CS380: Computer Graphics

# Illumination and Shading

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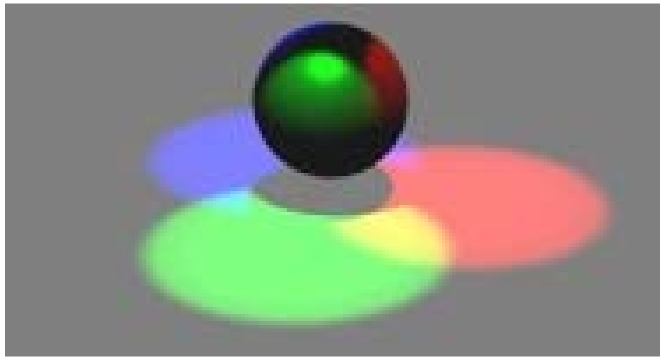
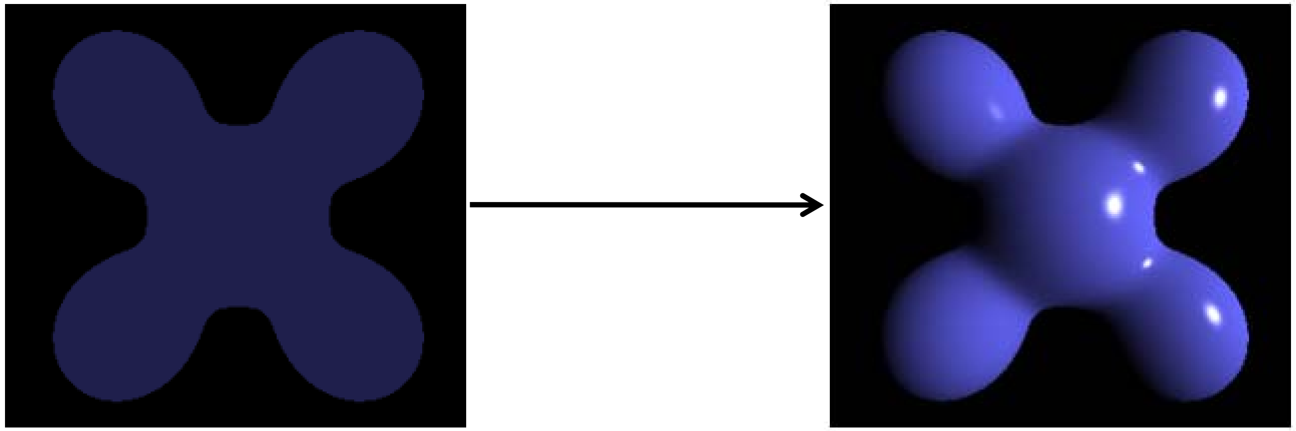
(윤성의)

Course URL:
http://sglab.kaist.ac.kr/~sungeui/CG/

# Course Objectives (Ch. 10)

- **Know how to consider lights during rendering models**
  - **Light sources**
  - **Illumination models**
  - **Shading**
  - **Local vs. global illumination**

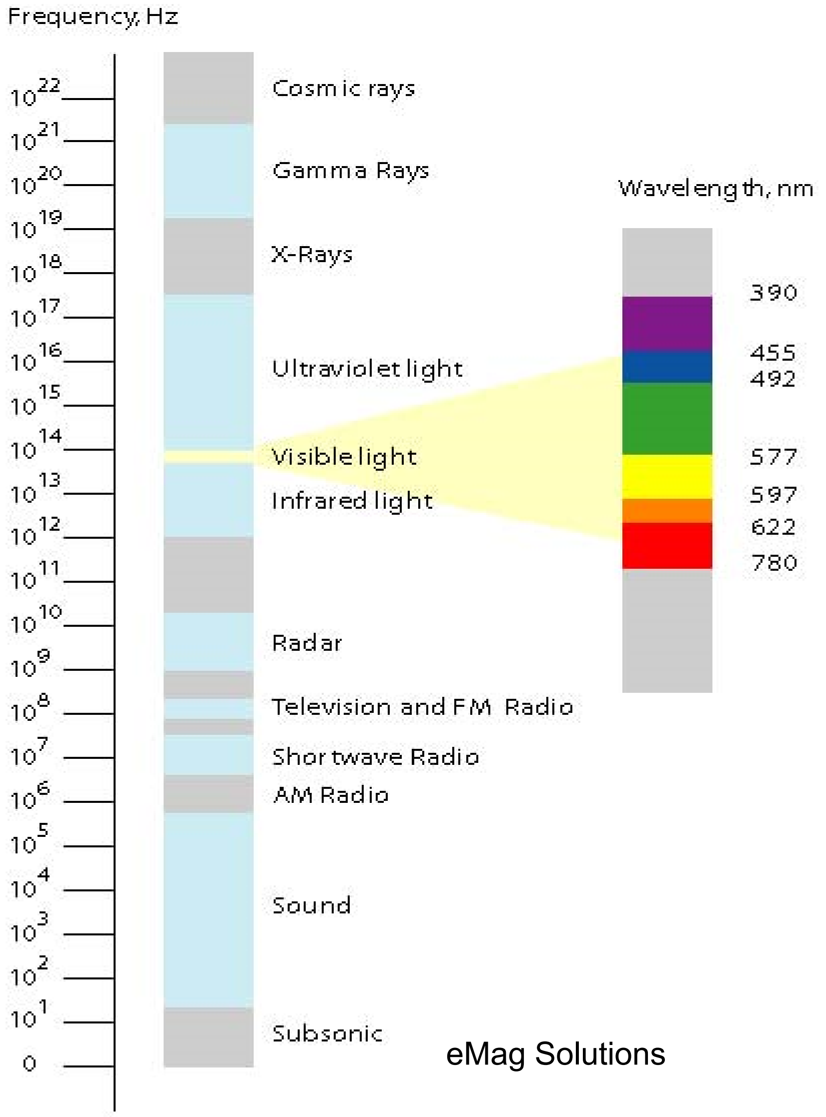




## Question: How Can We See Objects?

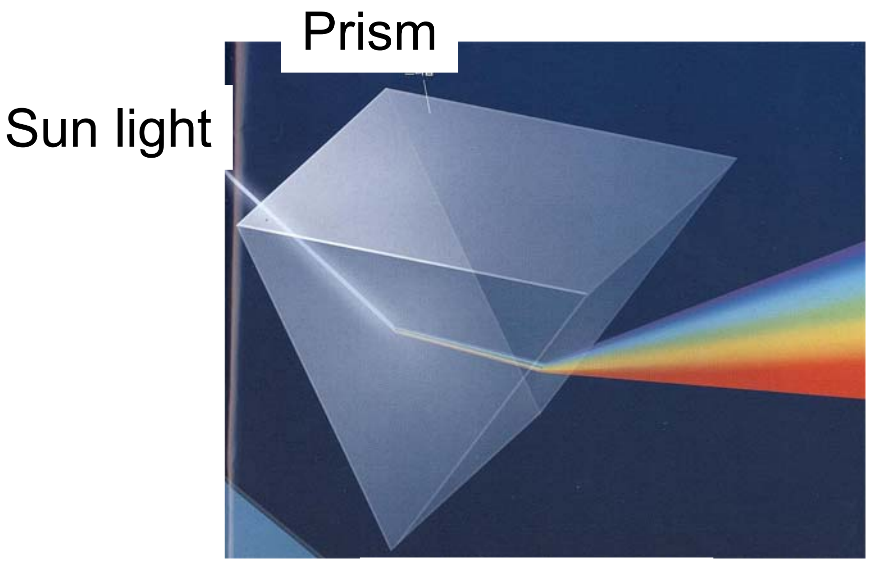
- Emission and *reflection*!

# Question: How Can We See Objects?



eMag Solutions

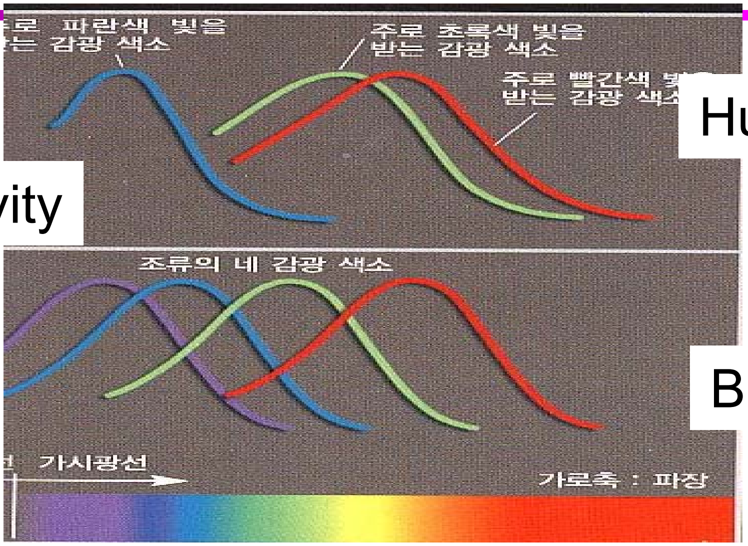
**Light (sub-class of electromagnetic waves)**



From Newton magazine

# Question: How Can We See Objects?

Sensitivity



Human

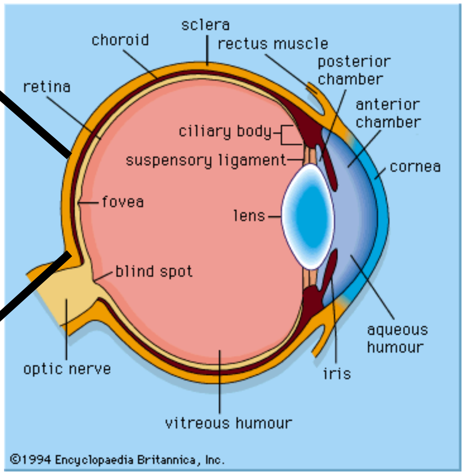
Birds

**Light**
**(sub-class of electromagnetic waves)**

Rod and cone

원추세포(파란색 센서)
원추세포(초록색 센서)

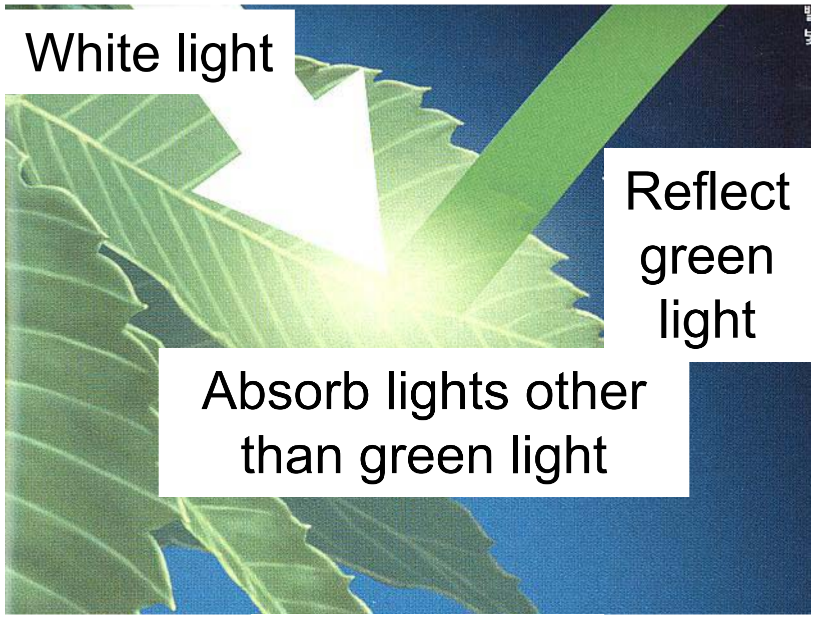
From Newton magazine



**Eye**

# Question: How Can We See Objects?

- **Emission and *reflection*!**



From Newton magazine

**Light
(sub-class of
electromagnetic waves)**

**Eye**

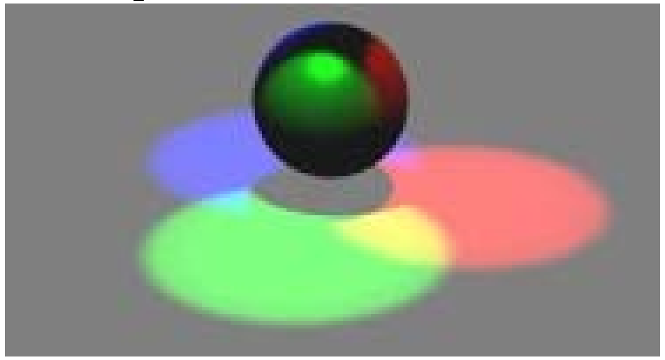
- **How about mirrors and white papers?**

## Illumination Models

- Physically-based
  - Models based on the actual physics of light's interactions with matter
- Empirical
  - Simple formulations that approximate observed phenomenon

## Two Components of Illumination

- Light sources:
  - Emittance spectrum (color)
  - Geometry (position and direction)
  - Directional attenuation

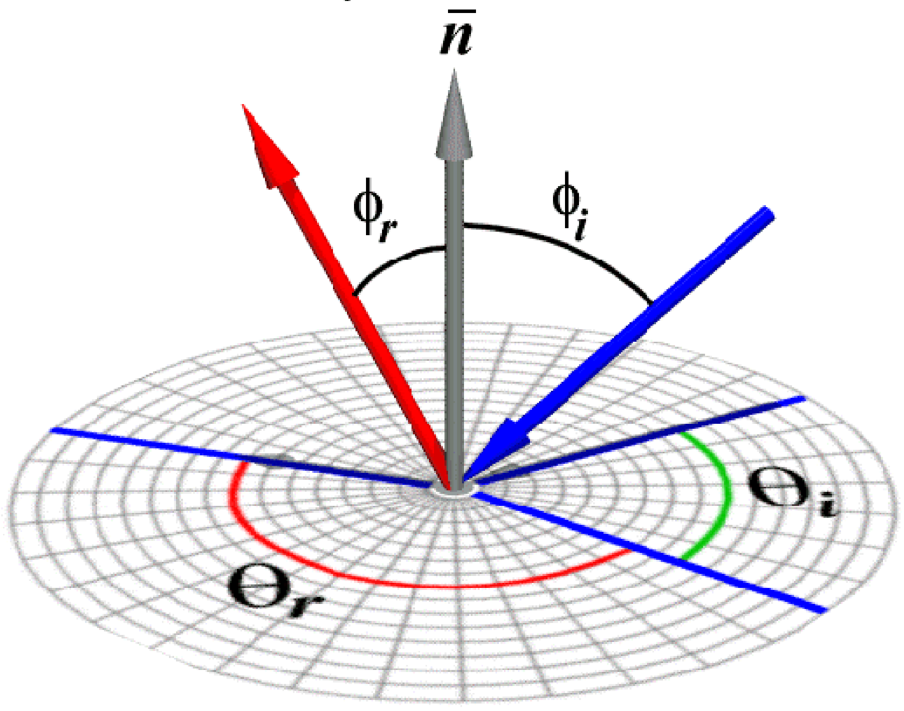


- Surface properties:
  - Reflectance spectrum (color)
  - Geometry (position, orientation, and micro-structure)
  - Absorption

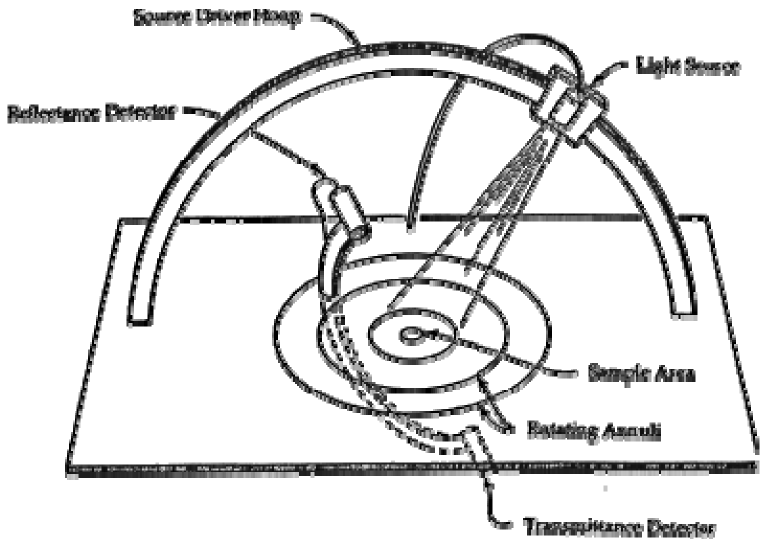
# Bi-Directional Reflectance Distribution Function (BRDF)

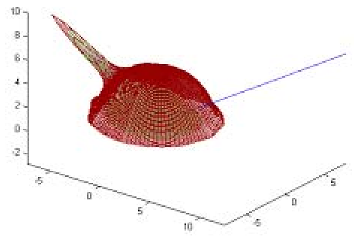
- **Describes the transport of irradiance to radiance**

$\rho(\theta_r, \phi_r, \theta_i, \phi_i)$



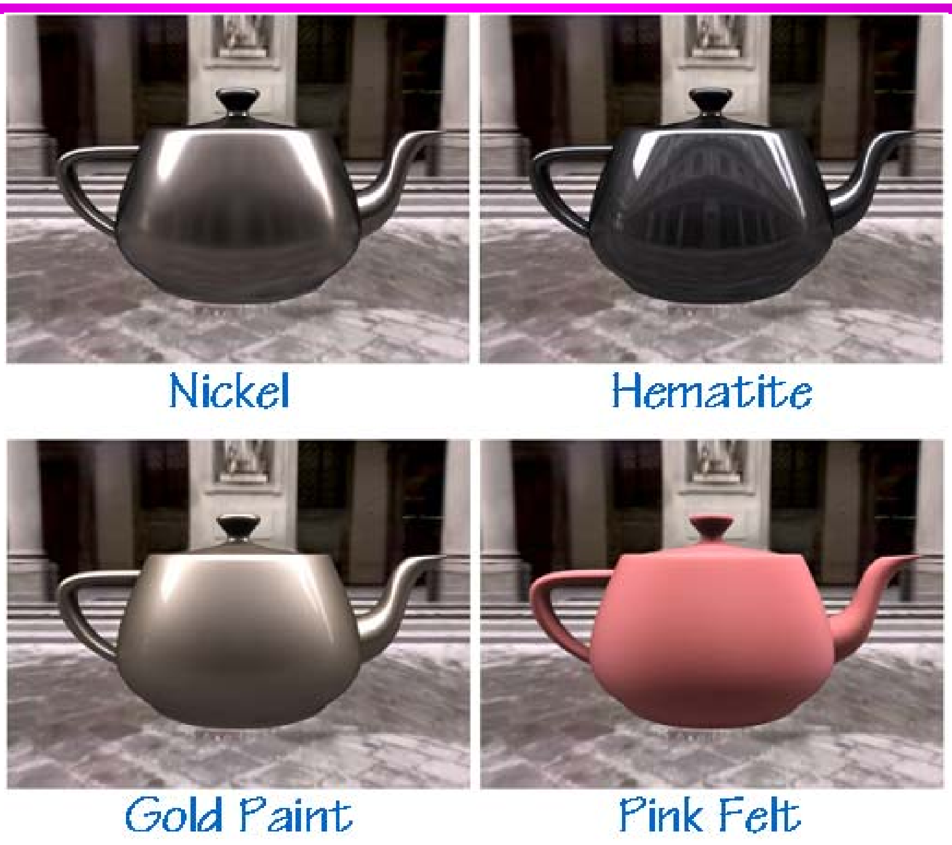
# Measuring BRDFs





- **Goniophotometer**
    - **One 4D measurement at a time (slow)**

## How to use BRDF Data?



*One can make direct use of acquired BRDFs in a renderer*

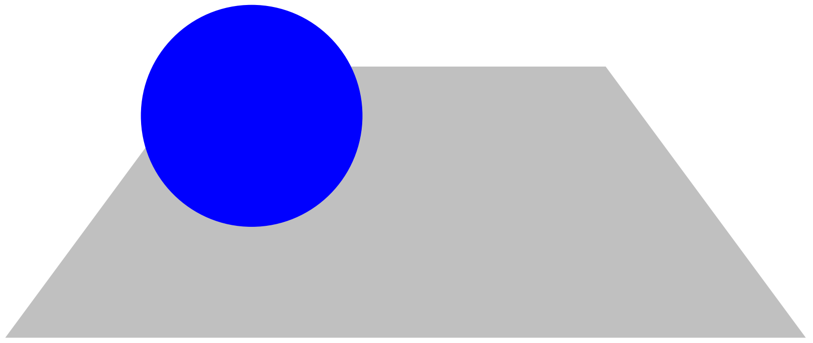
## Two Components of Illumination

- Simplifications used by most computer graphics systems:
  - Compute only direct illumination from the emitters to the reflectors of the scene
  - Ignore the geometry of light emitters, and consider only the geometry of reflectors

## Ambient Light Source

- A simple <u>hack</u> for indirect illumination
  - Incoming ambient illumination ($I_{i,a}$) is constant for all surfaces in the scene
  - Reflected ambient illumination ($I_{r,a}$) depends only on the surface's ambient reflection coefficient ($k_a$) and not its position or orientation $I_{r,a} = k_a I_{i,a}$

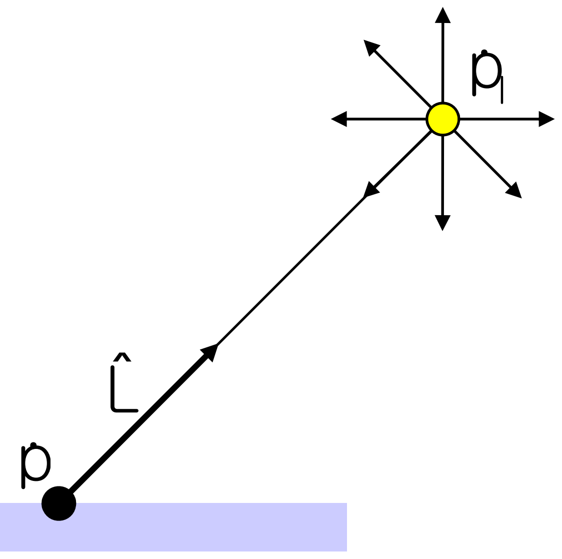
  - These quantities typically specified as (R, G, B) triples



# Point Light Sources

- **Point light sources emit rays from a single point**
  - **Simple approximation to a local light source such as a light bulb**

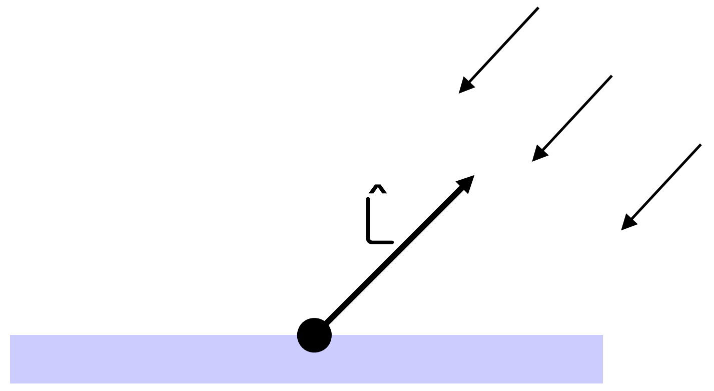
$$\hat{L} = \frac{\dot{p}_l - \dot{p}}{\left\| \dot{p}_l - \dot{p} \right\|}$$



- **The direction to the light changes across the surface**

# Directional Light Sources

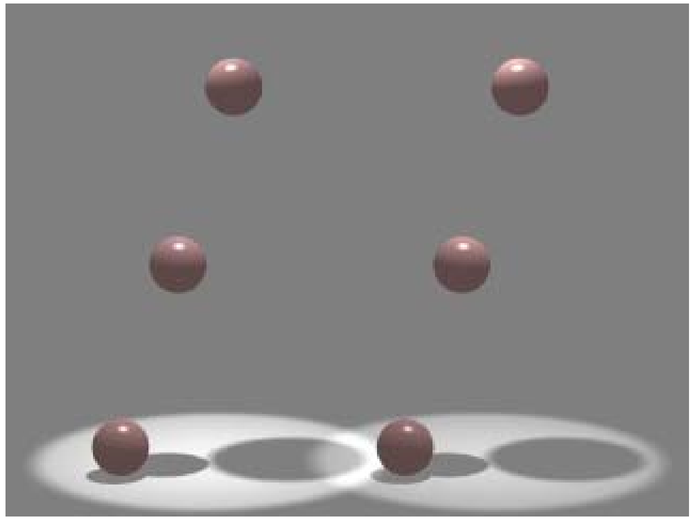
- Light rays are parallel and have no origin
  - Can be considered as a point light at infinity
  - A good approximation for sunlight

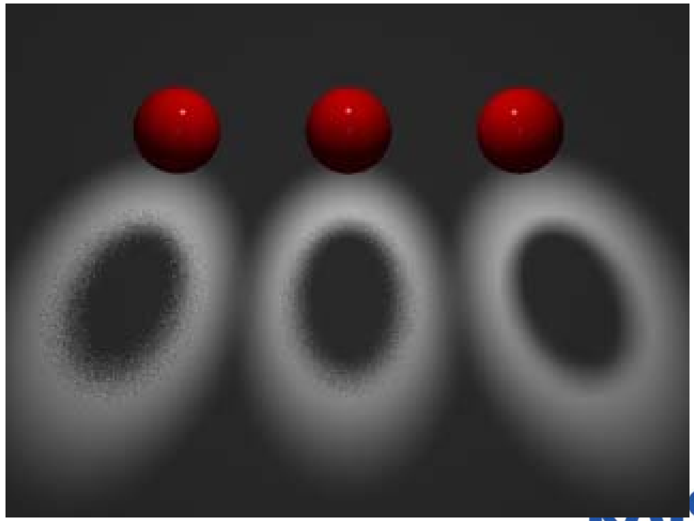


- The direction to the light source is constant over the surface
- How can we specify point and directional lights?

## Other Light Sources

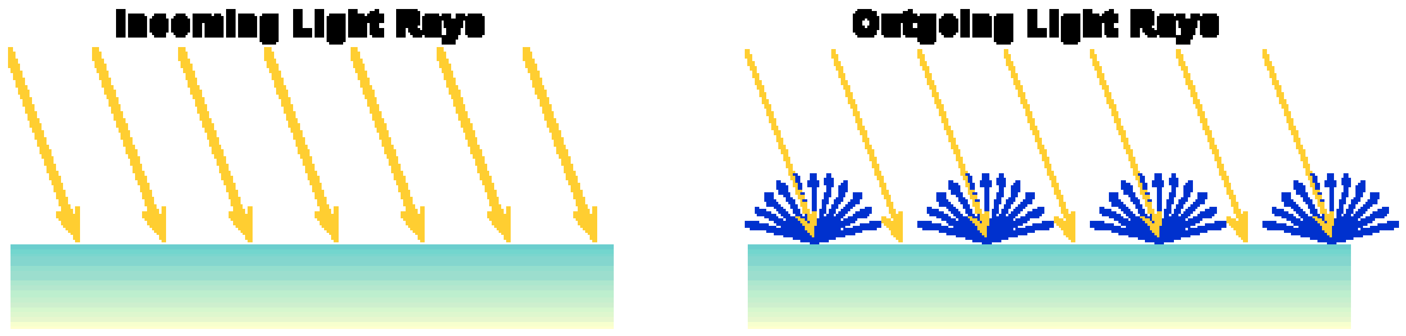
- Spotlights
  - Point source whose intensity falls off away from a given direction
- Area light sources
  - Occupies a 2D area (e.g. a polygon or a disk)
  - Generates *soft* shadows





## Ideal Diffuse Reflection

- Ideal diffuse reflectors (e.g., chalk)
  - Reflect uniformly over the hemisphere
  - Reflection is view-independent
  - Very rough at the microscopic level
- Follow Lambert’s cosine law

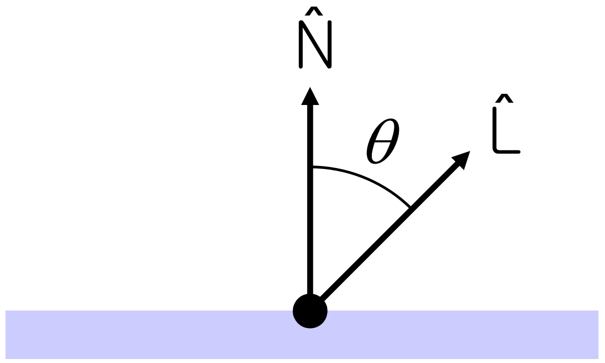


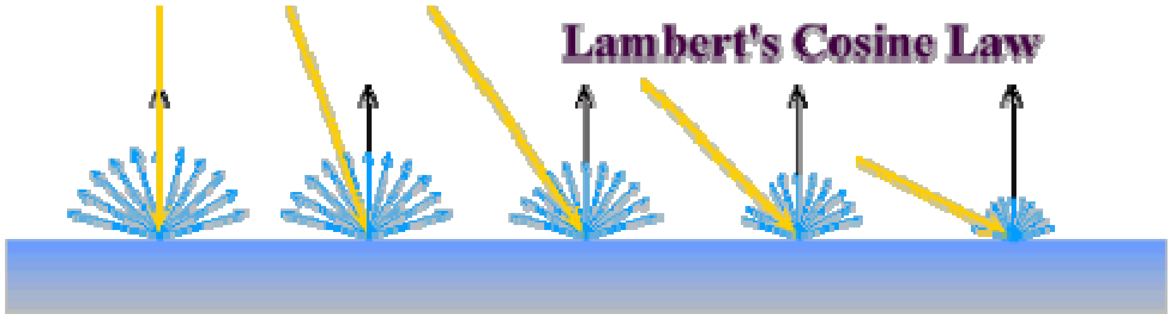
# Lambert's Cosine Law

- **The reflected energy from a small surface area from illumination arriving from direction $\hat{L}$ is proportional to the cosine of the angle between $\hat{L}$ and the surface normal**

$$I_r \approx I_i \cos\theta$$

$$\approx I_i(\hat{N} \bullet \hat{L})$$



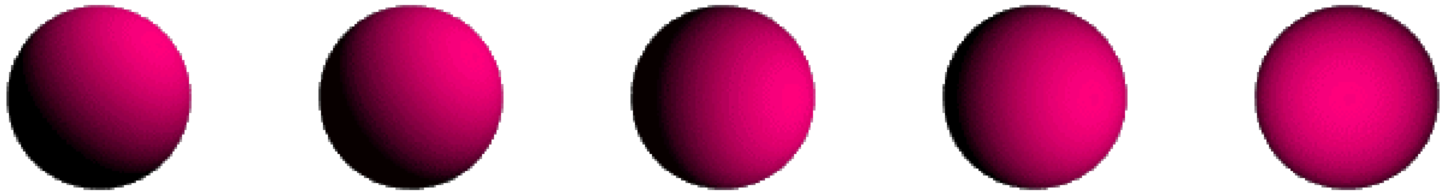


## Computing Diffuse Reflection

- Constant of proportionality depends on surface properties

$$I_{r,d} = k_d I_i (\hat{N} \bullet \hat{L})$$

  - The constant $k_d$ specifies how much of the incident light $I_i$ is diffusely reflected



Diffuse reflection for varying light directions

  - When $(\hat{N} \cdot \hat{L}) < 0$ the incident light is blocked by the surface itself and the diffuse reflection is 0

KAIST

## Specular Reflection

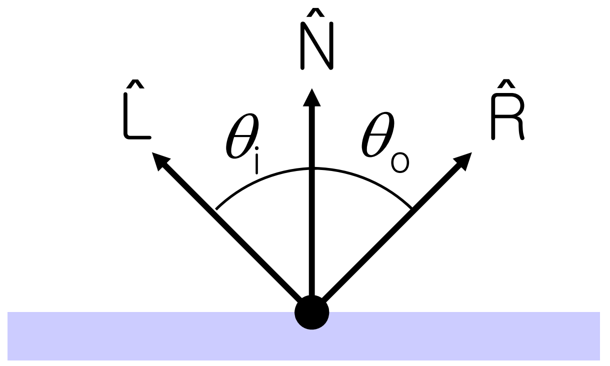
- Specular reflectors have a bright, view dependent highlight
  - E.g., polished metal, glossy car finish, a mirror
  - At the microscopic level a specular reflecting surface is very smooth
  - Specular reflection obeys Snell's law

Image source: astochimp.com and wiki

# Snell's Law

- The relationship between the angles of the incoming and reflected rays with the normal is given by:

$$n_i \sin\theta_i = n_o \sin\theta_o$$



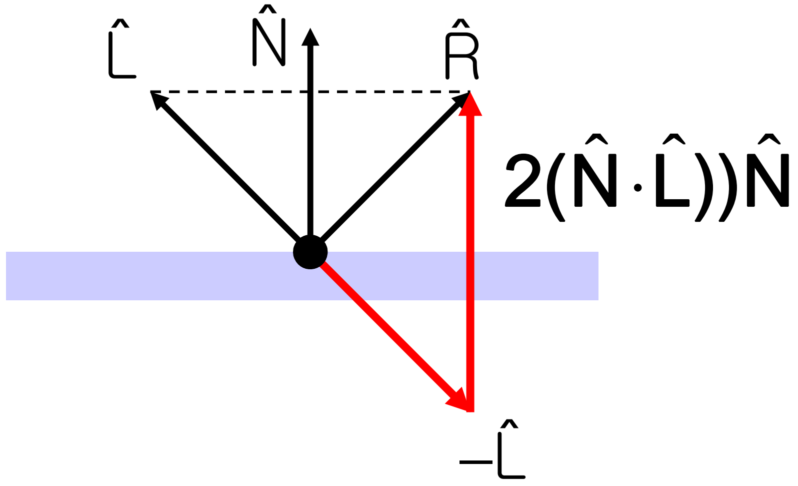
  - $n_i$ and $n_o$ are the indices of refraction for the incoming and outgoing ray, respectively
  - Reflection is a special case where $n_i = n_o$ so $\theta_o = \theta_i$
  - The incoming ray, the surface normal, and the reflected ray all lie in a common plane

# Computing the Reflection Vector

- **The vector R can be computed from the incoming light direction and the surface normal as shown below:**

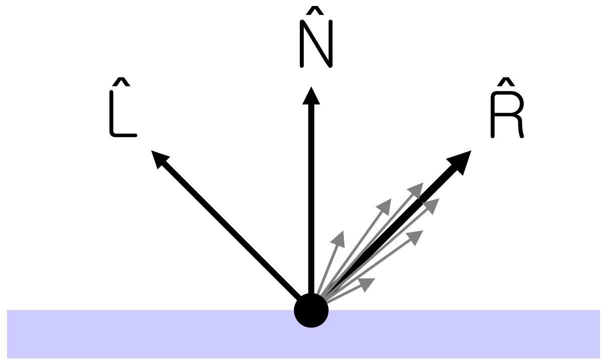
$$\hat{R} = (2(\hat{N} \cdot \hat{L}))\hat{N} - \hat{L}$$

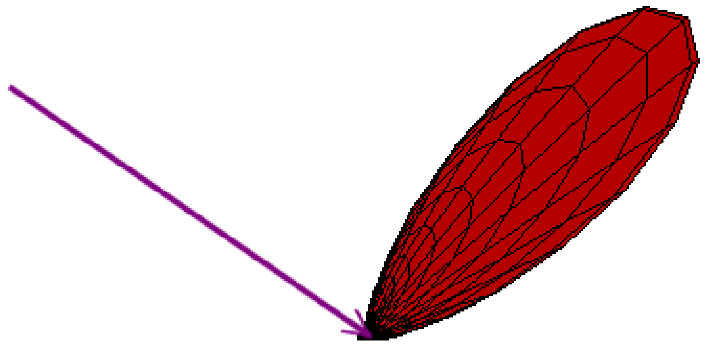
- **How?**



# Non-Ideal Reflectors

- **Snell's law applies only to *ideal* specular reflectors**
  - **Roughness of surfaces causes highlight to "spread out"**
  - **Empirical models try to simulate the appearance of this effect, without trying to capture the physics of it**

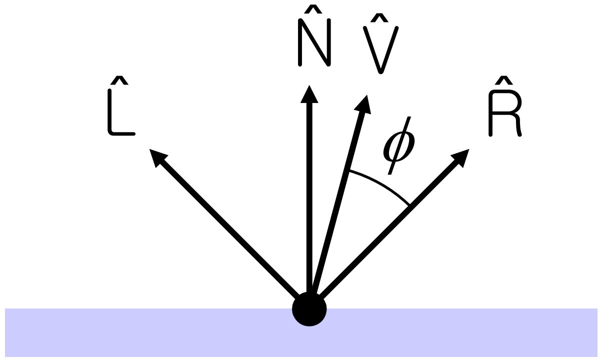




# Phong Illumination

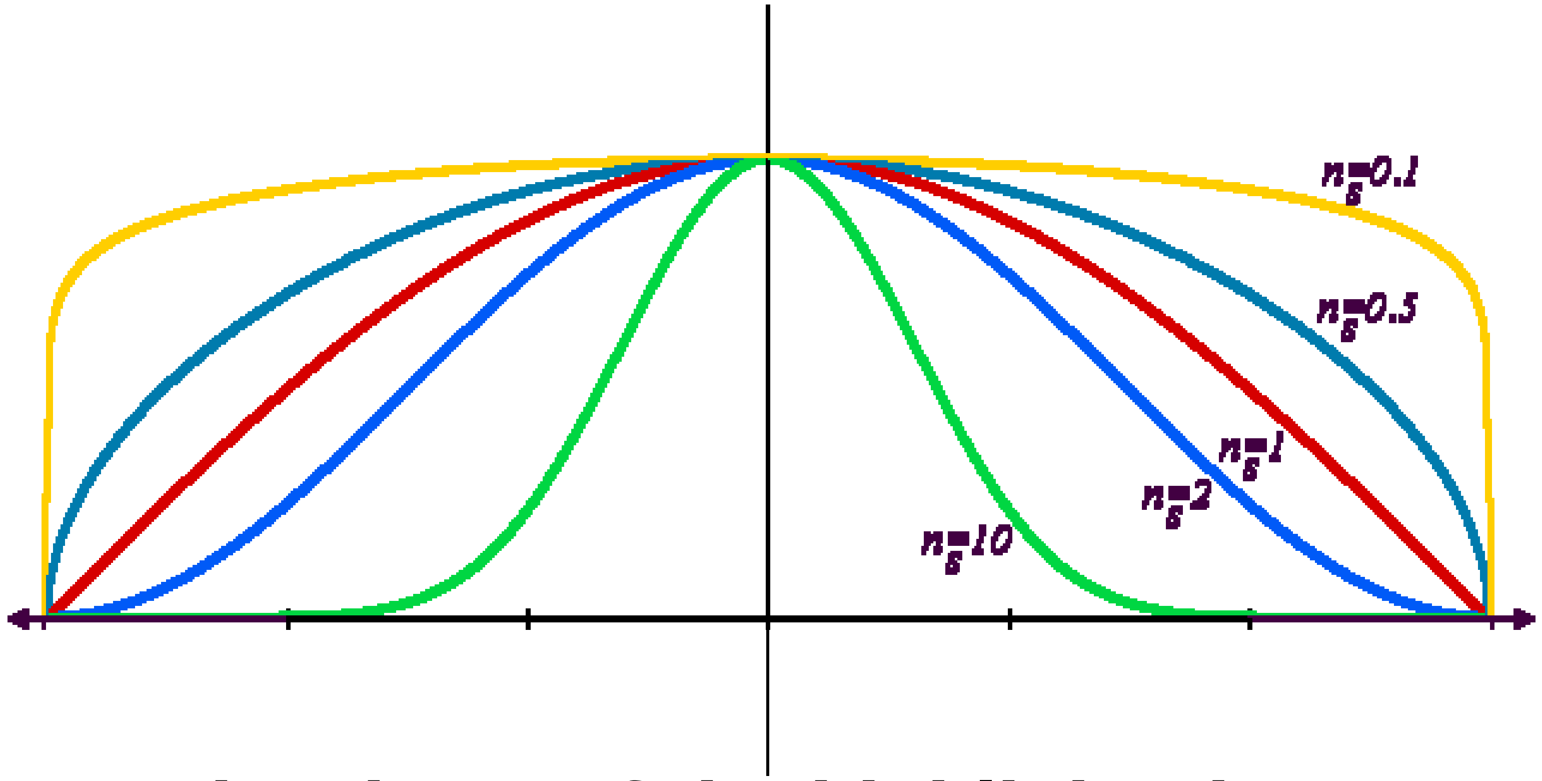
- One of the most commonly used illumination models in computer graphics
  - Empirical model and does not have no physical basis

$$I_r = k_s I_i (\cos\phi)^{n_s}$$
$$= k_s I_i (\hat{V} \bullet \hat{R})^{n_s}$$



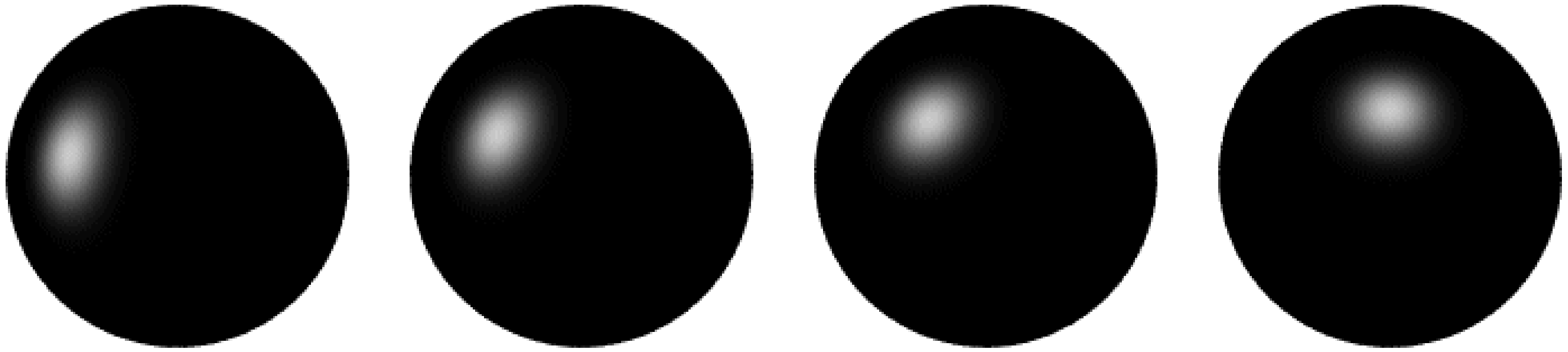
- $(\hat{V})$ is the direction to the viewer
  - $(\hat{V} \bullet \hat{R})$ is clamped to [0,1]
  - The specular exponent $n_s$ controls how quickly the highlight falls off

## Effect of Specular Exponent

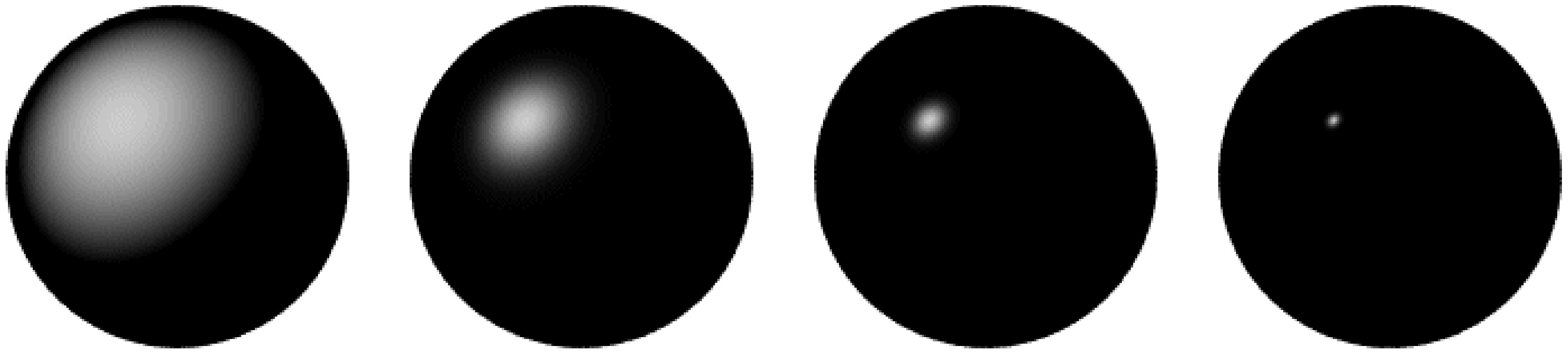


- **How the shape of the highlight changes with varying $n_s$**

# Examples of Phong



varying light direction



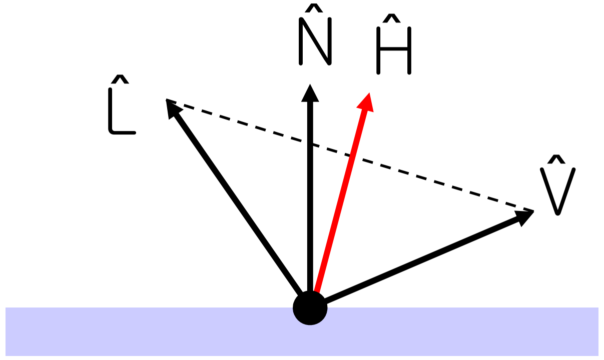
varying specular exponent

## Blinn & Torrance Variation

- Jim Blinn introduced another approach for computing Phong-like illumination based on the work of Ken Torrance:

$$\hat{H} = \frac{\hat{L} + \hat{V}}{\left|\hat{L} + \hat{V}\right|}$$

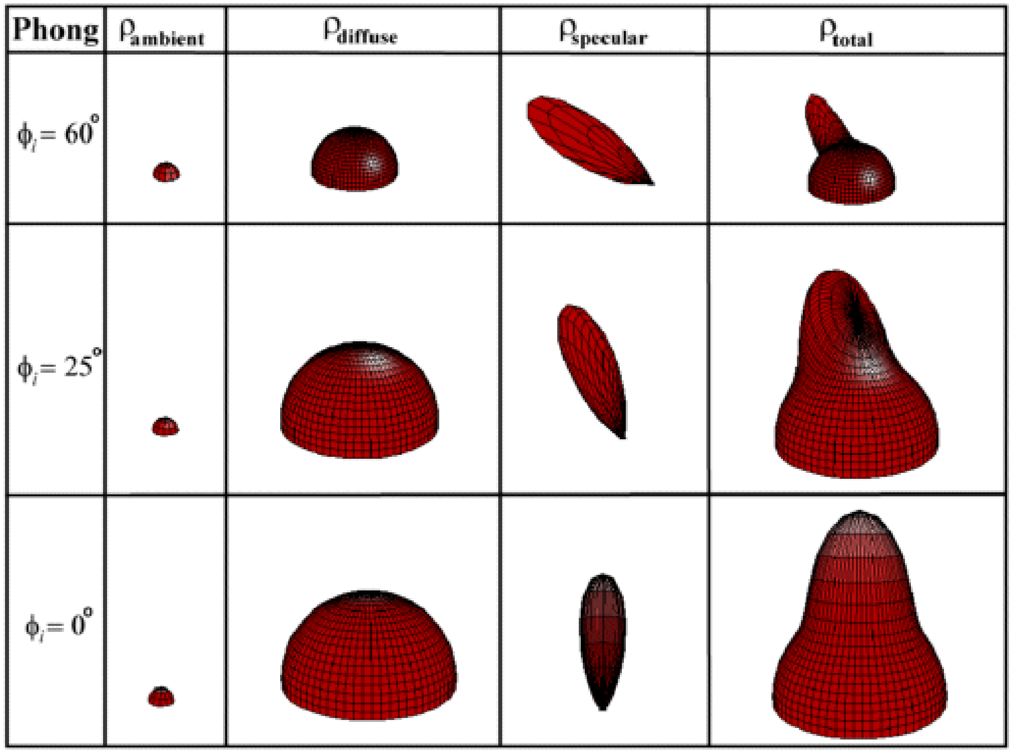
$$I_{r,s} = k_s I_i (\hat{N} \cdot \hat{H})^{n_s}$$



- $\hat{H}$ is the half-way vector that bisects the light and viewer directions

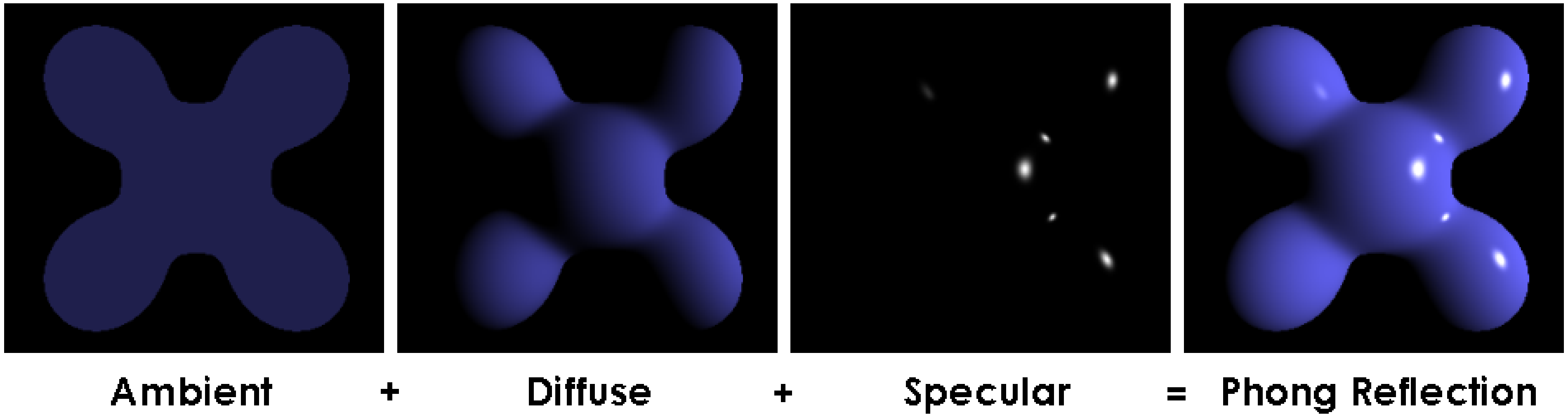
## Putting it All Together

$$I_r = \sum_{j=1}^{numLights} \left(k_a^j I_a^j + k_d^j I_d^j \max((\hat{N}\bullet\hat{L}_j),0) + k_s^j I_s^j \max((\hat{V}\bullet\hat{R}),0)\right)^{n_s}$$



## Putting it All Together

$$I_r = \sum_{j=1}^{numLights} \left( k_a^j I_a^j + k_d^j I_d^j \max((\hat{N} \bullet \hat{L}_j), 0) + k_s^j I_s^j \max((\hat{V} \bullet \hat{R}), 0)^{n_s} \right)$$



From Wikipedia

## OpenGL's Illumination Model

$$I_r = \sum_{j=1}^{numLights} (k_a^j I_a^j + k_d^j I_d^j \max((\hat{N} \bullet \hat{L}_j),0) + k_s^j I_s^j \max((\hat{V} \bullet \hat{R}),0))^{n_s}$$

- **Problems with empirical models:**
  - **What are the coefficients for copper?**
  - **What are $k_a$, $k_s$, and $n_s$?**
    **Are they measurable quantities?**
  - **Is my picture accurate? Is energy conserved?**

## Lights in OpenGL

- Light positions are specified in homogeneous coordinates
    - They are transformed by the current modelview matrix
- Directional light sources have w=0

## Lights in OpenGL

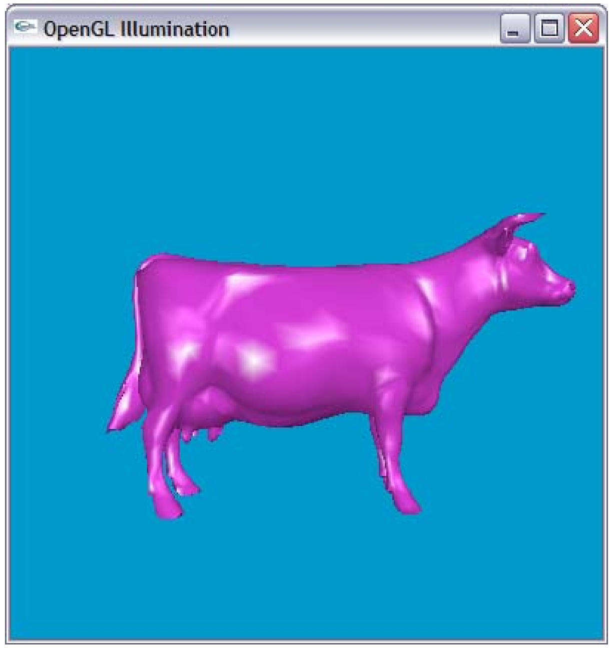
```
# define a directional light
lightDirection = [1, 1, 1, 0]
glLightfv(GL_LIGHT0, GL_POSITION, lightDirection)
glEnable(GL_LIGHT0)

# define a point light
lightPoint = [100, 100, 100, 1]
glLightfv(GL_LIGHT1, GL_POSITION, lightPoint)
glEnable(GL_LIGHT1)

# set up light’s color
glLightfv(GL_LIGHT0, GL_AMBIENT, ambientIntensity)
glLightfv(GL_LIGHT0, GL_DIFFUSE, diffuseIntensity)
glLightfv(GL_LIGHT0, GL_SPECULAR, specularIntensity)
```

## OpenGL Surface Properties

```
glMaterialfv(GL_FRONT, GL_AMBIENT, ambientColor)
glMaterialfv(GL_FRONT, GL_DIFFUSE, diffuseColor)
glMaterialfv(GL_FRONT, GL_SPECULAR, specularColor)
glMaterialfv(GL_FRONT, GL_SHININESS, nshininess)
```



## Illumination Methods

- Illumination can be expensive
  - Requires computation and normalizing of vectors for multiple light sources

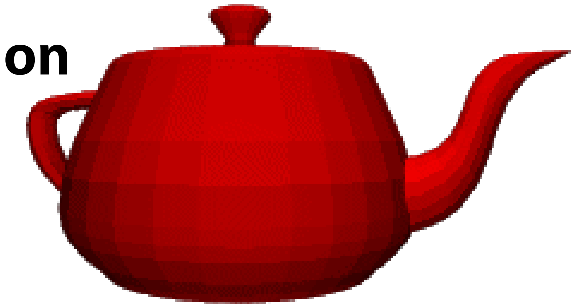
- Compute illumination for faces, vertices, or pixels with increasing realism and computing overhead
  - Correspond to flat, Gouraud, and Phong shading respectively

# Flat Shading

- The simplest shading method
  - Applies only one illumination calculation per face
- Illumination usually computed at the centroid of the face:

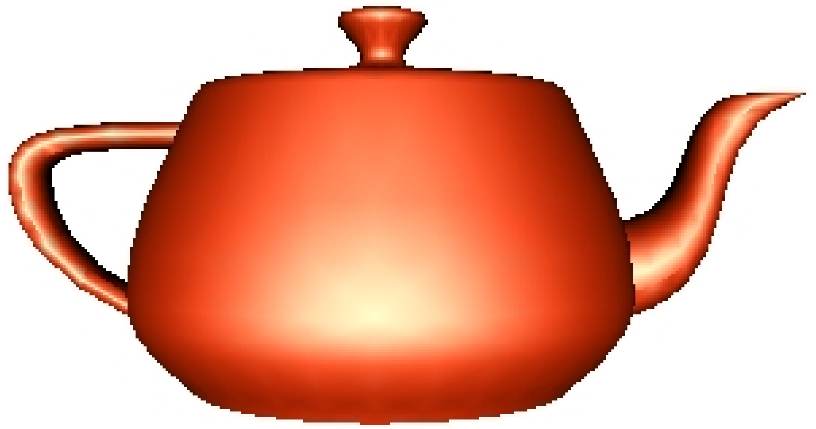
$$centroid = \frac{1}{n}\sum_{i=1}^{n} p_i$$

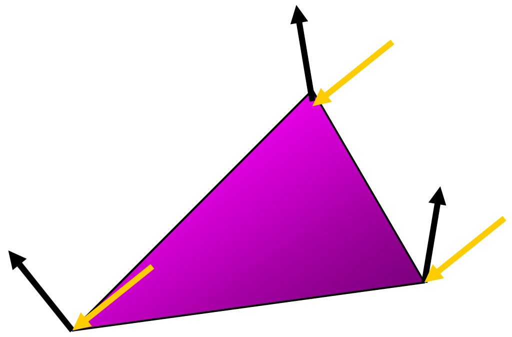
- Issues?



## Gouraud Shading

- Performs the illumination model on vertices and interpolates the intensity of the remaining points on the surface



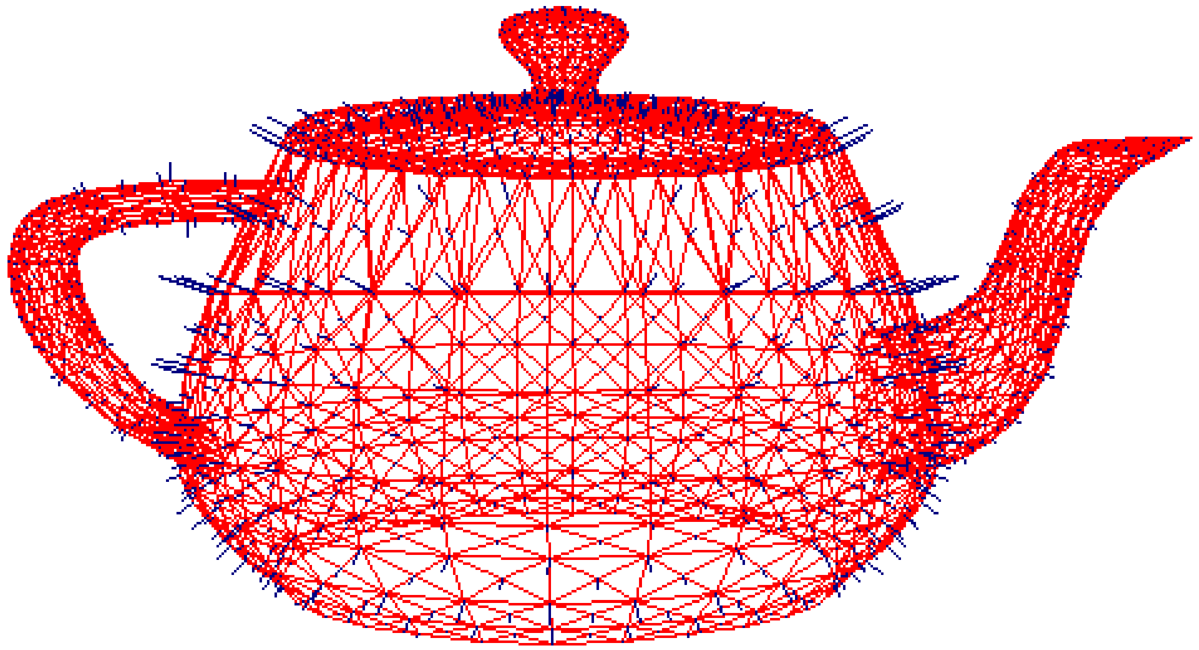


Notice that facet artifacts are still visible

## Vertex Normals

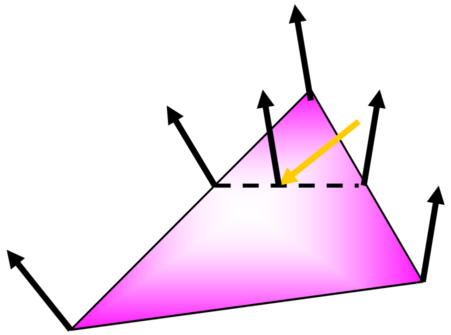
**If vertex normals are not provided they can often be approximated by averaging the normals of the facets which share the vertex**

$$\vec{n}_v = \sum_{i=1}^{k} \vec{n}_{face,i}$$



# Phong Shading

- Surface normal is linearly interpolated across polygonal facets, and the illumination model is applied at every point
  - Not to be confused with Phong's illumination model



- Phong shading will usually result in a very smooth appearance
  - However, evidence of the polygonal model can usually be seen along silhouettes

# Local Illumination

- Local illumination models compute the colors of points on surfaces by considering only local properties:
  - Position of the point
  - Surface properties
  - Properties of any light affect it
- No other objects in the scene are considered neither as light blockers nor as reflectors
- Typical of immediate-mode renders, such as OpenGL

## Global Illumination

- In the real world, light takes indirect paths
  - Light reflects off of other materials (possibly multiple objects)
  - Light is blocked by other objects
  - Light can be scattered
  - Light can be focused
  - Light can bend
- Harder to model
  - At each point we must consider not only every light source, but and other point that might have reflected light toward it

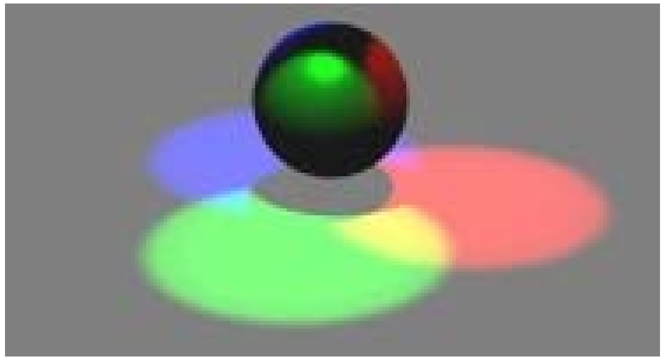
## Various Effects using Physically-based Models

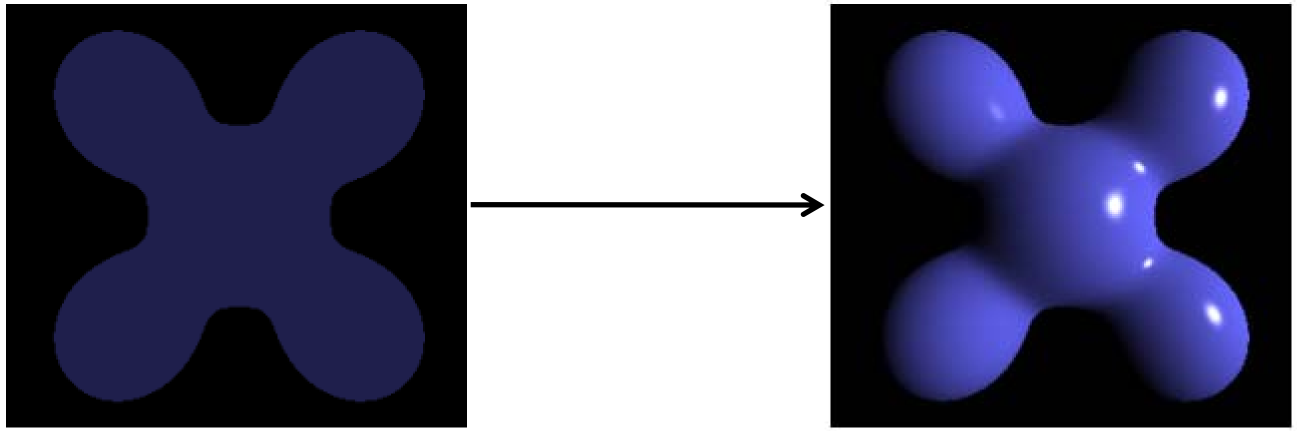
From slides of Pat Hanrahan

- There are still many open problems to accurately represent various natural materials and efficiently render them

## Course Objectives

- Know how to consider lights during rendering models
  - Light sources
  - Illumination models
  - Shading
  - Local vs. global illumination





## Reading Homework

- Read a chapter of “Texture Mapping”

## Next Time

- Texture mapping

## Homework

- Go over the next lecture slides before the class
- Watch 2 SIGGRAPH videos and submit your summaries before every Tue. class
  - Send an email to cs380ta@gmail.com
  - Just one paragraph for each summary

## Any Questions?

- Come up with one question on what we have discussed in the class and submit at the end of the class
  - 1 for already answered questions
  - 2 for typical questions
  - 3 for questions with thoughts or that surprised me

- Submit at least four times during the whole semester