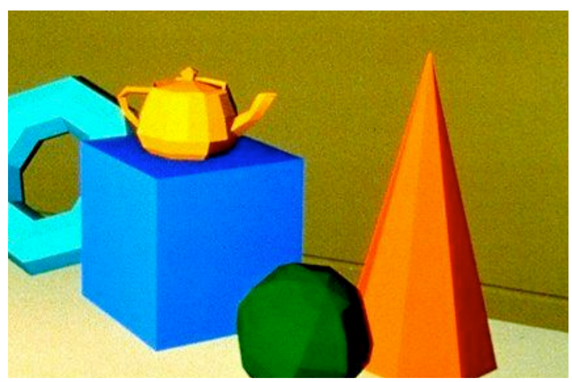
Illumination

(faking light effects via pixel colors)

Simple Lighting/Illumination Models

Scene rendered using direct lighting only

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

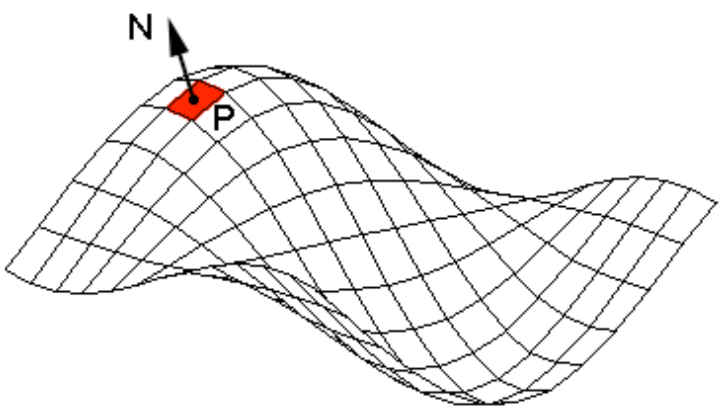
Photograph

(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

- Ideally, need to consider light coming to the viewer from each point on each surface in a scene: mathematically intractable

- Tractable: break each surface into surface elements
  - only consider a finite number of pieces of surface
  - figure out how much light comes to the viewer from each of these pieces of surface



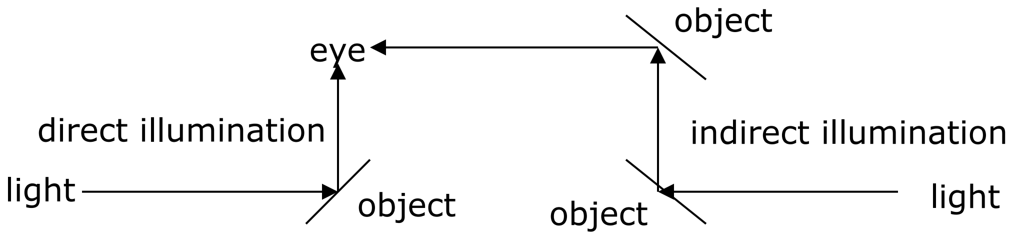
- Tangent plane approximation
  - most surfaces are curved, not flat
  - imagine breaking a surface up into a finite number of very small pieces. Pieces are still curved, but if they're small enough, can make them arbitrarily close to being flat

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."

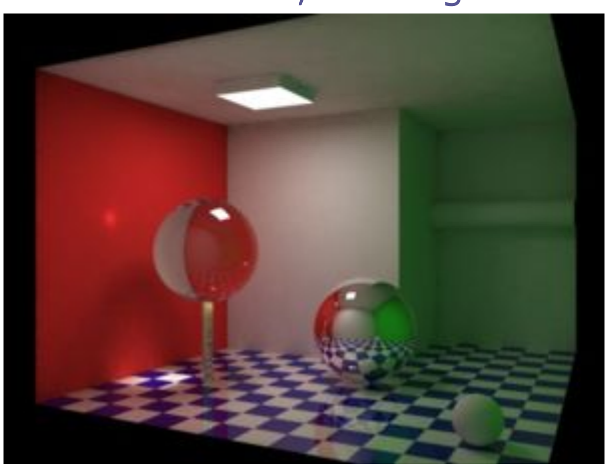
- Inter-object reflection
  - light bounces off other objects toward our surface element
  - when that light reaches our surface element, it brightens it (indirect illumination)



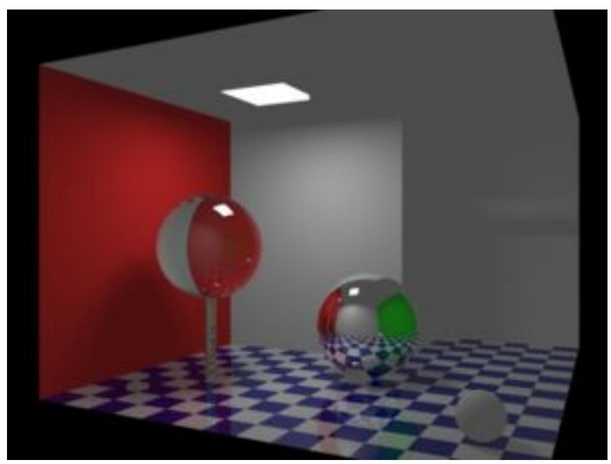
- Global illumination (GI)
  - simulates what happens when other objects affect light reaching a surface element
  - expensive to compute: light reaching surface element may be affected by many other objects in the scene

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
  - soft 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



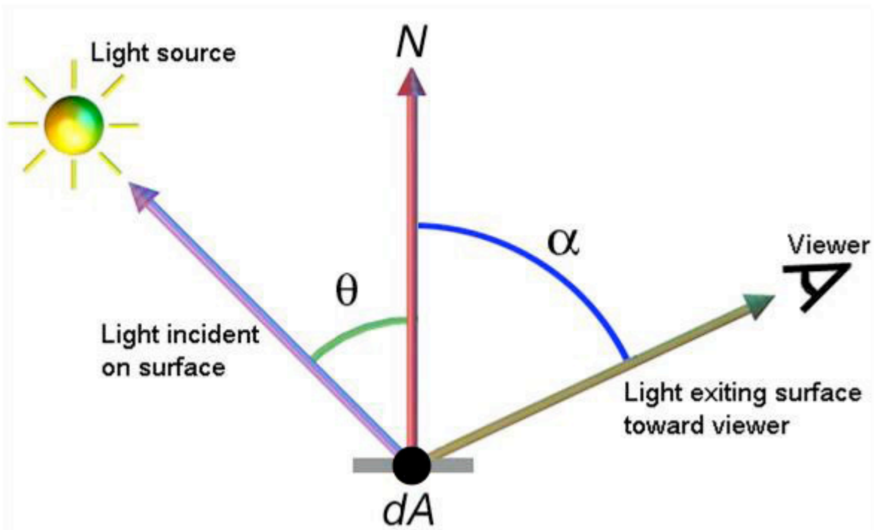
non-global illumination

Wikipedia: GI

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

Describing Light

- Consider light incident on/exiting from surface



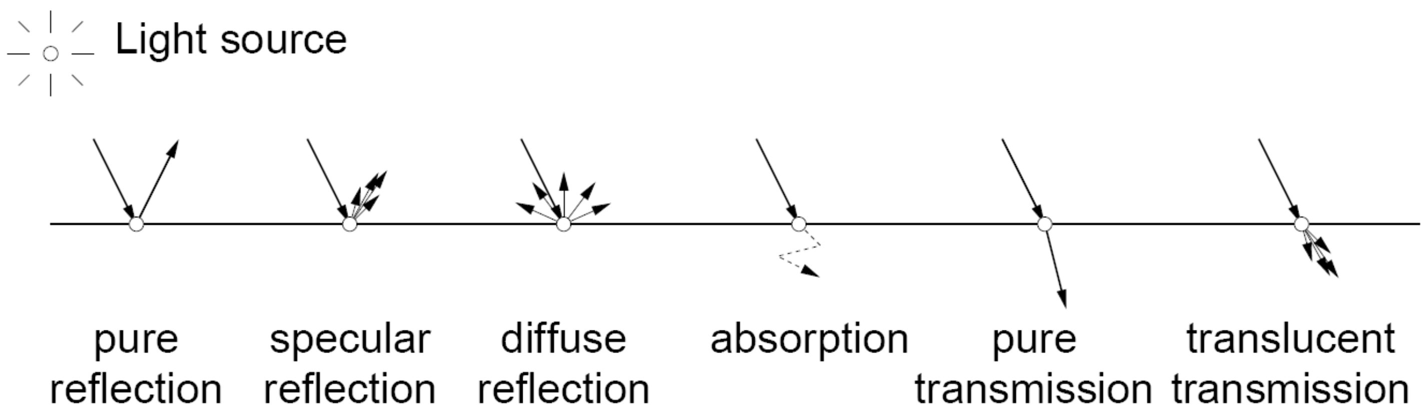
- Factors in computing "Light exiting surface"
  - Properties/characteristics of the light sources
    - Color and intensity of light sources; Position: finite distance to object or at infinity; Geometry: spot-light or with dimension (important for shadows); Physical properties (e.g., phosphorescence)
  - Properties/characteristics of the surface
    - Orientation/position: with respect to viewer and other (potentially blocking) objects; Physical properties of the surface (material): how much light it absorbs, reflects, or refracts;
- Difficult to define some of these inputs

Model of Light

For our purposes, simple model of light:

- photons* are emitted by light source
- they travel unimpeded (if no smoke, fog etc)
- until they hit surface

Afterwards, a few things can happen, depending on the characteristics of the surface:

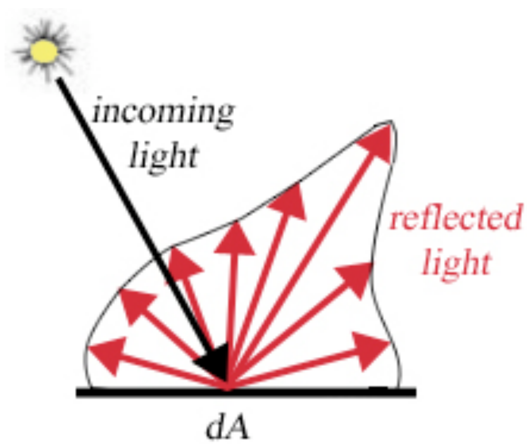


- Real surfaces posses various combinations of these elements and more (e.g., SSS - subsurface scattering, where light is transmitted under surface, bounced around, and then reflected at some other point)

* In physics, a photon is the elementary particle that carries the electromagnetic radiation of all wavelengths (including light)

Bidirectional Reflection Distribution Functions: BRDFs

- A relatively accurate description of surface characteristics
- Describes the probability than an incoming photon will leave in a particular outgoing direction
  - 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)
- Huge topic!

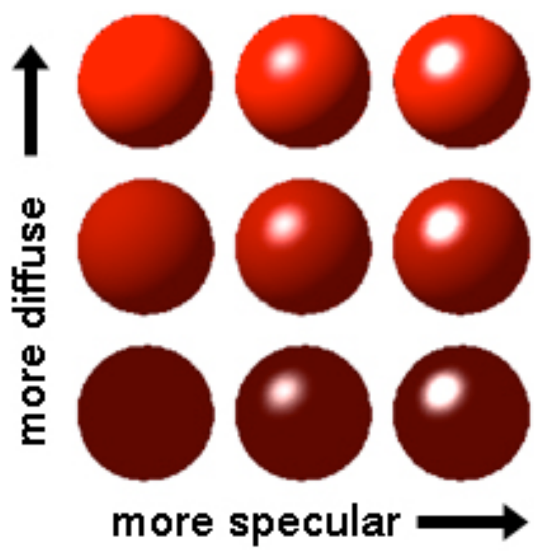


- Many different ways to get these BRDFs:
  - from analytical models
  - hacks: amb+diff+spec
  - measurements of actual surfaces

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

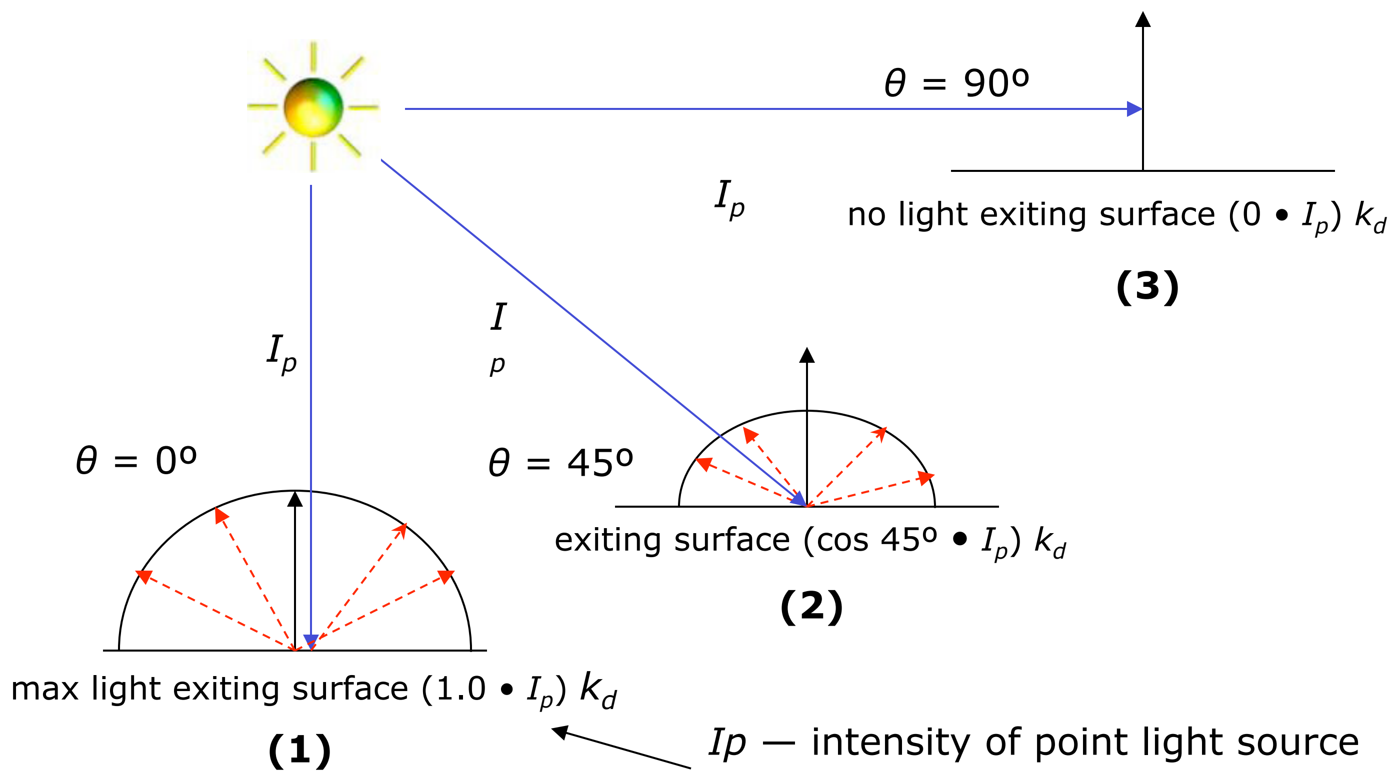


- Reflection caveats
  - NOT physically-based, and does NOT attempt to accurately calculate global illumination
  - does attempt to simulate some of the most important observable effects of common light interactions
  - can be computed quickly and efficiently, so still in use today in graphics software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

Reflection Characteristics of Surfaces: Difussion (1/3)

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)

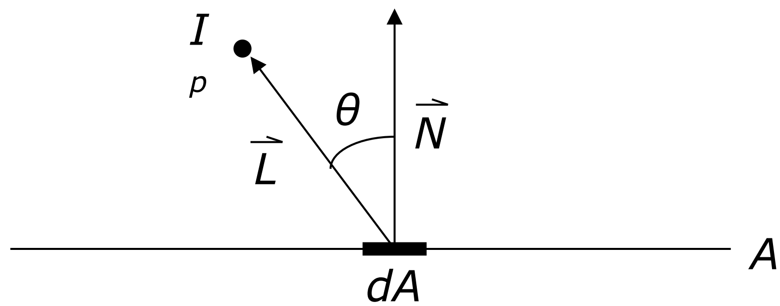


Ip — intensity of point light source
k_d—diffuse reflection coefficient

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

Reflection Characteristics of Surfaces: Difussion (2/3)

Lambert's cosine law:



$$I = I_p\, k_d \cos\theta,$$

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, two surfaces located at different distances from the light source but at the same angle would be identically illuminated – not good

Reflection Characteristics of Surfaces: Difussion (3/3)

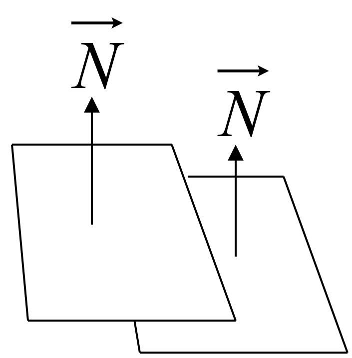
Reflection – Energy Density Falloff

- Light energy density falls off proportionally to the distance between source and surface:

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

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 – two surfaces at slightly different distances will be very differently illuminated

- 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: Ambient (1/2)

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

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

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: Ambient (2/2)

Colored Lights and Surfaces

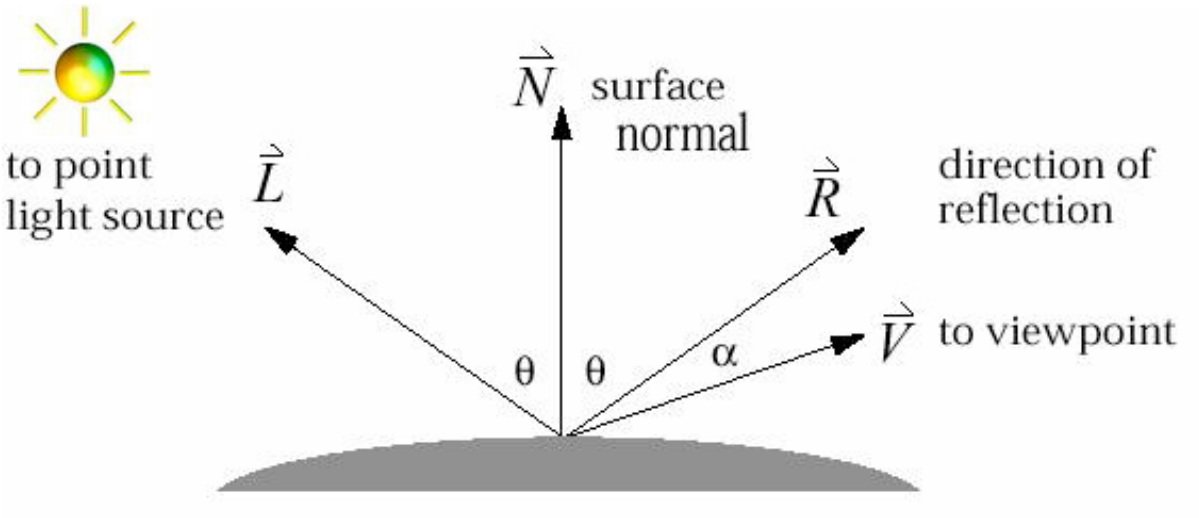
- Write separate equation for each component of color model
  - represent an object's diffuse color by one value of O_d for each component
    - e.g., O_{dR}, O_{dG}, O_{dB} in RGB (object diffuse red etc.)
  - I_{pR}, I_{pG}, I_{pB} are reflected in proportion to k_dO_{dR}, k_dO_{dG}, k_dO_{dB}, respectively.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

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

Reflection Characteristics of Surfaces: Specular (1/2)

Specular Reflection

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

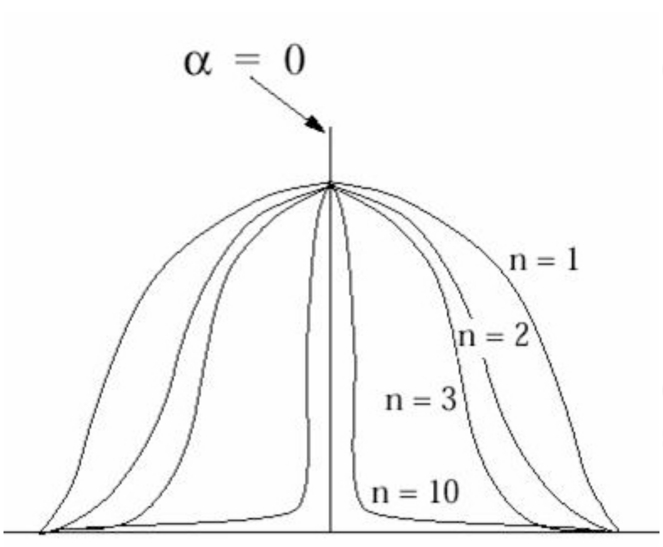


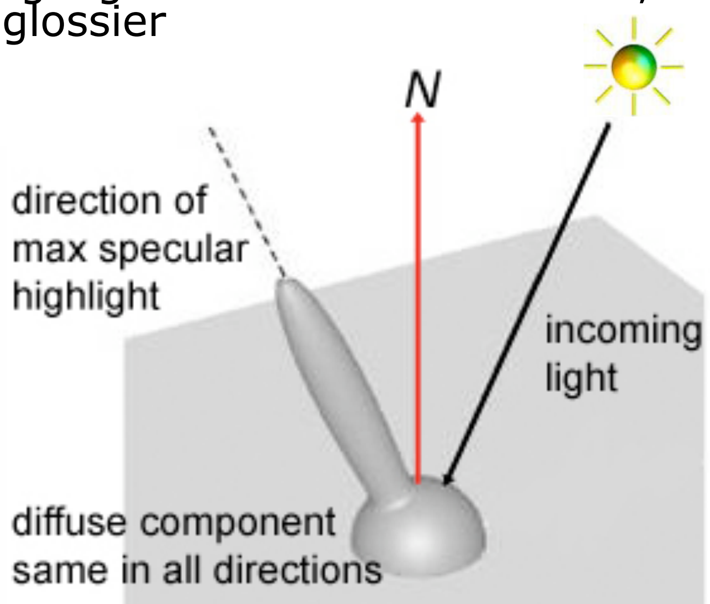
  - color depends on material and how it scatters light energy
    - in plastics: color of point light source
    - in metal: color of metal
    - in others: combine color of light and material
  - dependent on light source position <u>and</u> viewer position
  - for perfect reflector, we see light iff $\alpha = 0$
  - for real reflector, reflected light falls off as α increases
  - cosine law again? Not exactly: $I_p\, k_s \cos^n(\alpha)$

Reflection Characteristics of Surfaces (2/2)

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 (from Applets) to see how the reflection vector is calculated
  - paper – small n; metal – high n

  - more complex formulas allow for multi-directional variance of specular highlights

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

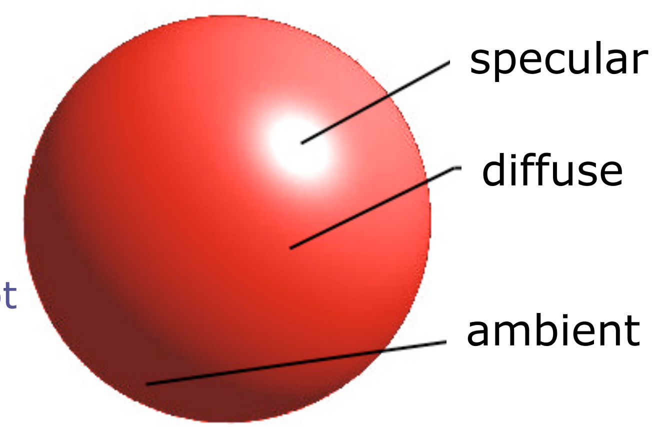
$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + f_{att} I_{p\lambda} [k_d O_{d\lambda} (\vec{N} \bullet \vec{L}) + k_s O_{s\lambda} (\vec{R} \bullet \vec{V})^n]$$

k_s - specular coefficient, fraction of light reflected
$O_{s\lambda}$ - object specular color (<u>not</u> necessarily the same as $O_{d\lambda}$)

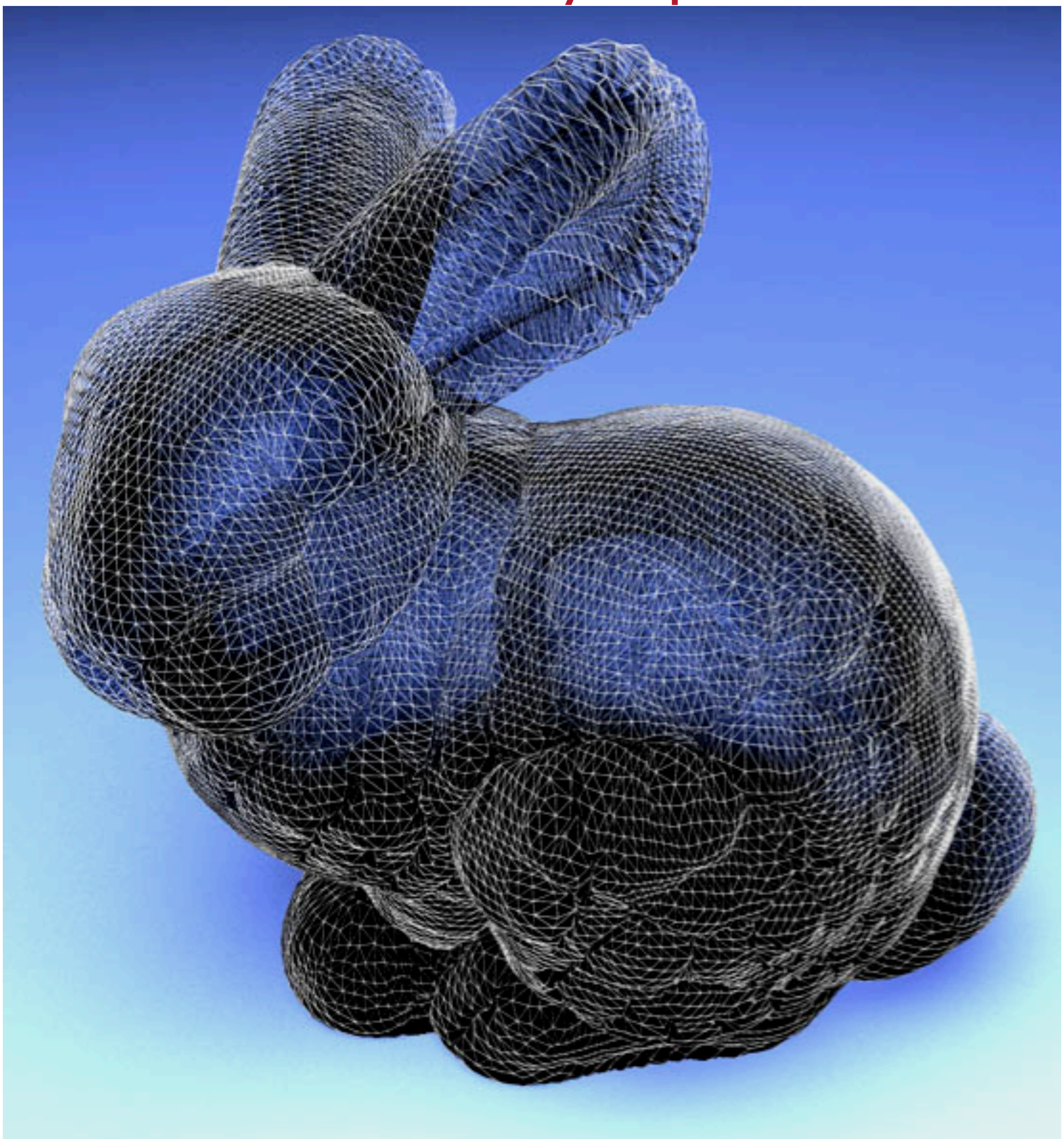
- For multiple point lights, simply sum contributions

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

- 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



How Many Ops?



Summary

- Illumination
- Global vs. local illumination
- Light, BRDFs & hacks
- Illumination models
  - Non-physically based
    - Lambert (diffuse) reflection
    - Ambient reflection
    - Specular reflection – the Phong reflection model
    - All together: the Phong Illumination model!
  - Physically-based