Volumetric Scattering Rendering

YIZHEN DING, University of California, Berkeley
SUNDI XIAO, University of California, Berkeley
JIAQI ZHANG, University of California, Berkeley

In this project, we implemented a global illumination algorithm that takes into account the media of light transmission when doing ray tracing. Volumes of all participating media are assumed to be homogeneous 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. Additionally, we added another type of light: spotlight to validate the scattering effect of our approach.

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

ACM Reference Format:
Yizhen Ding, Sundi Xiao, and Jiaqi Zhang. 2020. Volumetric Scattering Rendering. 1, 1 (May 2020), 5 pages. https://doi.org/10.1145/1122445.1122456

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 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. There are 4 types of interactions between rays and particles: in-scattering, out-scattering, emission and absorption [1]. For effects like foggy, smoky or dusty, there is no emission. As for the property of media, there are homogeneous or non-homogeneous, isotropic or anisotropic settings of media depending on physical attributes of participating medium. This paper only focus on foggy effects with homogeneous media. 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. Furthermore, we implemented spotlight features and tried different sampling methods to perform in-scattering rendering: Spherical sampling and importance sampling.

Authors' addresses: Yizhen Ding, ding33@berkeley.edu, University of California, Berkeley; Sundi Xiao, sxiao6@berkeley.edu, University of California, Berkeley; Jiaqi Zhang, jiaqi_zhang@berkeley.edu, University of California, Berkeley.

Fig. 1. Foggy Forest

2 METHODOLOGY

2.1 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[1].

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 $L_i(x \rightarrow \omega)$ along the whole ray, which is:

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

Combined extinction and in-scattering, we can get the final mathematic model of scattering media:[2]

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

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.

2.2 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 spherical sampling at each point of the ray, as the figure 2 shows.

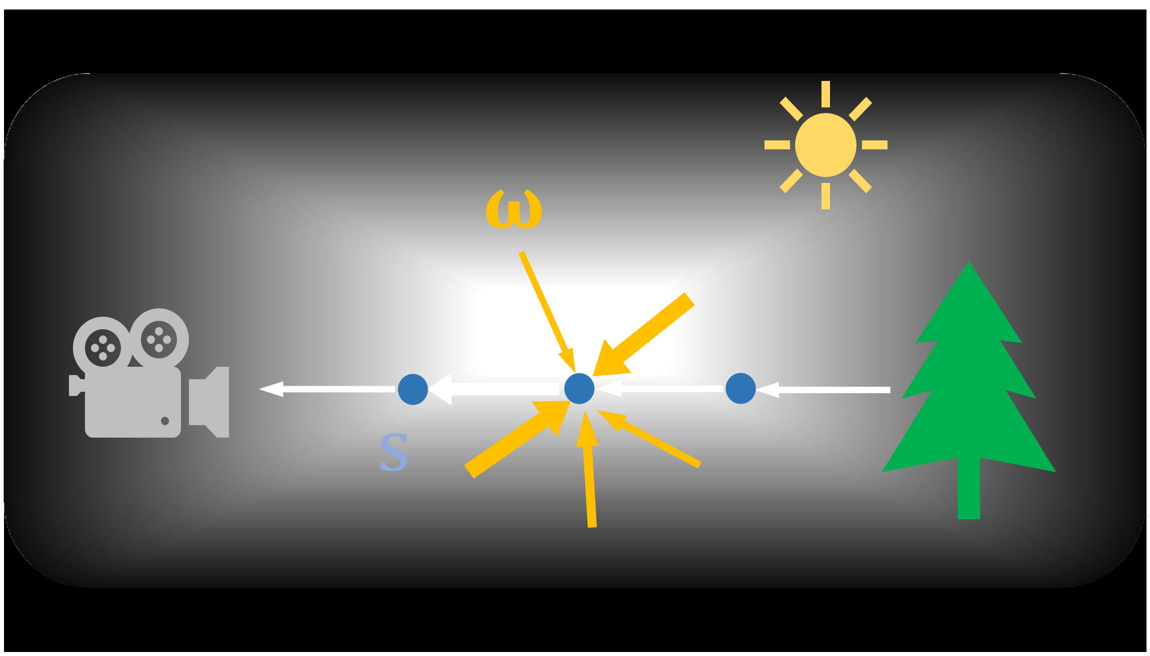

Fig. 2. Segment line sampling and uniform spherical sampling

2.3 Importance Sampling

When we evaluate the irradiance of a sample point, it is very inefficient to sample the whole sphere around that point. Because the irradiance of one point is always determined by a few directions: light ray incident directions, which means that the equal-probability sampling of all the directions is not effective enough to generate irradiance observations from the light distribution. It is worse when light source is a delta type light source. In this case, it is impossible for a randomly generated ray to hit the light source.

Therefore, we used importance sampling to better generate irradiance of each point. To be more specific, when we evaluate the irradiance of one sample point, we sample light source instead of the sphere around sample point. Experiment shows that importance sampling is good at evaluating irradiance of sample point even the sample frequency is low.

2.4 Spot light

Spot light is implemented to validate the scattering effect. Different from point light, spot light only return its radiance if the angle between w_i and direction vector is smaller than the max angle ϕ.

Just like figure 3 shows, a spot light is determined by the direction vector d, max emission angle ϕ, and radiance intensity.

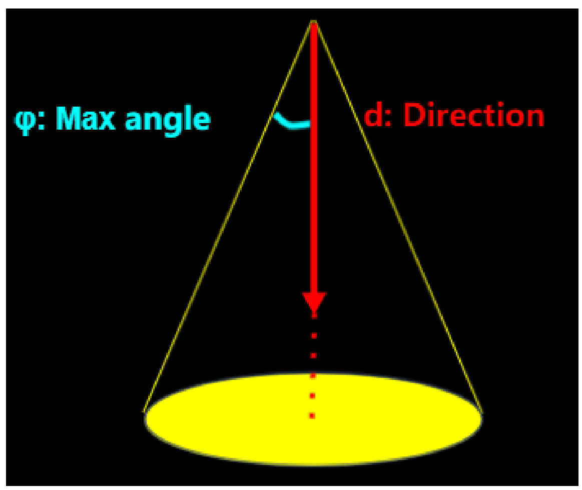

Fig. 3. Spot light

3 EXPERIMENT

In order to compare the effect by tuning parameter g in phase function, we rendered different figures shown in Fig. 4-6 using $g = -0.5$, $g = 0$ and $g = 0.5$. For $g < 0$: backward scattering, the foggy effect is less obvious and light is darker compared to $g \geq 0$, which is reasonable since more light radiance would transmit backward than toward to the camera.

We added another type of light: spotlight. Fig. 7 and Fig. 8 are images using spherical sampling and importance sampling to calculate in-scattering radiance correspondingly. We started with spherical sampling but the result is not what we expected and the reason is that it is nearly impossible for randomly sampled ray to reach a spot light. Therefore,

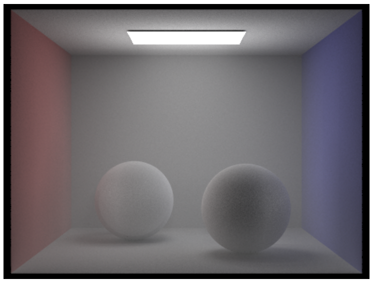

Fig. 4. $g = -0.5$, backward scattering

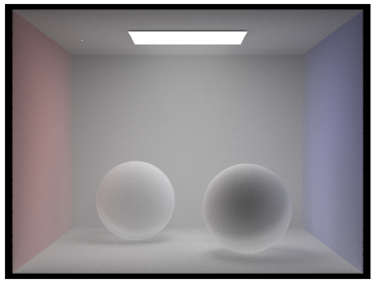

Fig. 5. $g = 0$, isotropic scattering

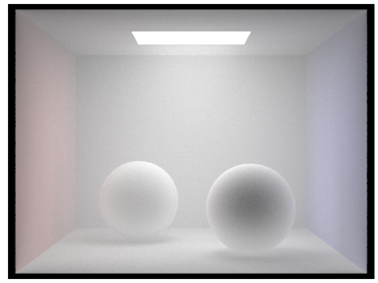

Fig. 6. $g = 0.5$, forward scattering

we changed to importance sampling by taking sample rays directly from the light source. To make our result looks more appealing, we added two more light sources in different colors shown in Fig. 9.

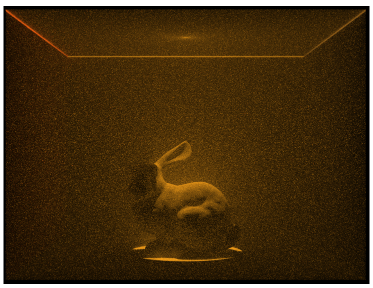

Fig. 7. spherical sampling with spotlight

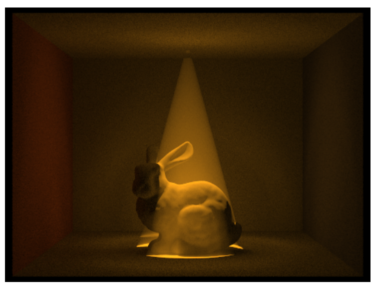

Fig. 8. importance sampling with spotlight

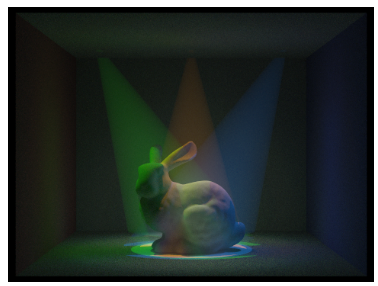

Fig. 9. cool bunny with three spotlights

4 CONCLUSION

In this project, we've extend Project 3-1 to simulate the fog effect in the scene. To sum up, we've successfully implemented the volumetric scattering rendering with homogeneous media and added an extra feature spotlight. We learned how to take into account the medium when doing ray tracing, how to use Blender to modify scenes and how to choose sampling methods to reach ultimate results.

REFERENCES

[1] Wojciech Jarosz. 2008. *Efficient Monte Carlo Methods for Light Transport in Scattering Media.* Ph.D. Dissertation. UC San Diego.

[2] Eric P. Lafortune and Yves D. Willems. 1996. Rendering Participating Media with Bidirectional Path Tracing. *Eurographics Rendering Techniques '96* (1996), 91–100. https://doi.org/10.1007/978-3-7091-7484-5_10