Worksheet 8

In previous exercises, we rendered refractive objects by continuing the path in the direction of refraction only (except in the case of total internal reflection). In the real world, a transparent object partially reflects and partially refracts light. The reflectance (the amount of reflection) depends on the angle of incidence of the ray and some light is lost due to absorption. The transmittance (the amount of light that is not absorbed) depends on the distance that the ray travels through the medium. In this set of exercises, we include physically based Fresnel reflectance and absorption in the ray tracing framework.

Learning Objectives

- Implement shaders for rendering transparent objects.

- Simulate the angle-dependency of reflectance as it appears in transparent objects.

- Simulate absorption of light as a function of the distance that a ray moves through a medium.

- Use Fresnel's equations for reflection and Bouguer's law of exponential attenuation.

Fresnel Reflectance

To capture the angle-dependency of reflectance R, we need the Fresnel equations. The form of these equations most easily used in graphics is

$$
\begin{aligned}
\tilde{r}_\perp &= \frac{n_i \cos\theta_i - n_t \cos\theta_t}{n_i \cos\theta_i + n_t \cos\theta_t} \\
\tilde{r}_\parallel &= \frac{n_t \cos\theta_i - n_i \cos\theta_t}{n_t \cos\theta_i + n_i \cos\theta_t} \\
R &= \frac{1}{2}\left(|\tilde{r}_\perp|^2 + |\tilde{r}_\parallel|^2\right) \;,
\end{aligned}
$$

where n_i is the refractive index of the medium from which the incident ray reaches the surface, n_t is the refractive index of the medium that the ray transmits into, θ_i is the angle of incidence, and θ_t is the angle of refraction.

1. Start from the Cornell box with a mirror ball and a glass ball (Worksheet 6, Part 3) and include progressive updating (Worksheet 7, Part 1). Set the background color to the original blue color $(r, g, b, a) = (0.1, 0.3, 0.6, 1.0)$. Implement a function, `fresnel_R` for computing the Fresnel reflectance R given $\cos\theta_i$, $\cos\theta_t$, and n_i/n_t as arguments. Set $R = 1$ in the case of total internal reflection. Implement a shader for transparent objects that is the same as the one for refractive objects except for using the Fresnel reflectance R in a Russian roulette as the probability of tracing reflection instead of refraction.

2. Switch off the light outside the box (set the background color to zero) and include soft shadows and indirect illumination (Worksheet 7, Parts 2 and 3) in the rendering of the Cornell box with the mirror and glass balls. Include caustic illumination by setting the emit flag to true in the shaders for specular materials (mirror and transparent). This should be done as we do not explicitly evaluate the direct illumination in these shaders.

(reference) 1.   2. (reference)
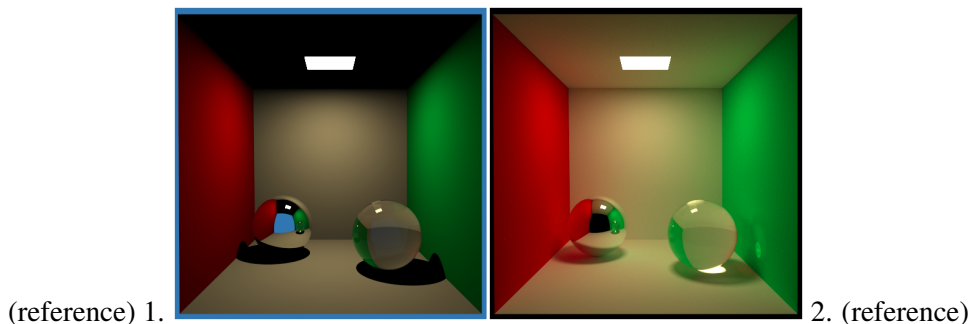
Absorption

To capture absorption, we need Bouguer's law of exponential attenuation for computing the transmittance T_r of a light ray that moves a certain distance s through a medium. Bouguer's law is [**B**, Section 14.3.2]:

$$L = L_0 T_r = L_0 \exp(-\sigma_t s) \ ,$$

where σ_t is called the extinction coefficient. In a transparent medium, the extinction coefficient equals the absorption coefficient ($\sigma_t = \sigma_a$).

3. Extend your `intersect_scene` function to set a non-zero extinction coefficient in the `HitInfo` struct when the glass sphere is hit. Pick an RGB extinction coefficient that gives the sphere an interesting color. In the shader for transparent materials, use Bouguer's law of exponential attenuation to capture absorption: when the transparent material is hit from the inside, use a Russian roulette to decide on transmission or absorption. The average of the beam transmittances $T_r = \exp(-\sigma_t s)$ in the different color bands is the probability of transmission (continuing the path). Remember to multiply the path `factor` by the RGB beam transmittance and divide by the probability.

Reading Material

The curriculum for Worksheet 8 is (15 pages)

B Chapter 14. *Reflection Models*.