Atmospheric Scattering

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Abstract

In this work assignment we picked up an already existent project developed in ®Unity 3D and tried to replicate it on tool we used on our classes, the Nau3D. The report describes the whole replication process since the atmospheric effects' analysis, to the shaders' translation for Nau3D, until the final simulation, which led to the results presented.

Introduction

Our atmosphere is a mixture of several processes which result in various effects that are noticeable throughout the day, these effects can cause sun's light reflection, refraction or absorption. One of the most important is the scattering effect. Scattering is the process by which small particles in the atmosphere diffuse a portion of the incident radiation emanated from the sun. The scattering of sunlight in the atmosphere causes diffuse sky radiation, which is the reason for the blue color of the sky and the yellow tone of the sun itself, or even the clouds' white color.

This phenomenon has been simulated using computer graphics, mostly to achieve a certain realism in a virtual world. This problem ban be studied from two different angles: the view from the Earth's surface, or the view from space. A project with this features already existed for the Unity 3D engine, with both angles mentioned before. On this work assignment a new version for Nau3D engine was developed based on the previous mentioned project, although only the latter angle was focused on. The objective is to mimic atmospheric effects that a person would be able to see if they were in space, looking at Earth. The scene created is constituted by only two concentric spheres, one simulates the Earth and the other slightly bigger the atmosphere.

Atmospheric Scattering

As mentioned before, scattering is the redirection of electromagnetic energy by the suspended particles in the atmosphere. Depending on the size of the particle which the light reached the type of scattering will be different: if the size is smaller than the wavelength of visible light, the effect is Rayleigh scattering, if it's about the same size, the effect is applied is Mie scattering. Rayleigh scattering influences the color of the sky, from the usual blue to the sunset red/yellow shades, due to the very small size of the average atmosphere particle (smaller that the wavelength reaching it). Mie scattering is responsible for the white/grey clouds' colors which contain water droplets with a similar size as the wavelength reaching it.

Figure 1. Atmospheric scattering effect

Rayleigh Scattering

The blue color of sky and the yellow tone of the sun are two phenomenon that happen due to the Rayleigh scattering effect. This kind of scattering occurs when light or other electromagnetic radiation reaches particles that are much smaller than the wavelength of the radiation. Those particles can be individual atoms or molecules. This scattering effect can also ensue through solids or liquids but it is most common in gases and is resultant from the electric polarizability of the particles by the electric field oscillation, causing them to move at the same frequency.

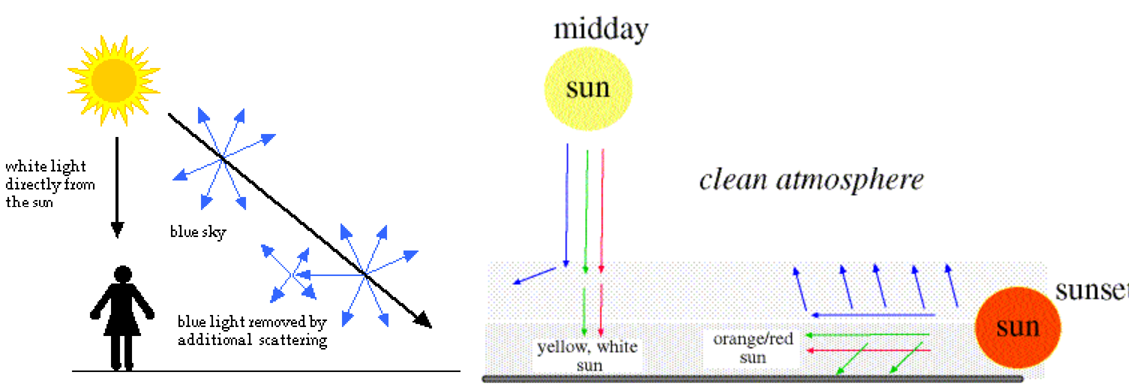

Figure 2. Rayleigh scattering

Below some formulas are shown that allowed us the production of the Rayleigh scattering light effect. The implemented version was a simplification of these formulas which otherwise would have resulted on an enormous load of computing and we pretend to have results within an acceptable framing rate. The simplified version implemented does not produce the precise effect we need but produces a similar effect and simultaneously a great efficiency.

The first formula shown defines which type of scattering to be calculated (Rayleigh or Mie). Although on this work assignment only the Rayleigh scattering was simulated.

$$x = \frac{2\pi r}{\gamma}$$

On this formula r is the particle's radius and γ is the wavelength of the light. Objects with $x \gg 1$ act like a geometry shape, scattering light according to their projected area. When $x \cong 1$ the Mie scattering is applied (see Mie Scattering). The Rayleigh scattering is applied when $x \ll 1$, or by other words, when the particle is minuscule. This means that the particle size (radius) is nearly ten times smaller than the length of the light and the entire surface re-radiates with the same phase. Since the particles are randomly positioned, the scattered light can assume many different phases depending to the point it arrives.

The next formula calculates the intensity I of light scattered by any sphere with a small diameter d and refractive index n from a not polarized beam light of wavelength γ and intensity I_o.

$$I = I_0 \frac{1 + \cos^2 \theta}{2R^2} \left(\frac{2\pi}{\gamma}\right)^4 \left(\frac{n^2 - 1}{n^2 + 2}\right)^2 \left(\frac{d}{2}\right)^6$$

Where R is the distance to the particle and θ is the scattering angle. The Rayleigh scattering cross-section is calculated by averaging this over all angles. Consider the equation below:

$$\sigma_s = \frac{2\pi^5}{3} \frac{d^6}{\gamma^4} \left(\frac{n^2 - 1}{n^2 + 2}\right)^2$$

For example, let's imagine a group of scattering particles. The fraction of light scattered is the number of particles per volume unit N times the cross-section. Most of Earth's atmosphere is constituted by nitrogen (nearly 78%). Its cross-section is 5.1×10^{-31} m^2 at a wavelength of 532 nm (green light). Thus, at atmospheric pressure, we have nearly 2×10^{25} molecules per cubic meter which results on a fraction about 10^{-5} of the light that will be scattered for every meter it travels. The dependence of strong wavelength means that shorter wavelengths (implies more frequency, which means blue color) are scattered more powerfully than longer wavelengths (means less frequency, so it belongs to red color). Figure 3 illustrate exactly what we referenced above.

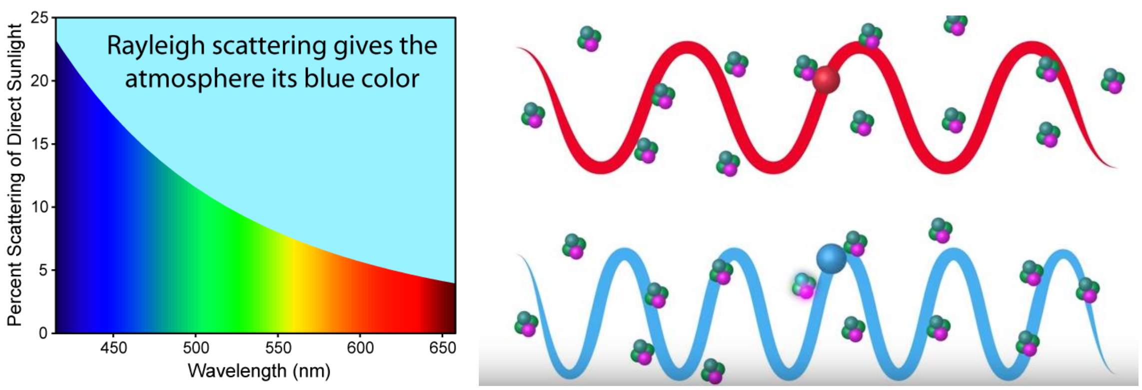

Figure 3. Proportion of light scattered at the atmosphere

If we could animate Figure 3 we would see that the blue ball (that represents the blue color once it has bigger frequency and consequently less wavelength) hit the atmosphere particles many times more than the red one, hence the blue color of the sky.

The previous light equation was adapted to single particles as atoms. The following approach was designed to produce the same lighting effects now on molecules. Essentially, the equation converts into something like:

$$I = I_0 \frac{8\pi^4 \alpha^2}{\gamma^4 R^2} \left(1 + \cos^2\theta\right)$$

Where α represents the molecular polarizability factor.

Mie Scattering

By the other hand, the Mie scattering is applied to larger particles where their size is similar to the wavelength of the light, instead of being much smaller or much larger. For example, water droplets are capable of producing the Mie scattering lighting effects. They can be simulated by using some objects like spheres, cylinders or a cluster of both. Therefore, when the particle's size turns out to be 10% larger than the wavelength of the incident radiation, Mie scattering is used to find the radiation intensity. The intensity is calculated from the summation of an infinity series of terms and it originates from the Rayleigh scattering in several aspects.

An important aspect to this scattering is that has a direction, unlike Rayleigh scattering, which is mainly forward, the distance and spread will fluctuate depending on the particle size: the bigger the particle the bigger the scattering. Clouds are composed by numerous water droplets and all wavelengths of visible light are scattered identically through this type of scattering, giving them the white and grey colors. In Figure 4 we can see that for distinct radius we can have different Mie scatterings. Figure 5 explains the reason behind Figure 4 (a) dissimilar behavior when comparing to (b) and (c).

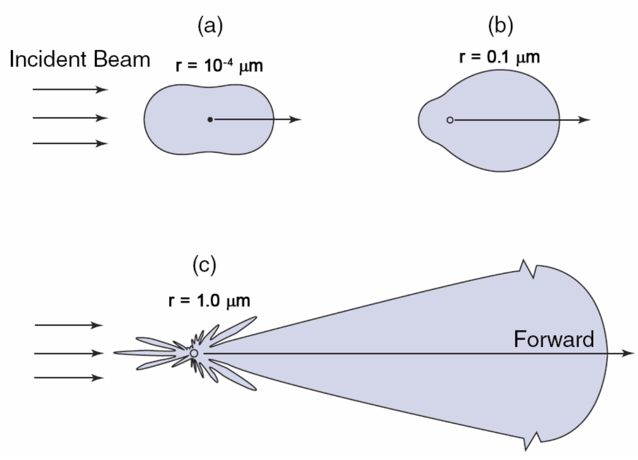

Figure 4. Mie scattering for different particle's radius

This "medium" size particles are usually considered as spheres in order to simulate the Mie scattering by applying the anomalous diffraction approximation formula. The formula is shown underneath:

$$Q = 2 - \frac{4}{p}\sin p + \frac{4}{p^2}(1 - \cos p)\ , p = \frac{4\pi a(n-1)}{\gamma}$$

Where Q is the efficiency scattering factor (also defined as the ratio between the scattering cross-section and the geometrical cross-section, πa^2) and p is the phase of delay while the wave is going through the center of the sphere. The a variable represents the sphere radius, n characterizes the ratio of refractive indices inside and γ is the light wavelength.

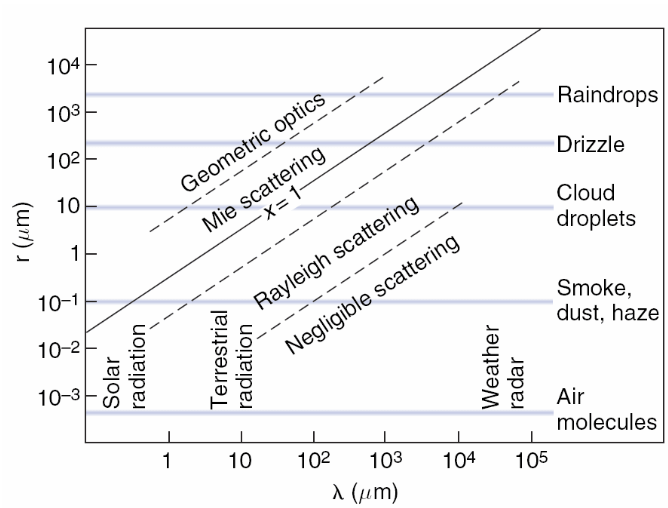

Figure 5. Types of scattering according to the radius and wavelength

Figure 5 sums up all that was referenced before, studying it allows us to easily see which is the most appropriate scattering type depending on the particle's radius and the light's wavelength. In Figure 4 (a) an estrange fact was seen and now it can be understood. The particle radius was too short for applying the Mie scattering, it was preferable to choose a Rayleigh scattering.

Result Comparison

Using the fact that there were two projects which simulate atmospheric effects viewed from space, the result obtain from them was compared, and although the effects are very similar there where some differences. When positioning the camera to obtain Figure 6 it was noticed some red/yellow shades on Earth's edge, slightly visible on this figure. Regardless, the effect obtained was very similar, as shown on Figure 6.

Figure 6. Atmospheric Scattering effect observed from space. Left image collected from Nau3D, right image from Unity 3D

It is believed that the small differences are owing to the diverse way that lights are defined, since minuscule variations in the light's position or direction on the Nau3D XML file would change the simulated result by a great deal.

When changing the camera position to obtain Figure 7 some dissimilarities are also observable, mainly on earth, where the shader being used on Nau3D does not implement atmospheric effects, consequently Unity 3D's result is more realistic.

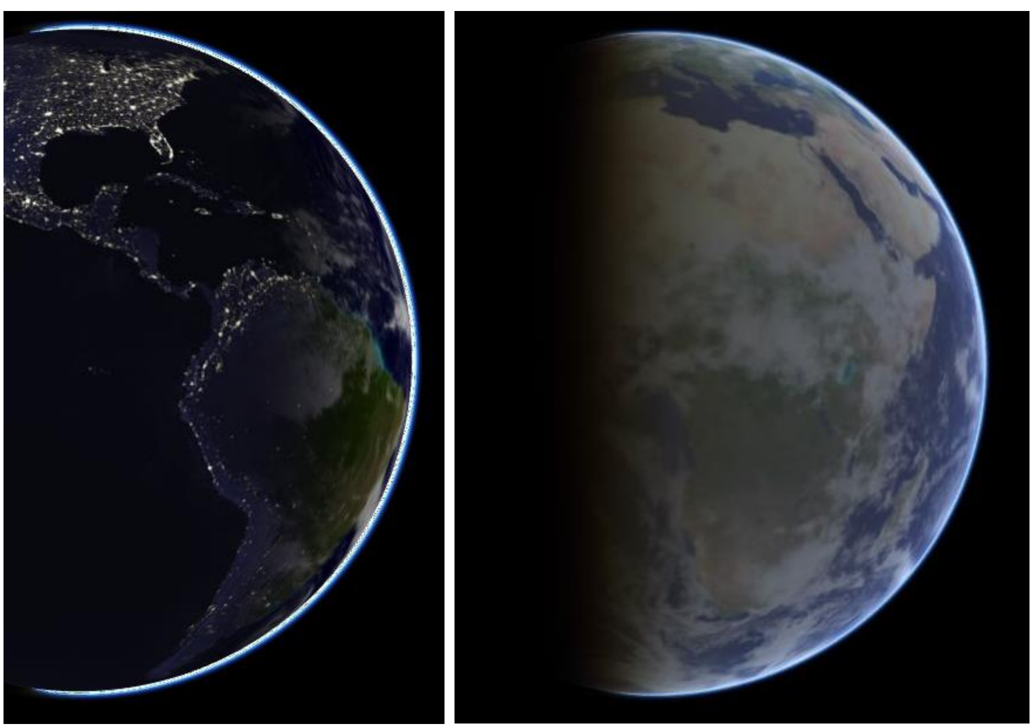

Figure 7. Atmospheric scattering effect observed from space. Left image collected from Nau3D, right image from Unity 3D

Conclusion

This work assignment, based on an already existent Unity 3D project, has allowed for us to study the reason behind some atmospheric effects, specifically its scattering. In order to simulate its effects some of the Unity's project's shaders were translated. This process revealed to be more challenging than expected, as the shaders for the scene where the camera was on Earth's surface were not translated and some inaccuracies were found in the translated shaders as well. This is probably attributable to the diverse way of defining components, as mentioned before. Obviously this would be the first area to explore, if trying to improve this work assignment. In spite of these problems a solution was still developed, yet limited by them. It is possible to visualize an approximation our atmosphere scattering effects from space.

References

[1] "Atmospheric Radiation," Weather Edge, [Online]. Available: http://www.severewx.com/Radiation/scattering.html.

[2] "Mie scattering," Wikipedia, 2 February 2016. [Online]. Available: https://en.wikipedia.org/wiki/Mie_scattering.

[3] "Rayleigh scattering," Wikipedia, 21 January 2016. [Online]. Available: https://en.wikipedia.org/wiki/Rayleigh_scattering.

Annex – Sunrise in Unity 3D

As mentioned before, on this work assignment it was not possible to translate the Unity 3D shader where the point of view was the Earth's surface in order to use them on the Nau3D engine. Even so the preexistent project was used to simulate the atmospheric effects that can be seen every day, such as the sunrise, sunset, general color of the sky, and so on… Figure 8 represents three sunrise stages from Unity 3D recreation, where the sky's colors variation is explicit, and .varying with the sun's position.

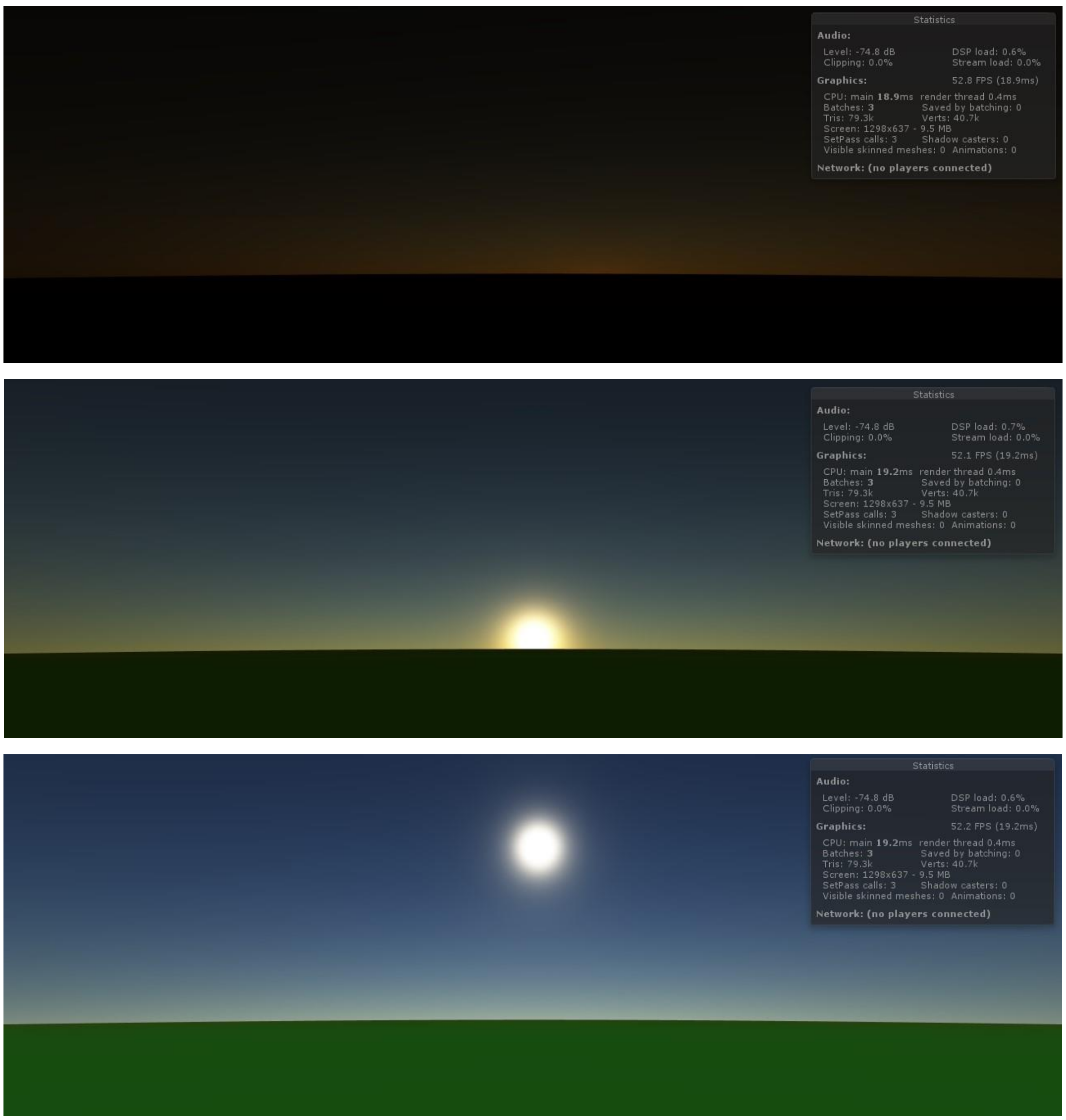

Figure 8. Scattering simulated in Unity3D observed from the planet's surface during sunrise