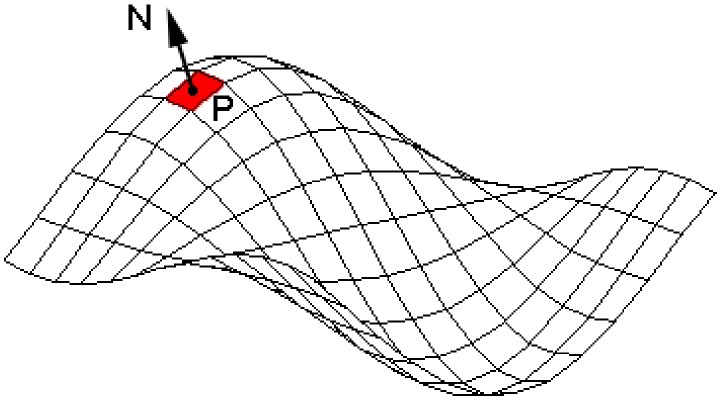
Light From a Scene

- Sampling a scene
  - ideally, need to consider light coming to the viewer from each point on each surface in a scene
- Points in a scene
  - points are the smallest units of our scene: can think of them having no area or infinitesimal area
  - there are an infinite number of visible points: mathematically intractable
- Surface elements
  - only consider a finite number of differential pieces of surface
  - figure out how much light comes to the viewer from each of these pieces of surface



Surface Elements

- Tangent plane approximation
  - most surfaces are curved, not flat
  - a surface element is a differential area on that surface
  - imagine breaking a surface up into a finite number of very small pieces. Pieces are still curved, but if they're small enough, can make them arbitrarily close to being flat



- Surface normals
  - each surface element is an incremental piece of a plane, centered around a point, with a normal
  - in Shapes, you broke the sphere up into triangles, with each vertex having an associated normal. The small area around a vertex is a surface element used to calculate "illumination."

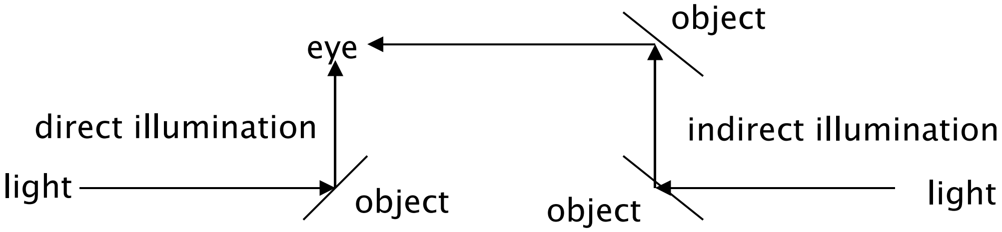
- Illumination
  - light rays coming from the rest of the scene strike that surface element, and (after some percentage of absorption, refraction or subsurface scattering) head out in different directions
  - we want to calculate the intensity and chromaticity values of the light that goes in the direction of the viewer from that surface element (if the viewer moves, those values will change)
  - this is defined as the "illumination" of that surface element

Global Illumination

- Lights and shadows
  - most light striking a surface element comes directly from emissive light sources in the scene (direct illumination)
  - sometimes light from source is blocked by other objects
  - surface element is then in “shadow” from that light source

from Pixar’s “Luxo Jr.”

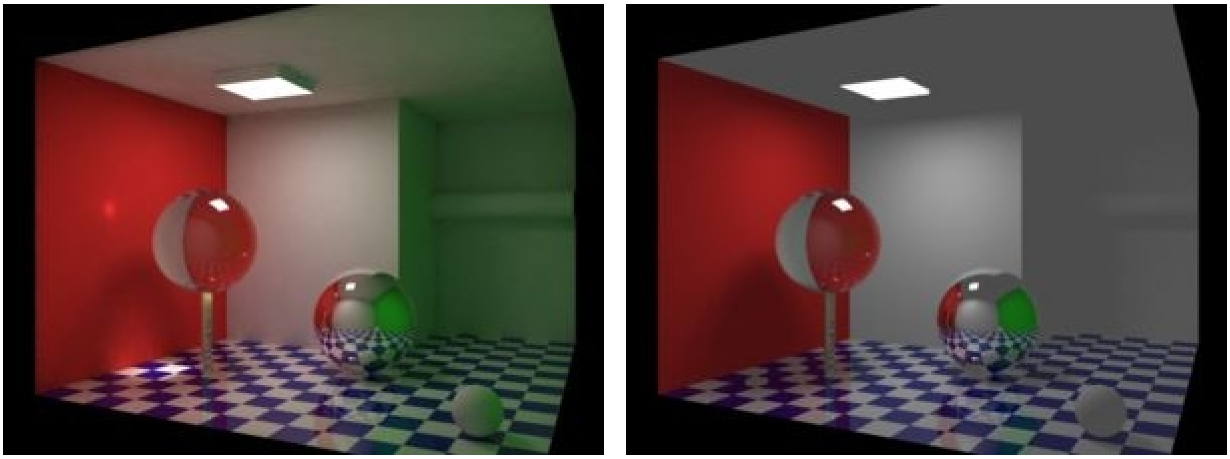
- Inter-object reflection
  - light bounces off other objects toward our surface element
  - when that light reaches our surface element, it brightens it (indirect illumination)



- Global illumination (GI)
  - simulates what happens when other objects affect light reaching a surface element
  - expensive to compute: light reaching surface element may be affected by many other objects in the scene

Non-Global Illumination

- Concentrate on light from light sources
  - ignore effects of all other objects in the scene when considering a particular surface element
  - pro: scene can be rendered much faster
  - con: pay a price in lost realism; lose interesting effects of light transport
- We lose effects of global illumination
  - shadows
  - inter-object reflection
  - refraction, i.e. bending of light at translucent surfaces
  - volumetric effects of participating media such as air, water, and fog



global illumination

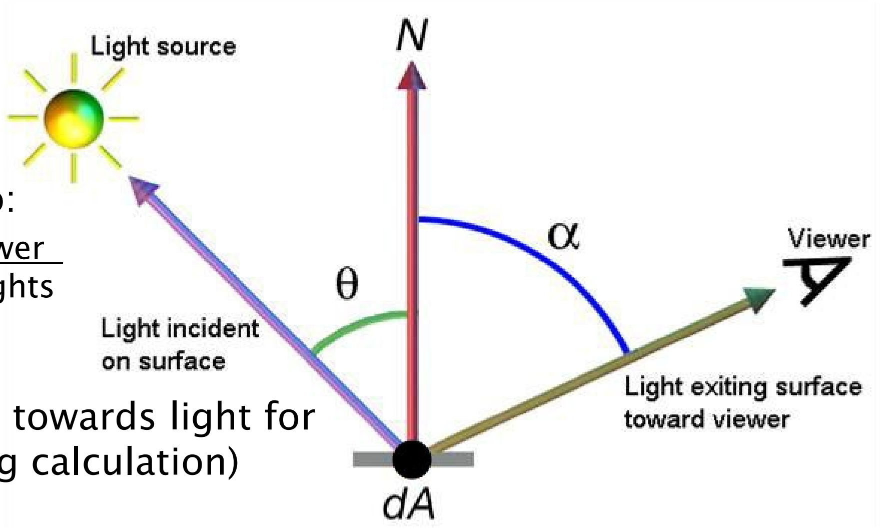
non-global illumination

Wikipedia: GI

- Trade-Offs
  - depending on what you can afford, pick the effects you need and ignore the rest

Describing Light

- Units of light
  - light incident on/exiting from surface measured in specific terms defined later in the radiosity lecture



for now, concentrate on ratio:

$$\frac{\text{Light exiting surface toward viewer}}{\text{Light incident on surface from lights}}$$

(light vector towards light for lighting calculation)

- Factors in computing “Light exiting surface”
  - geometric relationship of surface with respect to lights
  - light incident on surface (color and intensity of emitters and reflectors in the scene)
  - geometric relationship of surface with respect to viewer and other (potentially blocking) objects
  - physical properties of the surface (material)
    - how much light it absorbs, reflects, or refracts
  - optionally: polarization, fluorescence, phosphorescence
- Difficult to define some of these inputs
  - polarization of light, fluorescence, phosphorescence
  - effect of physical properties on light is not fully understood

Illumination Models

- An “Illumination Model” describes inputs, assumptions, and outputs used to calculate illumination of surface elements
  - choose global, non-global, or partially global simulation
  - decide which inputs we can specify during scene creation
  - make assumptions for values of inputs that cannot be specified
  - specify a function that takes inputs and assumptions and calculates the illumination of a surface element
- Physically-Based Illumination Models
  - some models of illumination are based on real physics
  - require accurate input data and make few assumptions
    - rarely have enough information to specify all those inputs.
  - takes a long time to compute illumination
- Non-Physically-Based Illumination Models
  - really just want a model that looks good enough for our application and can be calculated efficiently with available resources

Illumination and Shading

Overview (Next Two Lectures)

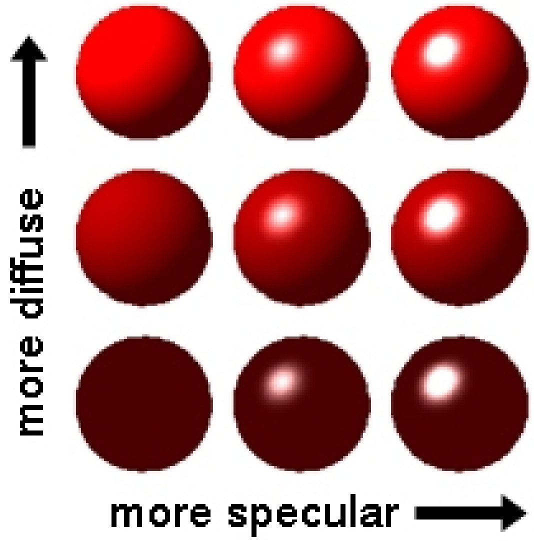
- Phong lighting model: one of the first easily-calculated illumination models to look good
  - simple, non-physical, non-global illumination model describes some observable reflection characteristics of surfaces
  - work done at University of Utah in the early 1970's
  - still used today, as it is easy to do in software and can be optimized in hardware
- Raytracing
  - calculating intersections of ray from eye through pixel w/ scene
  - applying our simple illumination model at intersection point
  - can be done in hardware thanks to new chips

- Simulating Global Effects
- Rendering Polygon Meshes
- Shading Polygons
- Surface Detail
  - texture mapping

A Simple Illumination Model

Components of a simple model

- Characteristics of surfaces:
  - ambient component
    - to account for non-specific global light
  - diffuse component
  - specular component

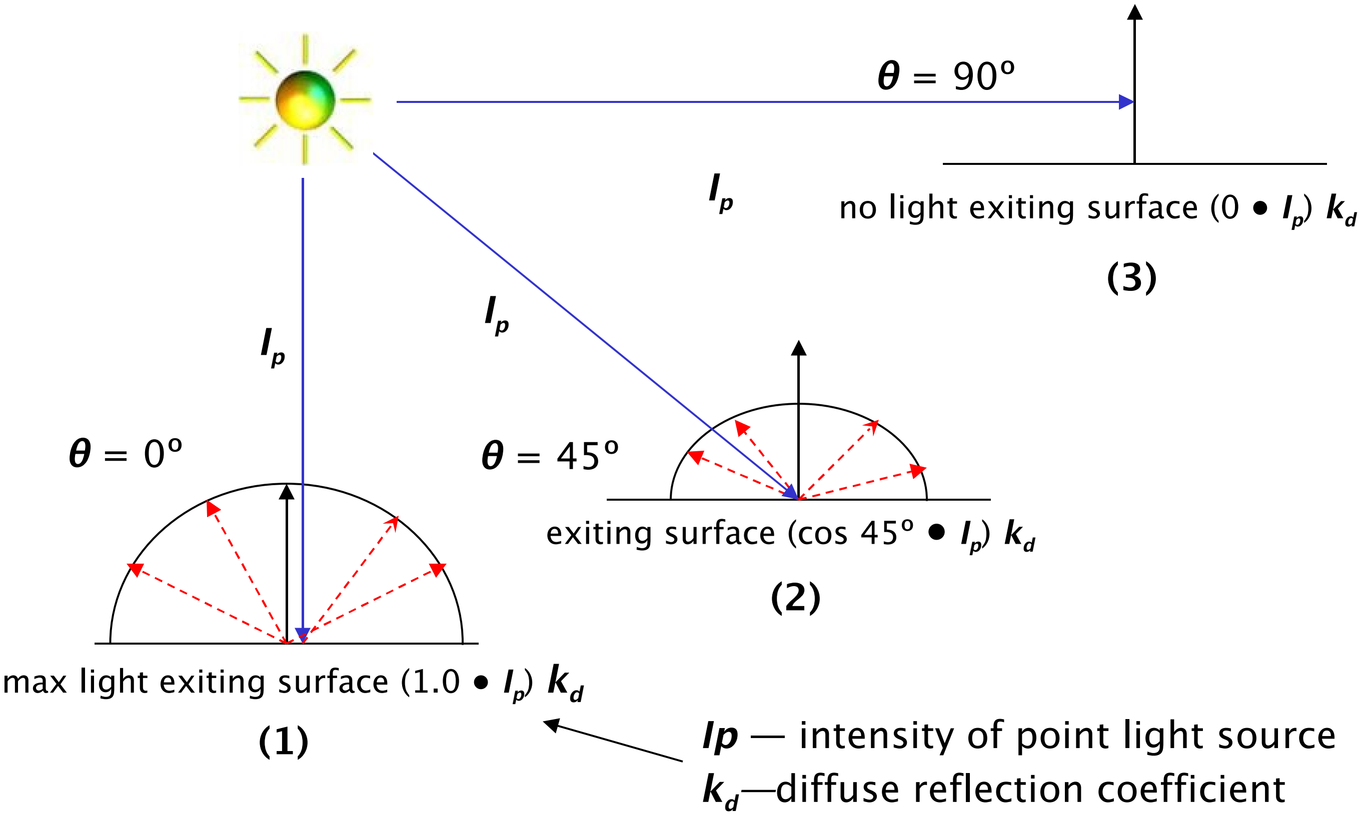


- Reflection caveats
  - NOT physically-based, and does NOT attempt to accurately calculate global illumination
  - does attempt to simulate some of the most important observable effects of common light interactions
  - can be computed quickly and efficiently, so still in use today in graphics software and especially in hardware renderers

Reflection Characteristics of Surfaces (1/7)

Diffuse Reflection

- Diffuse (Lambertian) reflection
  - typical of dull, matte surfaces (e.g., carpet)
  - independent of viewer position
  - dependent on light source position (in this case a point source, again a non-physical abstraction)



θ = 90°

I_p

no light exiting surface (0 • I_p) k_d

(3)

I_p

θ = 45°

exiting surface (cos 45° • I_p) k_d

(2)

I_p

θ = 0°

max light exiting surface (1.0 • I_p) k_d

(1)

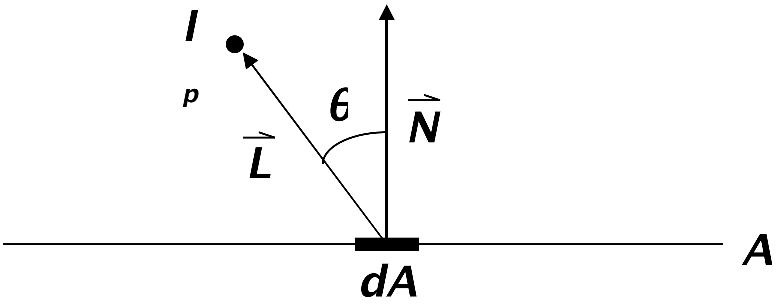
I_p — intensity of point light source

k_d—diffuse reflection coefficient

- In general, light exiting surface = cos(θ) I_p k_d

Reflection Characteristics of Surfaces (2/7)

Lambert's cosine law:



$$I = I_p k_d \cos \theta, \text{ i.e.,}$$

$$I = I_p k_d (\vec{N} \bullet \vec{L})$$

$\vec{N}$ — unit normal of ***A***

$\vec{L}$ — unit vector in direction of light

k_d — diffuse reflection coefficient;

specifies fraction of I_p reflected

- If we just use this, it doesn't look good – too harsh
- Dot Product Applet – http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/dotProduct/dot_product_guide.html

Reflection Characteristics of Surfaces (3/7)

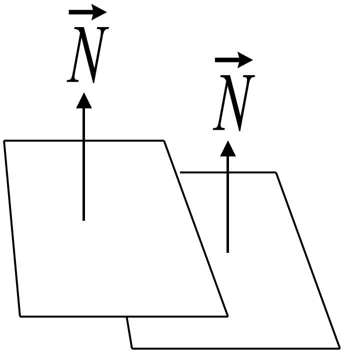
Reflection – Energy Density Falloff

- Should also model inverse square law energy density falloff due to spherical radiation pattern: intensity/unit area falls off as r^2

$$I = f_{att} * (I_p k_d)(N \bullet L), \text{ where } f_{att} = \frac{1}{(d_L)^2}$$

d_L—path length from light to object

- This makes surfaces with equal $k_d(\vec{N} \bullet \vec{L})$ vary in appearance if they are at different distances from the light—important if two surfaces overlap:



- Formula often creates harsh effect – we do not often see objects illuminated by point lights!
- Instead use: $f_{att} = \min\left(\frac{1}{c_1 + c_2 d_L + c_3 (d_L)^2}, 1\right)$

where c_1, c_2, c_3 are experimentally-defined constants. This is a heuristic! (nice word for a hack)

Reflection Characteristics of Surfaces (4/7)

Ambient Light

- Diffuse surfaces reflect light
- Some light goes to eye, some goes to scene
  - light bounces off of other objects and eventually reaches this surface element. Expensive to keep track of accurately, so we use another hack instead.
- Ambient component
  - independent of object position and viewer position
  - constant
  - exists in most environments—some light hits surface from all directions – a crude approximation of indirect lighting/global illumination
  - images without some form of ambient lighting look stark, they have too much contrast

$$I = I_a k_a + f_{att} I_p k_d (\vec{N} \bullet \vec{L})$$

I_a—intensity of ambient light

k_a—fraction reflected, $0 \leq k_a \leq 1$

- Total reflected Light Intensity = Ambient + Diffuse components

Reflection Characteristics of Surfaces (5/7)

Colored Lights and Surfaces

- Write separate equation for each component of color model
  - represent an object's diffuse color by one value of O_d for each component
    - e.g., O_{dR}, O_{dG}, O_{dB} in RGB
  - I_{pR}, I_{pG}, I_{pB} are reflected in proportion to k_dO_{dR}, k_dO_{dG}, k_dO_{dB}, respectively. This works the same way for ambient color.
  - e.g., for the red component:

$$I_R = I_{aR}k_aO_{dR} + f_{att}I_{pR}k_dO_{dR}(\vec{N} \bullet \vec{L})$$

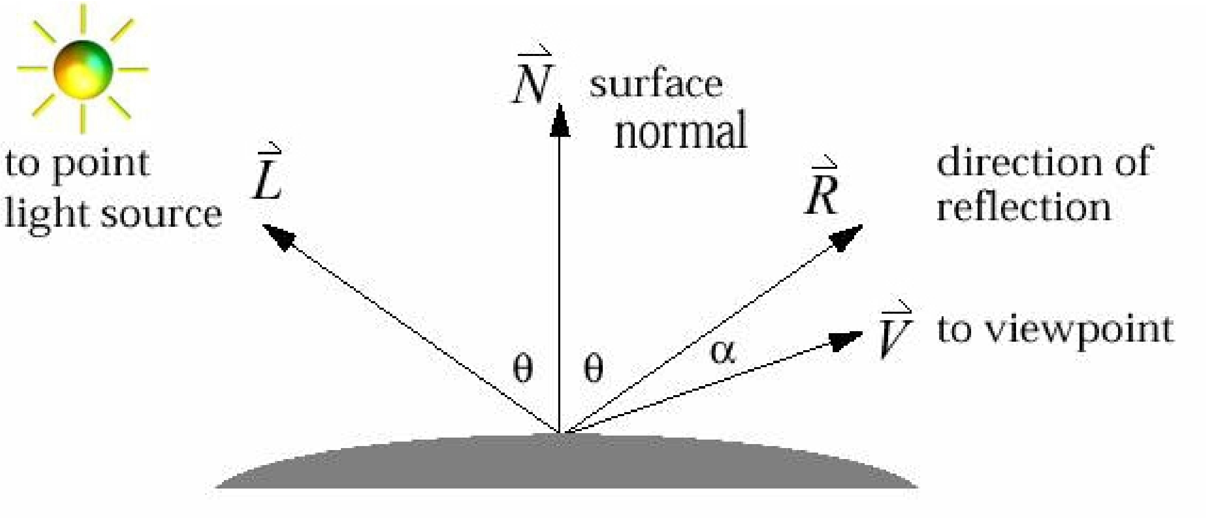
- This should be a wavelength dependent equation
  - evaluating illumination equation at only 3 points in the spectrum is wrong, but often yields acceptable pictures
  - to avoid restricting ourselves to one color sampling space, indicate wavelength dependence with λ. Thus, a better approximation:

$$I_\lambda = I_{a\lambda}k_aO_{d\lambda} + f_{att}I_{p\lambda}k_dO_{d\lambda}(\vec{N} \bullet \vec{L})$$

Reflection Characteristics of Surfaces (6/7)

Specular Reflection

- Directed reflection from shiny surfaces
  - typical of bright, shiny surfaces, e.g. mirrors.

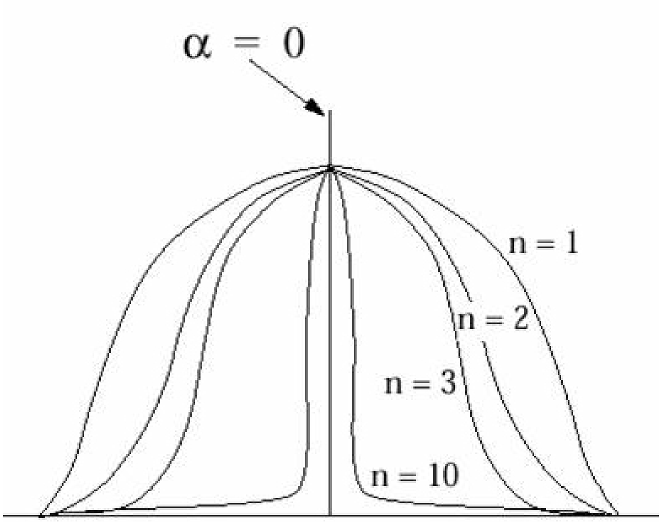


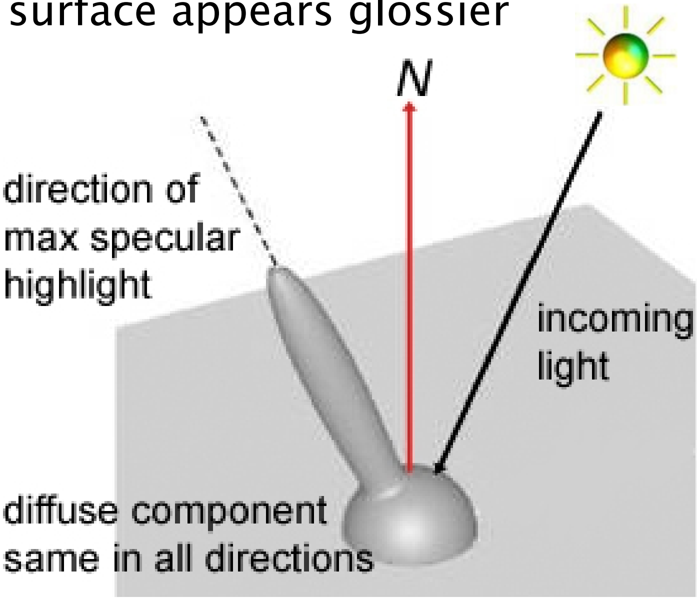
  - color depends on material and how it scatters light energy
    - in plastics: color of point light source
    - in metal: color of metal
    - in others: combine color of light and material
  - early model by Phong neglected effect of material color on specular highlight
    - made all surfaces look plastic
  - dependent on light source position <u>and</u> viewer position
  - for perfect reflector, we see light iff $\alpha = 0$
  - for real reflector, reflected light falls off as α increases
  - cosine law again? Not exactly

Reflection Characteristics of Surfaces (7/7)

Specular Reflection (cont.)

- Phong Approximation
  - specular reflection proportional to $\cos^n\alpha$
    - as ***n*** increases, highlight is more concentrated, surface appears glossier





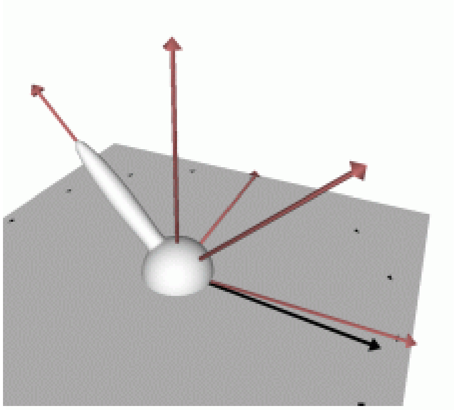
Phong reflection model: diffuse hemi-sphere with specular gaussian surface

  - run the 2D Reflection applet to see how the reflection vector is calculated:

    http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/reflection2D/reflection_2d_guide.html

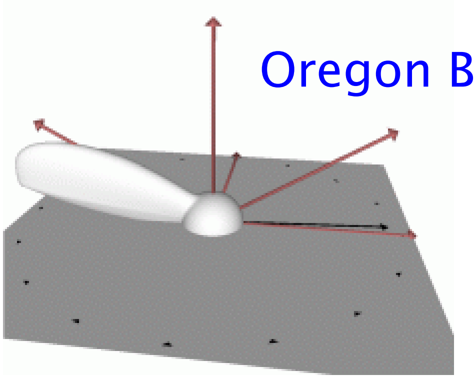
Bidirectional Reflection Distribution Functions

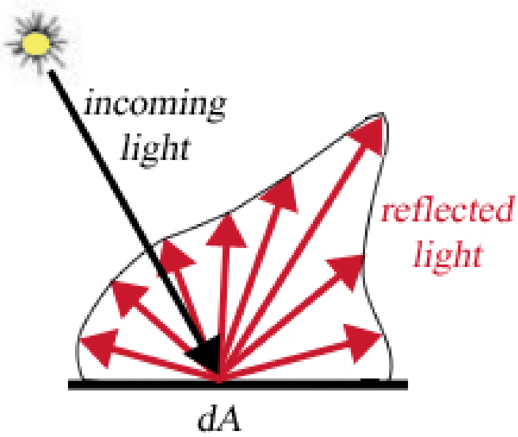
- In general, behavior of light is simulated by bi-directional reflectance distribution functions (**BRDFs**)
  - Lambertian and Phong approximations model simple BRDF
  - given incoming light ray, BRDF is used to calculate how much light will be reflected in a particular outgoing direction (function of incoming and outgoing angles)
  - can be obtained from analytical model or measurements of actual surfaces



Phong

Oregon BRDF Lab

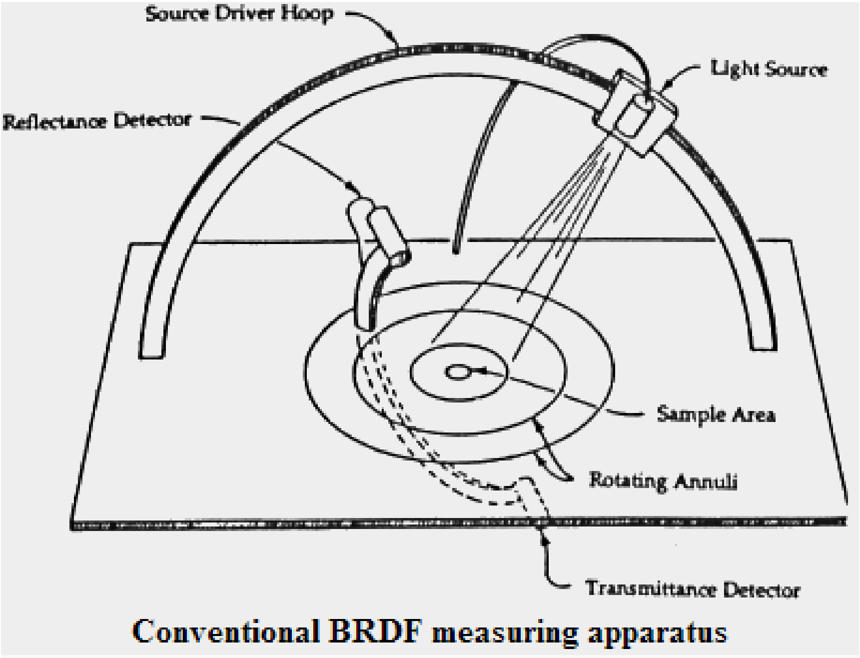




Cook-Torrance (more on last slide)

Physically Accurate BDRFs

- Can measure BDRF with mechanical device
  - analyzes reflection and transmittance from all angles
  - requires a lot of data, but provides accurate model of materials



Conventional BRDF measuring apparatus

Princeton BRDF Page

- often easier to fake BDRF with extensions to basic Phong model

Anisotropic BDRF

- A more complex formula allows variance of specular highlights in multiple directions
  - good for rendering brushed metal or surfaces like CDs/DVDs

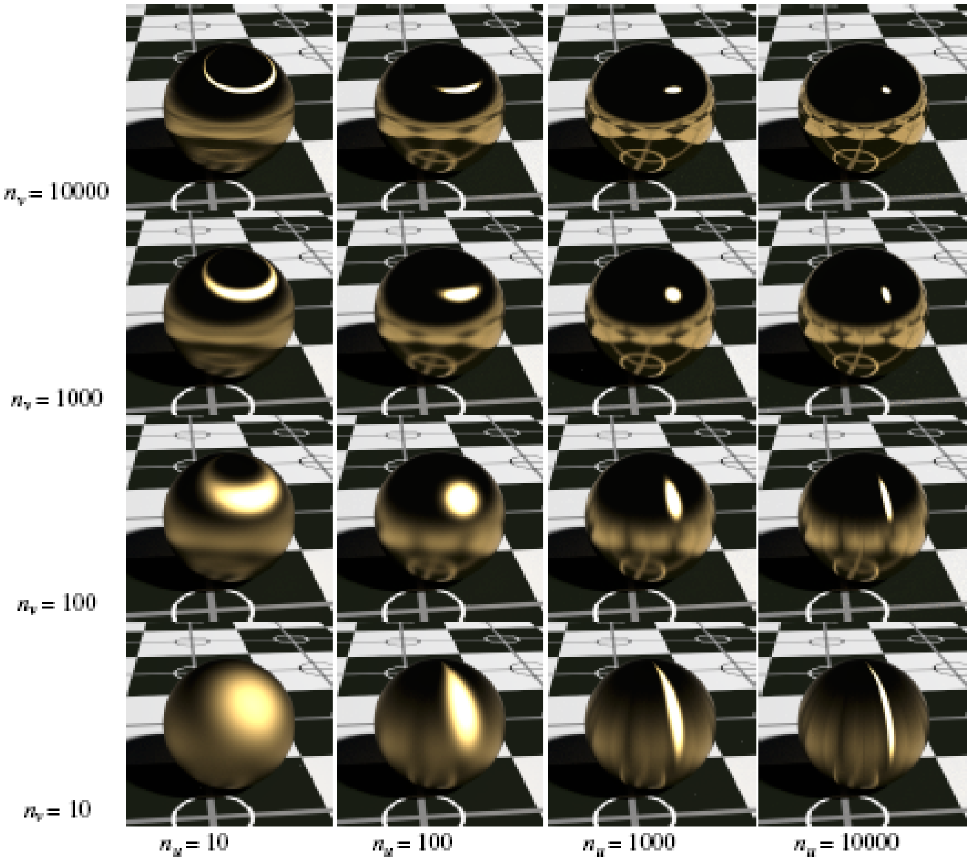


Figure 1: *Metallic spheres for various exponents.*

http://www.cs.utah.edu/~shirley/papers/jgtbrdf.pdf

A Simple Illumination Model

Non-Physical Lighting Equation based on ambient, diffuse, and specular hacks

- Energy from a single light reflected by a single surface element

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + f_{att} I_{p\lambda} [k_d O_{d\lambda} (\vec{N} \bullet \vec{L}) + k_s O_{s\lambda} (\vec{R} \bullet \vec{V})^n]$$

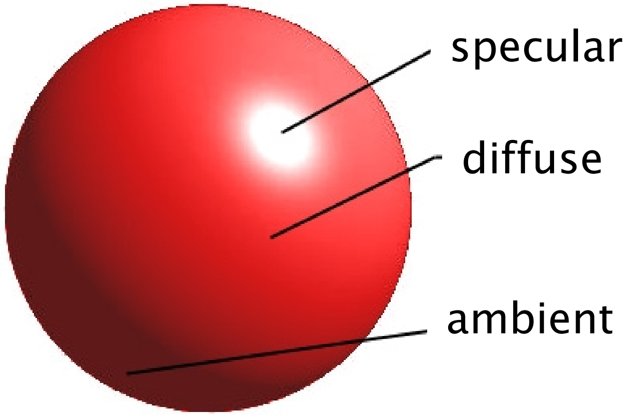
k_s – specular coefficient, fraction of light reflected

$O_{s\lambda}$ – object specular color (<u>not</u> necessarily the same as $O_{d\lambda}$)

- For multiple point lights, simply sum contributions

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + \sum_m f_{att} I_{p\lambda} [k_d O_{d\lambda} (N \cdot L) + k_S O_{S\lambda} (R \cdot V)^n]$$

- This is an easy-to-evaluate equation that gives useful results.
  - it is used in most real-time applications, but it has no basis in theory and does not model reflections correctly



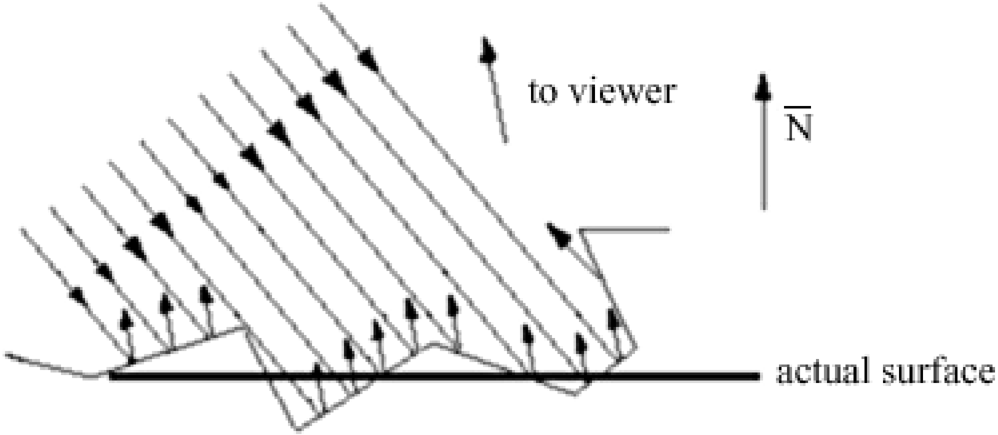
- For more on this model, see pages 721-734 in the book

More Physically-Based Illumination Models

Example: Torrance-Sparrow model

Adapted for graphics by Blinn, and later expanded by Cook and Torrance

- Models surface as shiny and made of randomly-oriented, perfectly reflecting, microscopic facets
- Accounts for geometry in following figure:



- Statistical descriptions: microfacet slope distribution, surface self-shadowing distribution
- For a detailed discussion of physically-based illumination models, consult section 16.7 of the textbook