Game Engines
CMPM 164, F2019

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Homework 2B - extended

2B: Implement a classic Whitted recursive ray tracer (due 10/17 at 11:59pm)

For a C grade: Ray trace 3 or more solid spherical objects with 2 or more lights using the Phong lighting model
For a B grade: Ray trace 3 or more solid and transparent and mirrored spherical objects (i.e., use reflection and refraction), including shadows
For an A grade: Same as above, but include at least one additional kind of shape (i.e., besides a sphere)

Comment code clearly to demonstrate that you understand what you are implementing.
Homework 2B – extra credit

Extra credit for each of the following:
- interactive camera
- implementing Fresnel effect
- complex shape or mesh
- outstanding aesthetics

Ideas for scene:
Disco ball?
Mirrored planes?
Import character mesh?
Use different refractive indices to simulate different materials?
Implement chromatic dispersion where different color channels have slightly different refractive behavior?
Ambient + Diffuse + Specular = Phong Reflection
Calculating color at intersections

Diffuse calculation:

Requires *Normal* vector and *Light* vector

\[
\text{DiffuseContribution} = \text{diffuseColor} \times \max( (\text{Normal} \cdot \text{Light}), 0.0 )
\]

The diffuse term is largest when the normal and the light are parallel. The diffuse term is 0 when the normal and the light are \( \geq \) perpendicular.
Calculating color at intersections

Specular calculation:

Requires Reflect vector and View vector. That is, it can change based on the position of the camera

\[
\text{SpecularContribution} = \text{specularColor} \times (\text{Reflect} \cdot \text{View})^{\text{shininessFactor}}
\]

The specular term is large only when the viewer direction is aligned with the reflection direction. The highlights are sharper the greater the shininessFactor is.

(Reflect vector is calculated using Light vector and Normal vector)
Calculating color at intersections

Alternative Specular calculation:

Requires *Normal* vector and a *Half* vector that is in between the *View* and the *Light* vectors.

\[
\text{SpecularContribution} = \text{specularColor} \times (\text{Normal} \cdot \text{Half})^{\text{shininessFactor}}
\]

The specular term is large only when the viewer direction is aligned with the reflection direction. The highlights are sharper the greater the shininessFactor is.
Calculating color at intersections

Calculate diffuse and specular contribution for each light and add them together

Check if light is not occluded by another object, otherwise move to next to light. If all lights are occluded, then the point is completely in shadow.
Reflection
Reflection
\[
\hat{U}' = \hat{R} - \hat{N}' = \hat{R} - (\hat{R} \cdot \hat{N})\hat{N}
\]
\[
\hat{U}'' = \hat{L} - \hat{N}'' = \hat{L} - (\hat{L} \cdot \hat{N})\hat{N}
\]
\[
\hat{R} - (\hat{R} \cdot \hat{N})\hat{N} = -(\hat{L} - (\hat{L} \cdot \hat{N})\hat{N})
\]
\[
\hat{R} - (\hat{L} \cdot \hat{N})\hat{N} = -(\hat{L} - (\hat{L} \cdot \hat{N})\hat{N})
\]
\[
\hat{R} = (\hat{L} \cdot \hat{N})\hat{N} - (\hat{L} - (\hat{L} \cdot \hat{N})\hat{N})
\]
\[
\hat{R} = (\hat{L} \cdot \hat{N})\hat{N} - \hat{L} + (\hat{L} \cdot \hat{N})\hat{N}
\]
\[
R = 2(\hat{N} \cdot \hat{L})\hat{N} - \hat{L}
\]
Refraction
Refraction
Snell’s Law

Snell’s Law describes the relationship between the angles of incidence and refraction when a light ray passes from one medium to another. The law is:

\[
\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2}
\]

where \(\theta_1\) and \(\theta_2\) are the angles of incidence and refraction, respectively, and \(v_1\) and \(v_2\) are the velocities of light in the first and second medium, respectively. \(n_1\) and \(n_2\) are the indices of refraction of the first and second medium, respectively.

The indices of refraction of the media are used to represent the factor by which a light ray’s speed decreases when traveling through a refractive medium, such as glass or water, as opposed to its velocity in a vacuum.

Refraction between two surfaces is reversible because if all conditions were identical, the angles would be the same for light propagating in the opposite direction.

Vacuum = 1.0
Air = 1.000293
Water = 1.33
Glass = 1.52
Diamond = 2.417

\[ A = M \sin(\theta_2), \]
\[ B = -N \cos(\theta_2). \]
\[ M = \frac{(I + C)}{\sin(\theta_1)}. \]
\[ C = \cos(\theta_1)N. \]
\[ T = A + B, \]
\[ T = M \sin(\theta_2) - N \cos(\theta_2), \]
\[ T = \frac{(I + C) \sin(\theta_2)}{\sin(\theta_1)} - N \cos(\theta_2), \]
\[ T = \frac{(I + \cos(\theta_1)N) \sin(\theta_2)}{\sin(\theta_1)} - N \cos(\theta_2). \]
\[ T = \frac{\eta_1}{\eta_2} (I + \cos(\theta_1)N) - N \cos(\theta_2). \]

\[ T = \frac{\eta_1}{\eta_2} (I + \cos(\theta_1)N) - N \sqrt{1 - \left(\frac{\eta_1}{\eta_2}\right)^2 \sin^2(\theta_1)}. \]
Refraction
Fresnel Effect

steep angle = weak reflection
shallow angle = strong reflection
Refraction

\[ F(\theta_i) L \]

\[ \theta_i \]

\[ \theta_t \]

\[ \frac{\sin^2 \theta_i}{\sin^2 \theta_t} L \]

\[ n_1 \]

\[ n_2 \]