Lighting

Wolfgang Heidrich

Course News

Assignment 1

- Due today!

Assignment 2

- Out later today
- Due Monday, Feb 28
- More later…

Homework 3

- Out today
- Discussed in labs next week

Course News

Quiz 1

- Discussed in labs this week

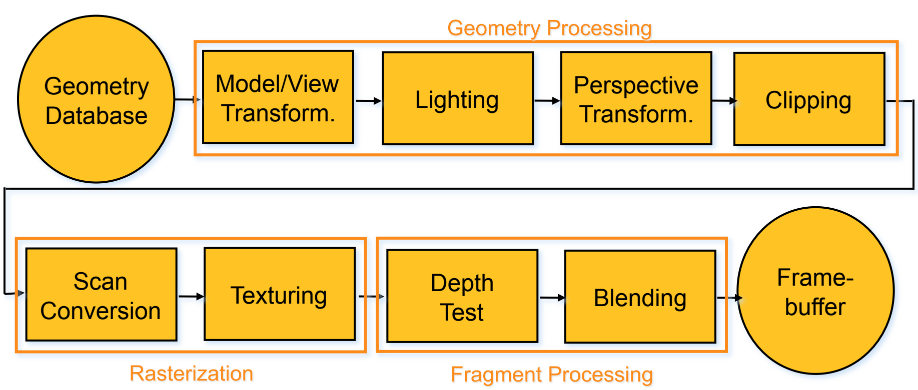
Reading

- Chapter 9, 3

Out of Town this Friday

- For grant review meeting
- Anika will fill in for me

The Rendering Pipeline



Lighting

Goal

- Model the interaction of light with surfaces to render realistic images

Contributing Factors

- Light sources
  - *Shape and color*
- Surface materials
  - *How surfaces reflect light*
- Transport of light
  - *How light moves in a scene (global illumination, later in the course)*

Light Sources and Materials

Appearance depends on

- Light sources, locations, properties
- Material (surface) properties
- Viewer position

Local illumination

- Compute at material, from light to viewer

Global illumination (later in course)

- Ray tracing: from viewer into scene
- Radiosity: between surface patches

Materials

Analyzing surface reflectance

- Illuminate surface point with a ray of light from different directions
- Observe how much light is reflected in all possible directions

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Materials

Light is linear

- If two rays illuminate the surface point the result is just the sum of the individual reflections for each ray
- For N directions the reflection is the sum of the individual N reflections
- For light arriving from a *continuum* of directions, the reflection is the *integral* over the reflections caused by the individual directions
  - *More on this when we talk about global illumination at the end of the term*

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Experiment

Goal:

- Visualize reflected light distribution for a given illuminating ray

Physical setup:

- Laser illumination
- Water tank with fluorescent dye
  - *Makes laser light visible as it travels through "empty" space*

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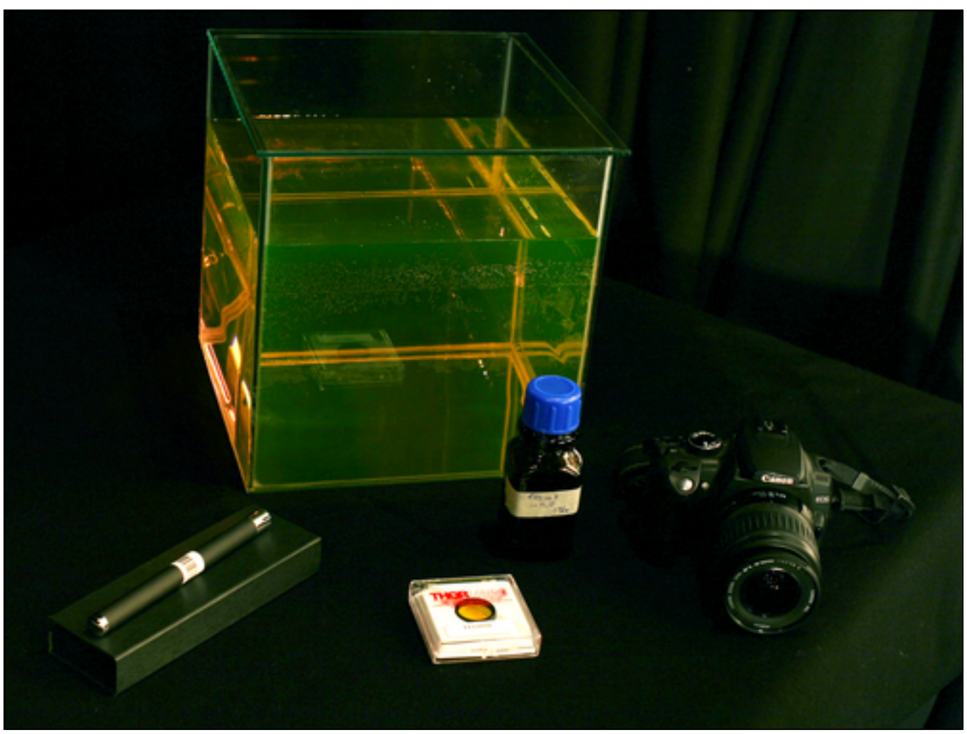
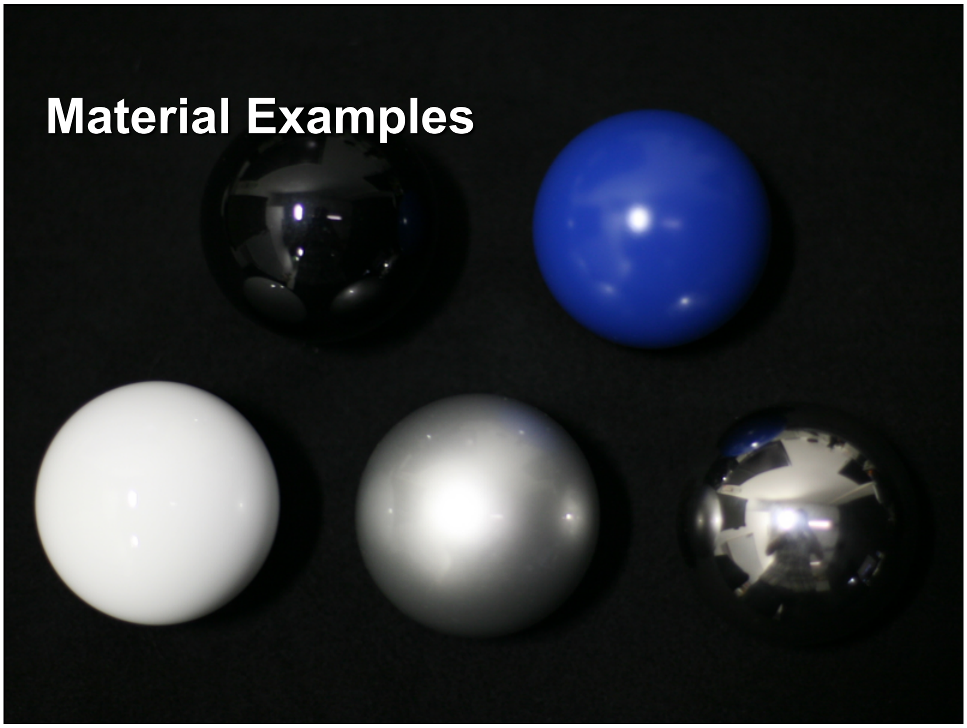
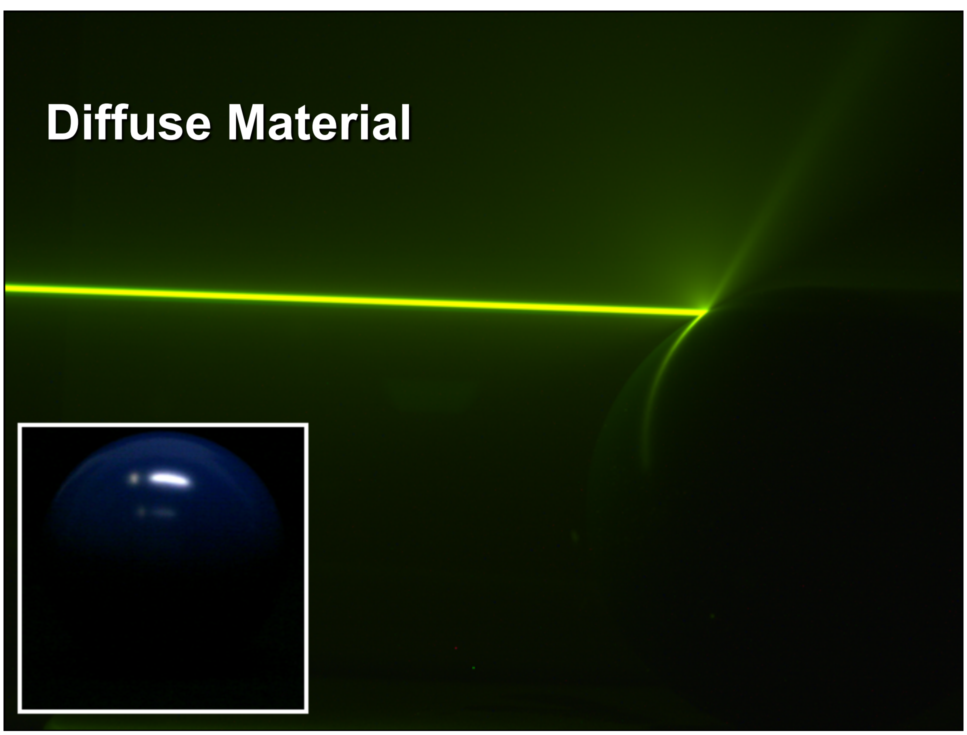
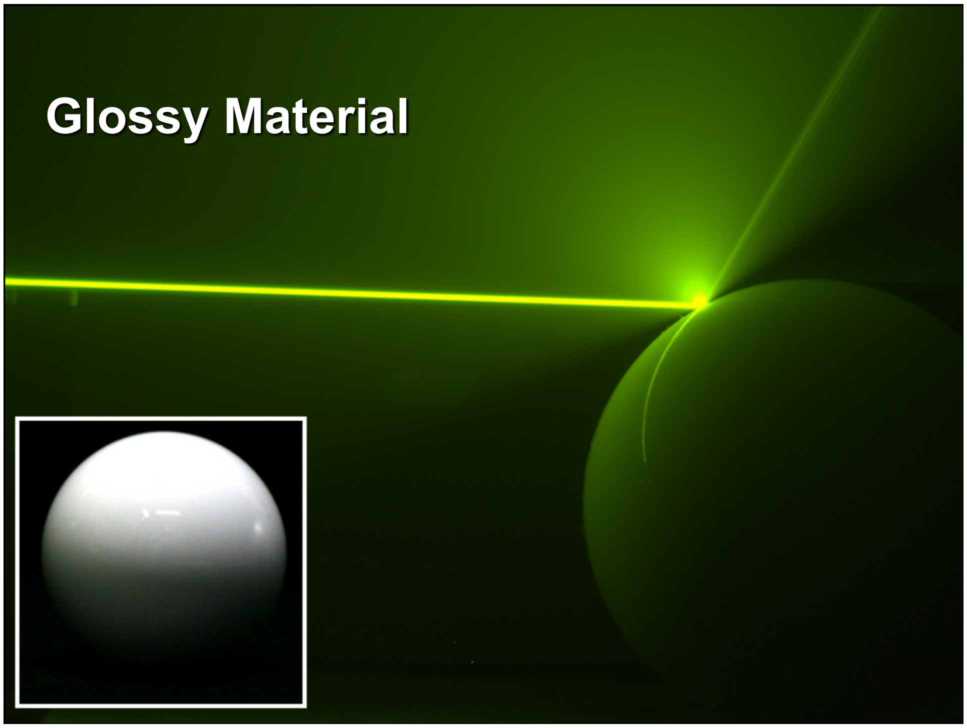
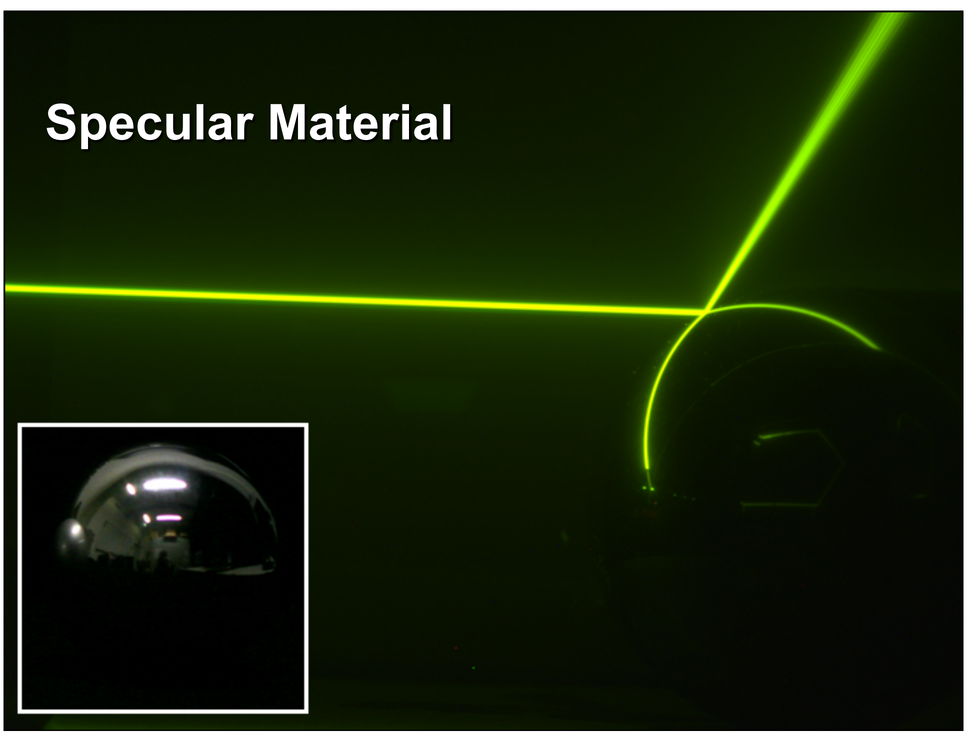
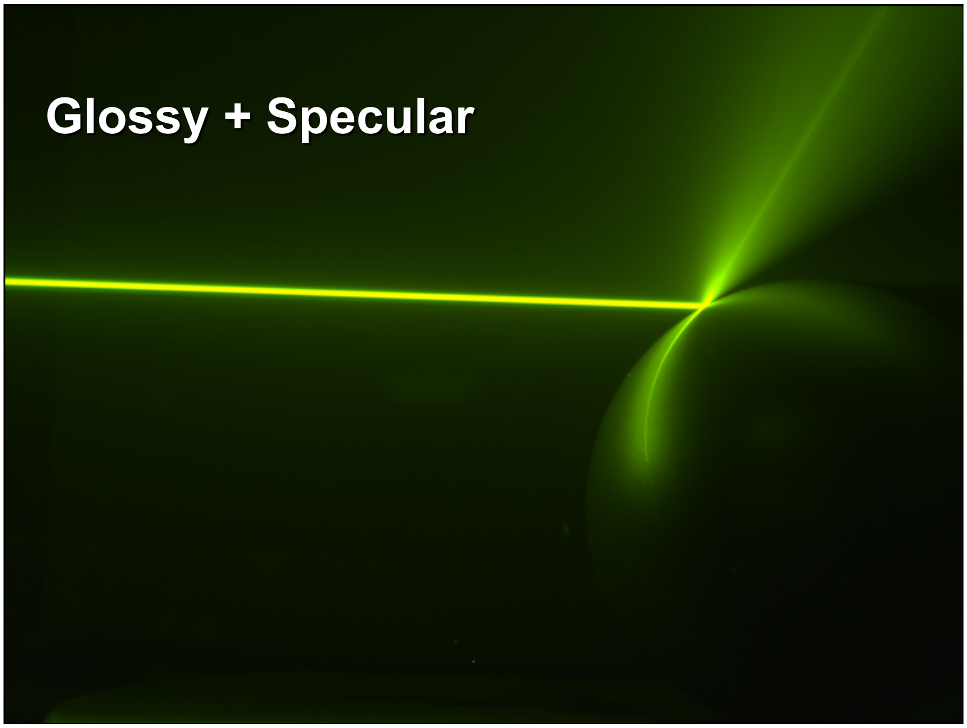


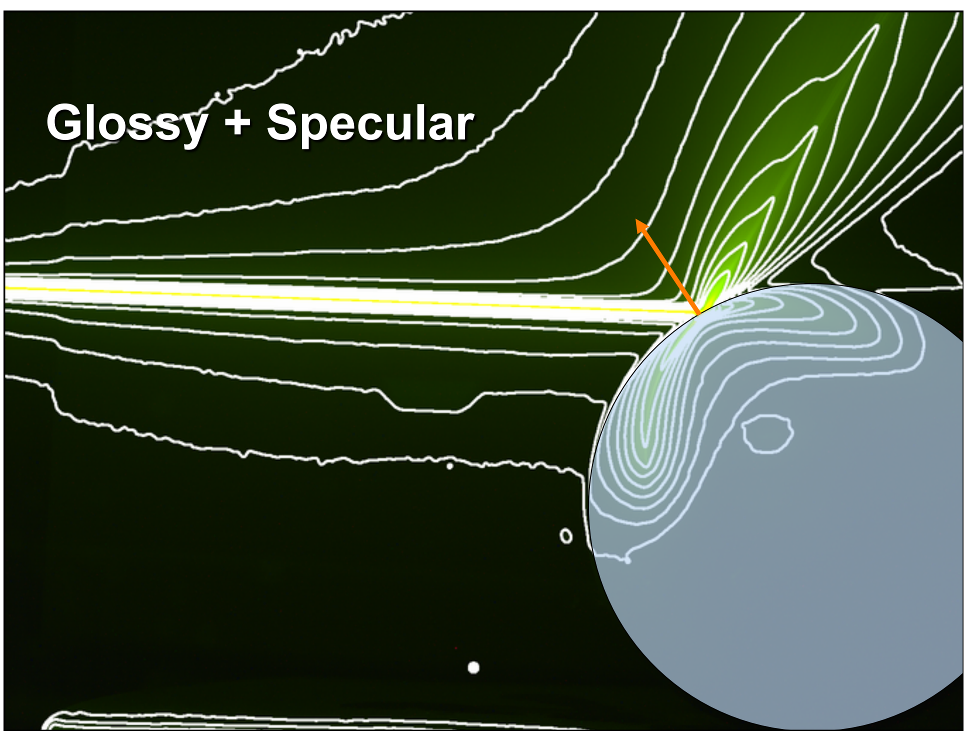

Material Examples


Diffuse Material


Glossy Material


Specular Material


Glossy + Specular


Glossy + Specular

BRDF

Model for all these effects:

- Bi-directional
  - *i.e. dependent on 2 directions: incident, exitant*
- Reflectance
  - *A model for surface reflection (not transmission)*
- Distribution
  - *Light is distributed over different exitant directions*
- Function

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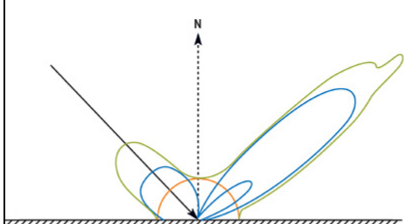
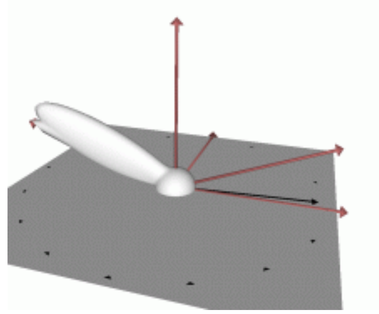
BRDF lobe plots

2D slice



3D surface



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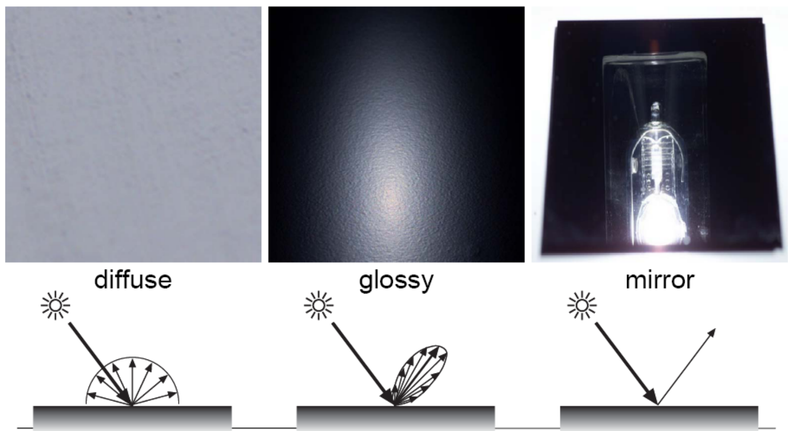
BRDF lobes and appearance



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Limitations of the BRDF Model

BRDFs cannot describe

- Light of one wavelength that gets absorbed and re-emitted at a different wavelength
  - *(fluorescence)*
- Light that gets absorbed and emitted much later
  - *(phosphorescence)*
- Light that penetrates the object surface, scatters in the interior of the object, and exits at a different point form where it entered
  - *(subsurface scattering)*

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Materials

Practical Considerations

- In practice, we often simplify the BRDF model further
- Derive specific formulas that describe different reflectance behaviors
  - *E.g. diffuse, glossy, specular*
- Computational efficiency is also a concern

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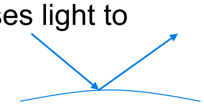
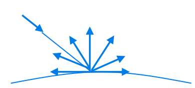
Types of Reflection

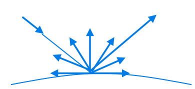
- *Specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.



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



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



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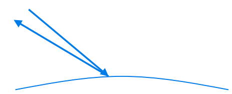
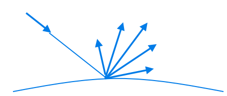
Types of Reflection

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



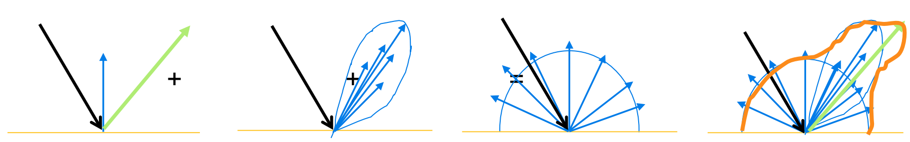
- *gloss* is the property of a material surface that involves mixed reflection and is responsible for the mirror like appearance of rough surfaces.



Reflectance Distribution Model

Most surfaces exhibit complex reflectances

- Vary with incident and reflected directions.
- Model with combination

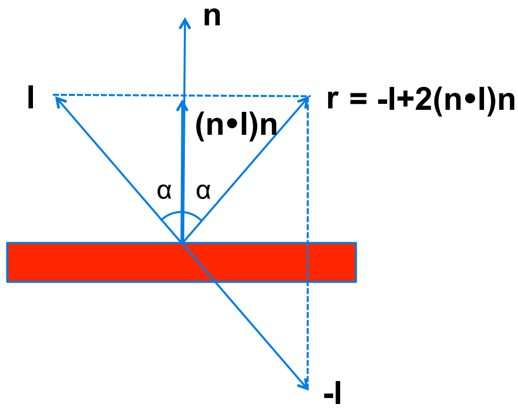


specular + glossy + diffuse =

reflectance distribution

Specular Reflection

Geometry of specular (mirror) reflection



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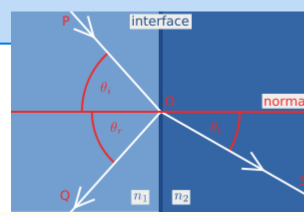
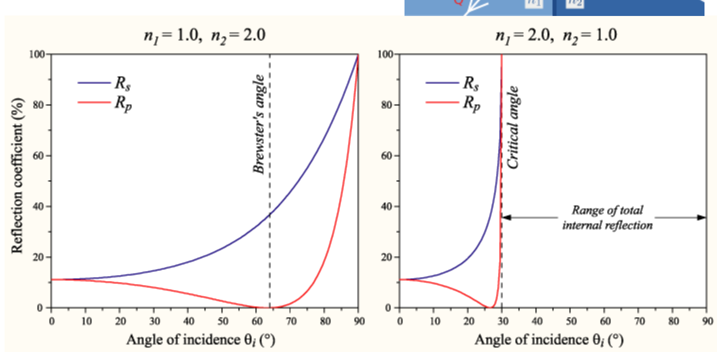
Fresnel Reflection
Physics of Mirrors





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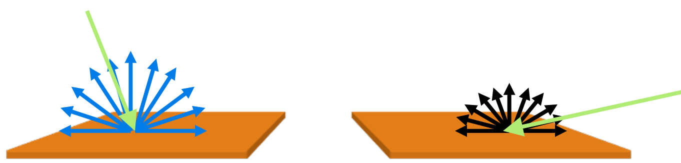
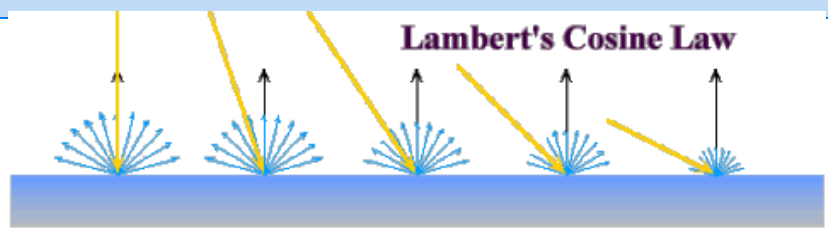
Physics of Diffuse Reflection

Ideal diffuse reflection

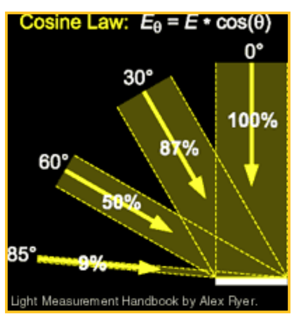
- Very rough surface at the microscopic level
  - *Real-world example: chalk*
- Microscopic variations mean incoming ray of light equally likely to be reflected in any direction over the hemisphere
- Reflected intensity only depends on light direction!



Lambert's "Law"

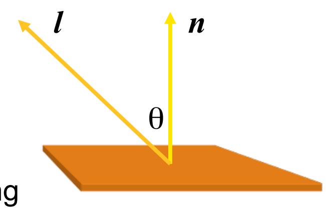


Intuitively: cross-sectional area of the "beam" intersecting an element of surface area is smaller for greater angles with the normal.



Computing Diffuse Reflection

- Depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \cos\theta$
- In practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\boldsymbol{n} \bullet \boldsymbol{l})$



- Always normalize vectors used in lighting
  - $\boldsymbol{n}$, $\boldsymbol{l}$ *should be unit vectors*
- Scalar (B/W intensity) or 3-tuple or 4-tuple (color)
  - k_d: *diffuse coefficient, surface color*
  - I_{light}: *incoming light intensity*
  - $I_{diffuse}$: *outgoing light intensity (for diffuse reflection)*

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Diffuse Lighting Examples

- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°

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Physics of Glossy Reflection

- At the microscopic level a glossy 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

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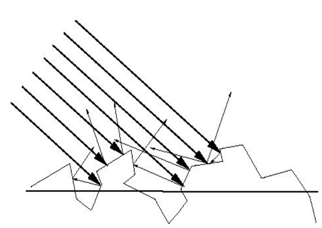
Glossy Reflectance

- 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…



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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

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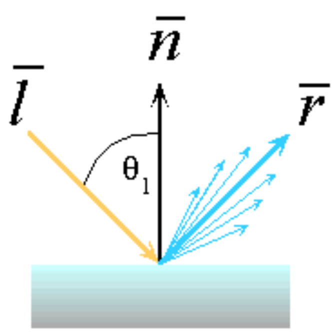
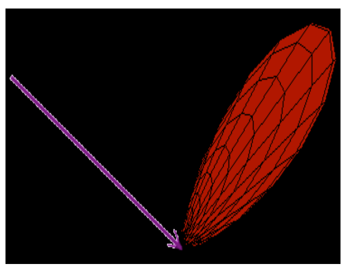
Empirical Approximation

Angular falloff





how might we model this falloff?

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Phong Lighting

Most common lighting model in computer graphics

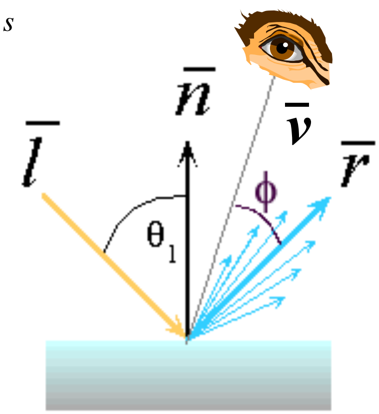
– *(Phong Bui-Tuong, 1975)*

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_{\mathbf{s}}\mathbf{I}_{\mathbf{light}}(\cos\phi)^{n_s}$$

n_s : purely empirical constant, varies rate of falloff

k_s: specular coefficient, highlight color

no physical basis, works ok in practice



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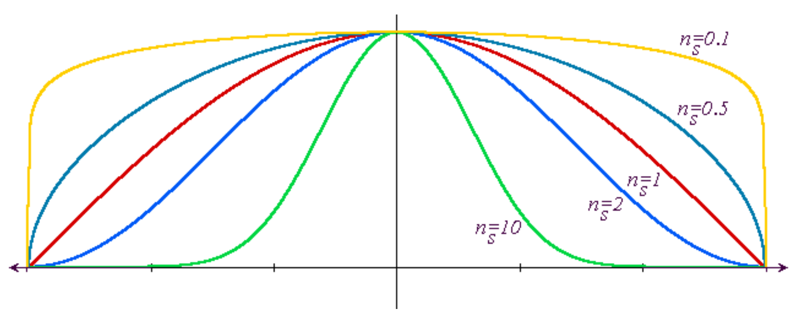
Phong Lighting: The n_s Term

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



Viewing angle – reflected angle

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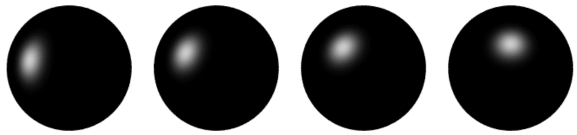
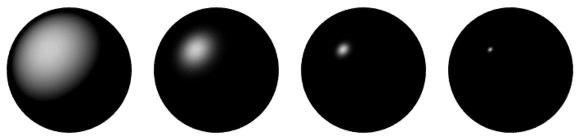
Phong Examples

varying l



varying n_{shiny}



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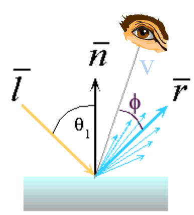
Calculating Phong Lighting

compute cosine term of Phong lighting with vectors

$$\mathbf{I}_{\mathbf{specular}} = \mathbf{k}_{\mathbf{s}} \mathbf{I}_{\mathbf{light}} (\mathbf{v} \bullet \mathbf{r})^{n_s}$$

- v: unit vector towards viewer/eye
- r: ideal reflectance direction (unit vector)
- k_s: specular component
  - *highlight color*
- I_{light}: incoming light intensity



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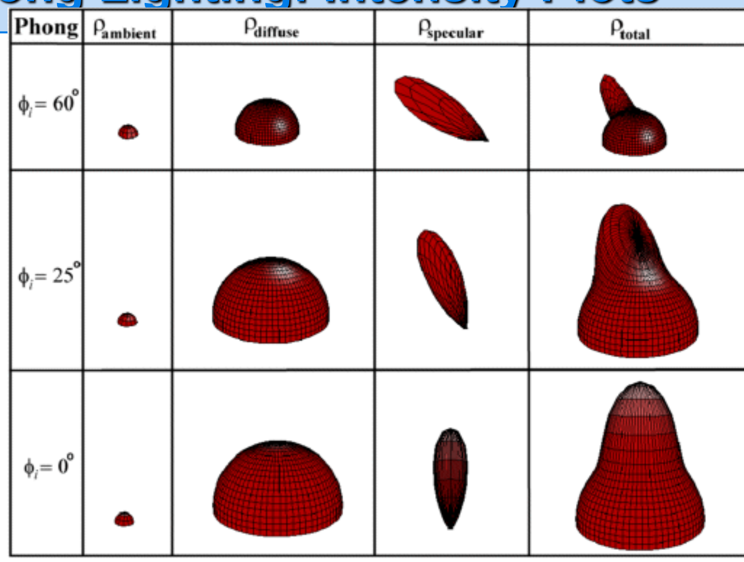
Phong Lighting: Intensity Plots



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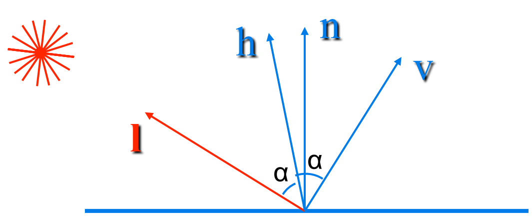
Alternative Model

Blinn-Phong model (Jim Blinn, 1977)

- Variation with better physical interpretation
  - $\mathbf{h}$: *halfway vector;* r: *roughness*

$$I_{out}(\mathbf{x}) = k_s \cdot (\mathbf{h} \cdot \mathbf{n})^{1/r} \cdot I_{in}(\mathbf{x}); \text{with } \mathbf{h} = (\mathbf{l} + \mathbf{v})/2$$



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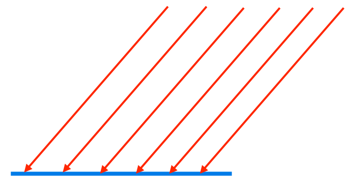
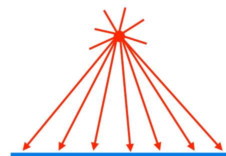
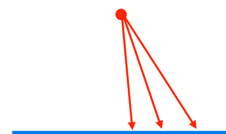
Simple Light Sources

Types of light sources

- Directional/parallel lights
  - *E.g.sun*
  - *Homogeneous vector*
- (Homogeneous) point lights
  - *Same intensity in all directions*
  - *Homogeneous point*
- Spot lights
  - *Limited set of directions*
  - *Point+direction+cutoff angle*







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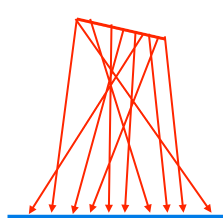
Light Sources

Area lights:

- Light sources with a finite area
- Can be considered a continuum of point lights
- Not available in many rendering systems



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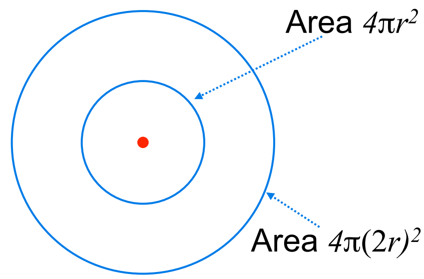
Light Source Falloff

Quadratic falloff (point- and spot lights)

- 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



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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*
  - $\mathbf{x}$: *object point*
  - r: *distance of light from* $\mathbf{x}$

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

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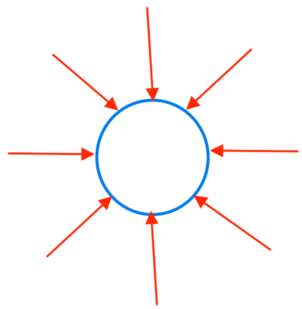
Light Sources

Ambient lights

- No identifiable source or direction
- Hack for replacing true global illumination
  - *(light bouncing off from other objects)*



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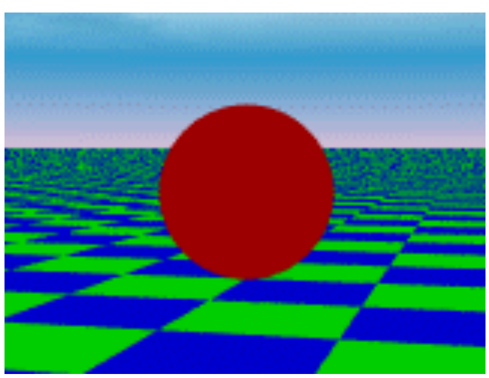
Ambient Light Sources

- Scene lit only with an ambient light source



Light Position Not Important

Viewer Position Not Important

Surface Angle Not Important

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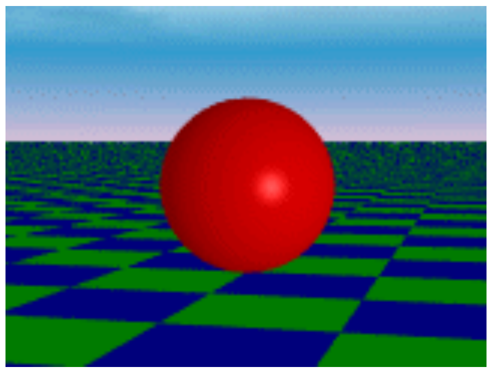
Directional Light Sources

- Scene lit with directional and ambient light

Surface Angle Important



Light Position Not Important

Viewer Position Not Important

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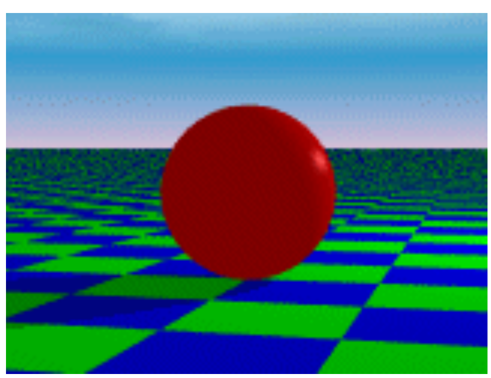
Point Light Sources

- Scene lit with ambient and point light source

Light Position Important

Viewer Position Important

Surface Angle Important



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Light Sources & Transformations

Geometry: positions and directions

- Standard: world coordinate system
  - *Effect: lights fixed wrt world geometry*
  - *Demo: http://www.xmission.com/~nate/tutors.html*
- Alternative: camera coordinate system
  - *Effect: lights attached to camera (car headlights)*
- Points and directions undergo normal model/view transformation

Illumination calculations: camera coords

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Lighting Review

Lighting models

- Ambient
  - *Normals don't matter*
- Lambert/diffuse
  - *Angle between surface normal and light*
- Phong/specular
  - *Surface normal, light, and viewpoint*

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Lighting in OpenGL

Light source: amount of RGB light emitted

- Value represents percentage of full intensity
  E.g., (1.0,0.5,0.5)
- Every light source emits ambient, diffuse, and specular light

Materials: amount of RGB light reflected

- Value represents percentage reflected
  e.g., (0.0,1.0,0.5)

Interaction: multiply components

- Red light (1,0,0) x green surface (0,1,0) = black (0,0,0)

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Lighting in OpenGL

```
glLightfv(GL_LIGHT0, GL_AMBIENT, amb_light_rgba );
glLightfv(GL_LIGHT0, GL_DIFFUSE, dif_light_rgba );
glLightfv(GL_LIGHT0, GL_SPECULAR, spec_light_rgba );
glLightfv(GL_LIGHT0, GL_POSITION, position);
glEnable(GL_LIGHT0);

glMaterialfv( GL_FRONT, GL_AMBIENT, ambient_rgba );
glMaterialfv( GL_FRONT, GL_DIFFUSE, diffuse_rgba );
glMaterialfv( GL_FRONT, GL_SPECULAR, specular_rgba );
glMaterialfv( GL_FRONT, GL_SHININESS, n );
```

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Coming Up:

Wednesday

- Shading

Friday

- Clipping; scan conversion

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