Volumetric Scattering Rendering

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In this project, we implemented a global illumination algorithm that takes into account the media of light transmission when doing ray tracing. Volumes are initially assumed to be homogeneous and then are extend to non-homogeneous media and four effects of media are taken into account: absorption, emission, in-scattering and out-scattering. With the help of the volumetric scattering algorithm, we can render more realistic 3D scene that contains fog, smoke or fire.

Additional Key Words and Phrases: computer graphics, volumetric scattering, Monte Carlo Integration

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1 INTRODUCTION

Global illumination is an algorithm that is used in computer graphics to make images more realistic in 3D scenes. The most common method takes radiance directly and indirectly from the light source, and only assumes lights only emitted and reflected when hitting surfaces. In reality, the media around the environment should be taken into account when estimating the light transmission. Absorption, scattering and emission of lights caused by media, which result in foggy, smoky or dusty effects, happen before light rays hit surfaces. More specifically, there are also homogeneous or non-homogeneous, isotropic or anisotropic settings of media depending on physical attributes of participating mediums. Fig. 1. is a perfect example that describes the phenomenon of fog.

In this project, started with implementing homogeneous and isotropic media, we assumed scattering characteristics of volume of all the participating media are all the same. According to Monte Carlo Integration, we computed an integral over all the volume and all the surface of ray paths. To extend from homogeneous to non-homogeneous, we proposed to discretize the medium into volume elements, each of which has its own parameters to describe the scattering effects, and then combine these homogeneous volumes to make up a whole non-homogeneous space.

2 RELATED WORK

Future work.

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Fig. 1. Foggy Forest

3 METHODOLOGY

3.1 Scattering Media

Assumption is necessary when simulate the behavior of light in the scattering media. To better derive the expressions about the light behavior, we assume the media consists of micro particles. However, we don't need to simulate each micro particle in the media explicitly because the particles are randomly distributed in the media. Instead, we use aggregate probability to simulate the behavior of light traverse in the media.

There are four light interaction events in scattering media: absorption, emission, out-scattering and in-scattering.

Extinction: Absorption and out-scattering are belong to this category. When a thin beam of light traversing a media, at each time step Δt, some fraction of light will be absorbed by the media. Suppose the light is starting at position x and travel in direction ω. The light radiance in the beginning is $L(x \rightarrow \omega)$. Therefore, we can write the remaining radiance of light after time Δt:

$$\lim_{x \rightarrow 0} \frac{L((x + \Delta t \cdot \omega) \rightarrow \omega) - L(x \rightarrow \omega)}{\Delta t} = (\omega \cdot \nabla_a) L(x \rightarrow \omega) = -\sigma_a(x) L(x \rightarrow \omega) \tag{1}$$

where $\sigma_a(x)$ is the absorption rate in the position x, and ∇_a denotes the gradient due to absorption. After integration, the remaining light radiance in position x is: $L(x, \omega) = L_o(x - d \cdot \omega, \omega) e^{-\sigma_a d}$, suppose the media is homogeneous so that $\sigma_a(x) = \sigma_a$.

Out-scattering is the same as absorption, so the final remaining extinction radiance due to out-scattering and absorption is:

$$L(x, \omega) = L_o(x - d \cdot \omega, \omega) e^{-\sigma d} \tag{2}$$

where $\sigma = \sigma_a + \sigma_o$

In-scattering: In addition to loss of radiance, radiance may be increased during its travels through the medium. This might be caused by the in-scattering light from the scene. The mathematic model of in-scattering light can be expressed as:

$$L_i(x \rightarrow \omega) = \sigma_i(x) \int_{\Omega_{4\pi}} p(x, \omega' \rightarrow \omega) L(x \leftarrow \omega') d\omega' \tag{3}$$

where $\sigma_i(x)$ is in-scattering coefficient. The formula above expressed the increased light caused by in-scattering at position x. To accumulate the in-scattering light along the whole ray(from its beginning to its ending), we need to integrate $L_i(x \to \omega)$ along the whole ray, which is:

$$L(x,\omega) = \sigma_i \int_0^d \int_{\Omega_{4\pi}} p(x - s\omega, \omega' \to \omega) L(x - s\omega, \omega') d\omega' ds \tag{4}$$

Combined extinction and in-scattering, we can get the final mathematic model of scattering media:

$$L(x,\omega) = \sigma_i \int_0^d \int_{\Omega_{4\pi}} p(x - s\omega, \omega' \to \omega) L(x - s\omega, \omega') d\omega' e^{-\sigma s} ds + L_o(x - d \cdot \omega, \omega) e^{-\sigma d} \tag{5}$$

where,

- $p(x, \omega, \omega')$ is phase function that indicates the scattering behavior of the media.
- σ_i is in-scattering coefficient.
- σ is extinction coefficient.
- d is the distance from the beginning to the ending of the ray.

3.2 Monte Carlo Estimation

In order to estimate the light behavior in scattering media, Monte Carlo estimation is needed. We use two samplings to describe light traveling behavior according to the math expression of scattering media in previous section. The one is segment path sampling along the ray and the other is uniform sphere sampling at each point of the ray, as the figure 2 shows.

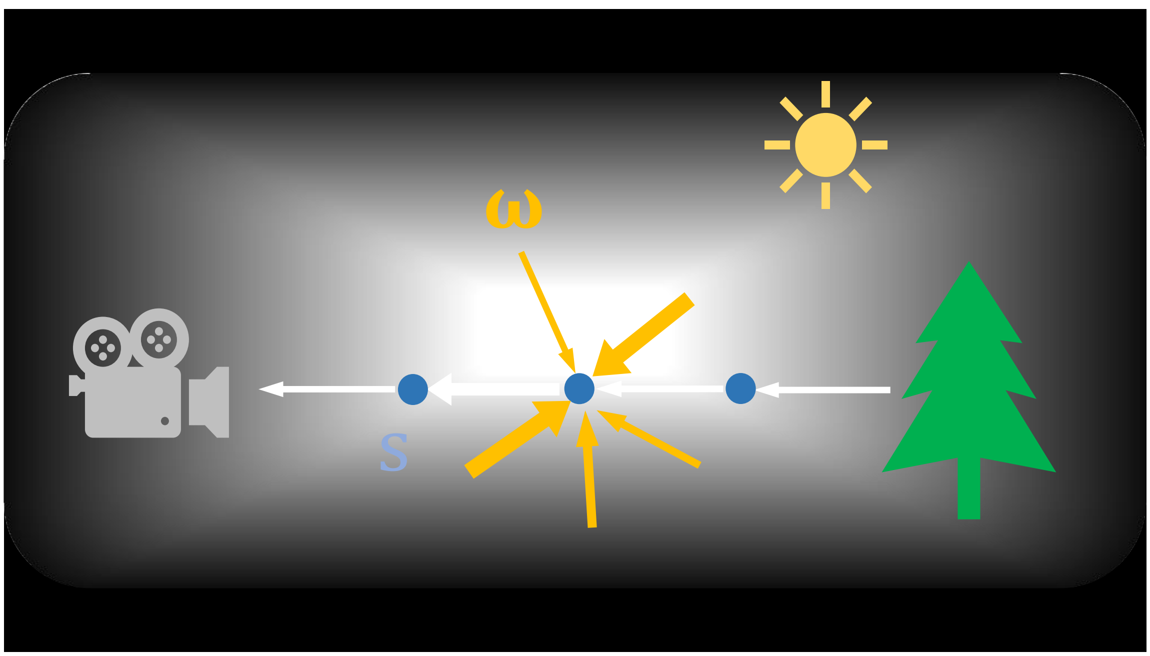

Fig. 2. Segment line sampling and uniform sphere sampling

4 EXPERIMENT

Future work.

5 CONCLUSION

Future work.