Real-Time Visual Simulation of Snow and Fog in Support of Safer Snowplow Design

NATSRL Seed Project
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Final Report

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Executive Summary

In snowing or foggy conditions, driving behind a snowplow creates a situation that can be extremely dangerous for the driver of the following vehicle. In these situations, drivers often misperceive their own speed and the motion of the approaching snowplow, which results in very unsafe following distances behind the snowplow. To better understand how humans drive under these conditions, this project focused on implementing a simulation environment that can recreate a snowy or foggy scene. The work focused on building the base software for an effective real-time snow rendering simulation environment. The approach for rendering the snow is based on research for real-time cloud simulation and rendering. We used a particle simulation technique, representing the individual particles of snow, to better approximate how light travels through a snow cloud. Our model attempts to capture the manner in which light entering a snow cloud scatters in different directions. The work was completed over the 2006 summer and will provide a substrate for future work on real-time snow rendering. The initial results represent snow fields containing tens of thousands of snow particles, with approximate light scattering and absorption for these conditions. More work is needed to better estimate the manner in which light propagates through a snow cloud. Additionally, including larger numbers of particles will help create more realistic scenes. The resulting rendering framework will be used as the basis for a simulator to empirically prototype snowplow colors and designs that better integrate with human perception capabilities under challenging driving situations.

Chapter 1
Introduction

In snowing or foggy conditions, following a snowplow creates a situation that can be extremely dangerous for the driver of the following vehicle. The danger comes from the human visual system's inability to accurately perceive speed and the motion of the snowplow which when taken together, results in setting up very unsafe following distances behind the snowplow, often resulting in accidents. During daylight, fog and snow help to enhance what is known as a low luminance-contrast situation[1-3]. Low luminance-contrast occurs when the difference between the apparent brightness of the different surfaces decreases, making it difficult to tell foreground from background. In addition, the orange color of most snowplows adds to this effect since the snow cloud around the truck is of similar brightness to the orange of the snowplow.

Unfortunately, understanding if certain configurations of snowplows create safer driving conditions is not trivial. First, creating experiments that research snowplow designs to increase luminance-contrast is extremely dangerous to perform in real settings. Second, creating mock snowplows to test configurations with differing arrangements of lights and colors is expensive and time-consuming. As a result, there is critical need to build a virtual environment capable of simulating the low luminance-contrast conditions caused by snow and fog. This virtual environment would serve as a test-bed to investigate how snowplow design can be augmented to reduce the problems caused by low luminance-contrast conditions. Until this need is met, following behind a snowplow will have added risk.

The long-term goal of this research is to create safer winter driving conditions by minimizing additional driving risks that are in our control. This includes building better snowplows with designs that factor in the nature of the human visual system. The objective of this research is to build a real-time visual simulation of the snow and fog surrounding a snowplow. This real-time simulation framework could then be used in a driving simulation application to help test the effects of snowplow colors and emergency light layout in different driving scenarios. Real-time computer graphics is capable of creating a rough approximation of fog using an exponential illumination falloff with distance, but this model can be improved through use of shading programs that simulate how light interacts with participating media. While fog can be simulated more easily than snow, the methods for rendering fog on current graphics hardware do not effectively represent how light interacts within a snow cloud. Snow clouds can be approximated through use of volumetric, computer graphics techniques that utilize particle simulation shading programs to model light (photon) interaction within a snow cloud. The simulation created for this research utilized this general technique to achieve a first-pass at an effective snow and fog visual simulation. The work was completed over the 2006 summer timeframe.

The current state of our snow rendering system requires additional research and development to improve the visual rendering so that it more closely matches the way photons interacts within the snow cloud. We plan to pursue the continued development of our snow rendering system as part of our future work. Future work on this project will result in a better approximation for rendering snow, validation of the model, and integration with a virtual driving simulation framework.

Chapter 2
Research Results

The basis for our snow cloud rendering algorithm was developed over the 2006 summer as part of the NATSRL Summer Seed Program. Our current snow rendering system uses a particle system approach to produce real-time renderings of a snow cloud. The work is based on research implementing real-time cloud rendering. Real-time cloud rendering attempts to produce a visualization of a cloud by solving for how light interacts with the water particles within the cloud. This is a difficult problem to solve since it generally requires coming up with a model for how light passes through and interacts with the moisture particles. Recent research focusing on cloud simulation has attempted to make the problem feasible by using a particle system to approximate the cloud [4-6]. This research solves for the light that statistically would be scattered towards the viewer's eye at each particle. The results from all particles in the cloud are then combined into an image-based composite of the cloud. Particles are sorted from back to front and the resulting cloud is visualized on the screen. This work attempts to reduce the cost of rendering clouds with many thousands of particles by amortizing the particle simulation over several simulation frames. Clouds nearer and in direct line of sight with the viewer have higher precedence. The result is very realistic clouds rendered at real-time rates.

In our system, individual particles of snow are used to approximate how light travels through a snow cloud by computing the directional scattering of the light on each particle. We then sort these particles and blend the effect of the light on particle across distance. The result is an attenuation of light depending on the density of the snow cloud. This initial pass at a snow rendering algorithm attempts to mimic the ways in which light entering the snow cloud is either absorbed or scattered. Our work is currently focused on rendering light interaction within a snow cloud, but may eventually incorporate spectral methods used to model falling snow [7]. However, the results from [7] may not work well for large snow clouds in real-time rendering settings as the work is only focused on slowly falling snow.

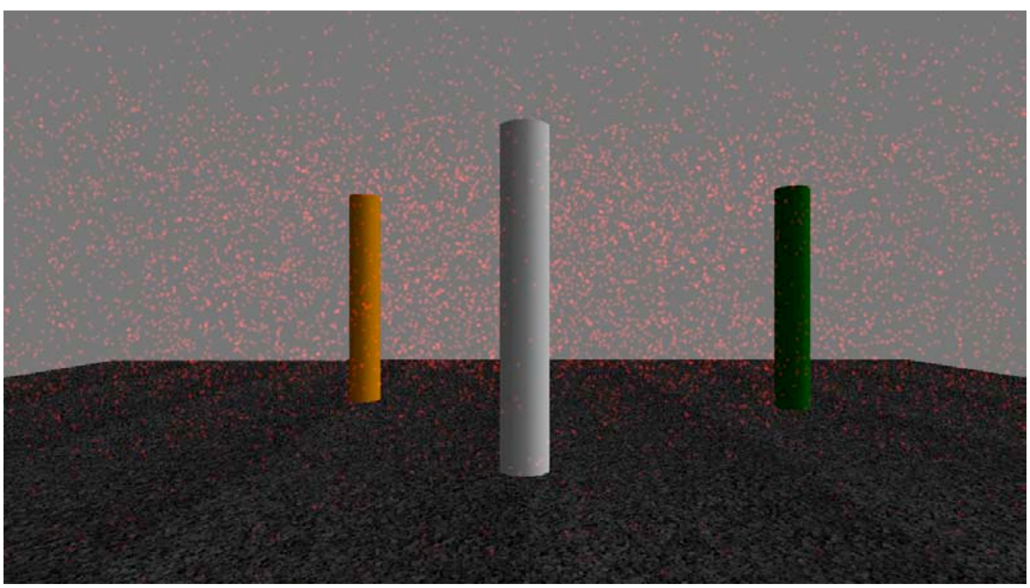

Figure 2.1. Visualization of Snow Particles

Figure 2.1 presents an image showing the underlying particles used in our snow simulation. Figures 2.2 through 2.4 show images from our simulation. In these images, areas with higher snow particle density produce areas in which the background is more obscured. In the case of the three pillars in the test scene, equiluminant (low luminance contrast) situations are beginning to form due to the snow particle density. Our continued work on this model will result in a better approximation to snow rendering and a validation of the perceptual qualities of the rendering.

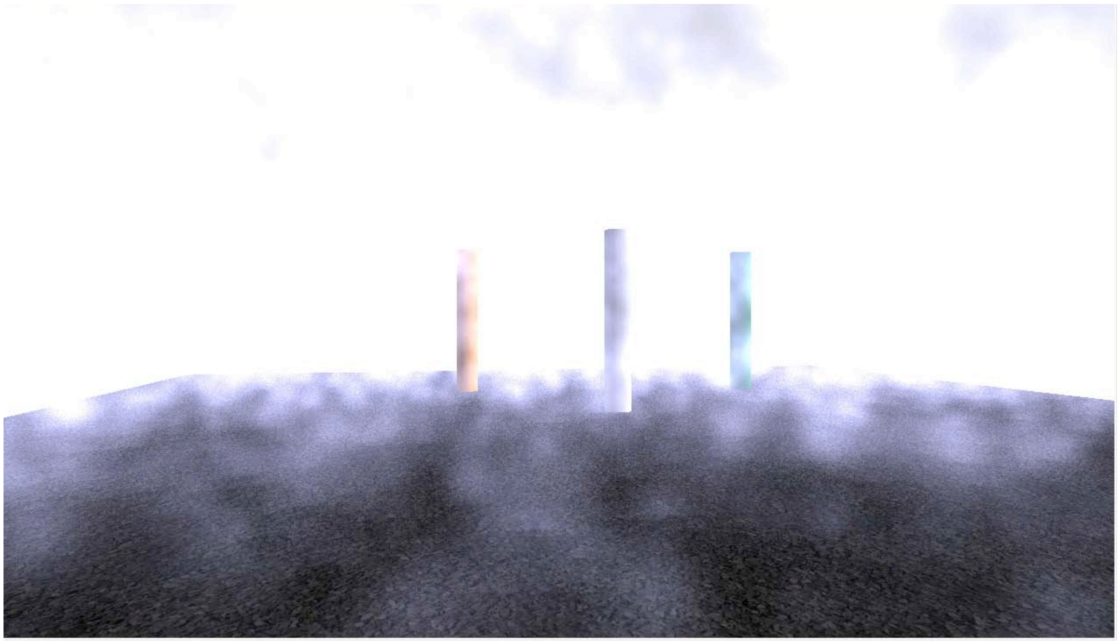

Figure 2.2. Example Snow Cloud

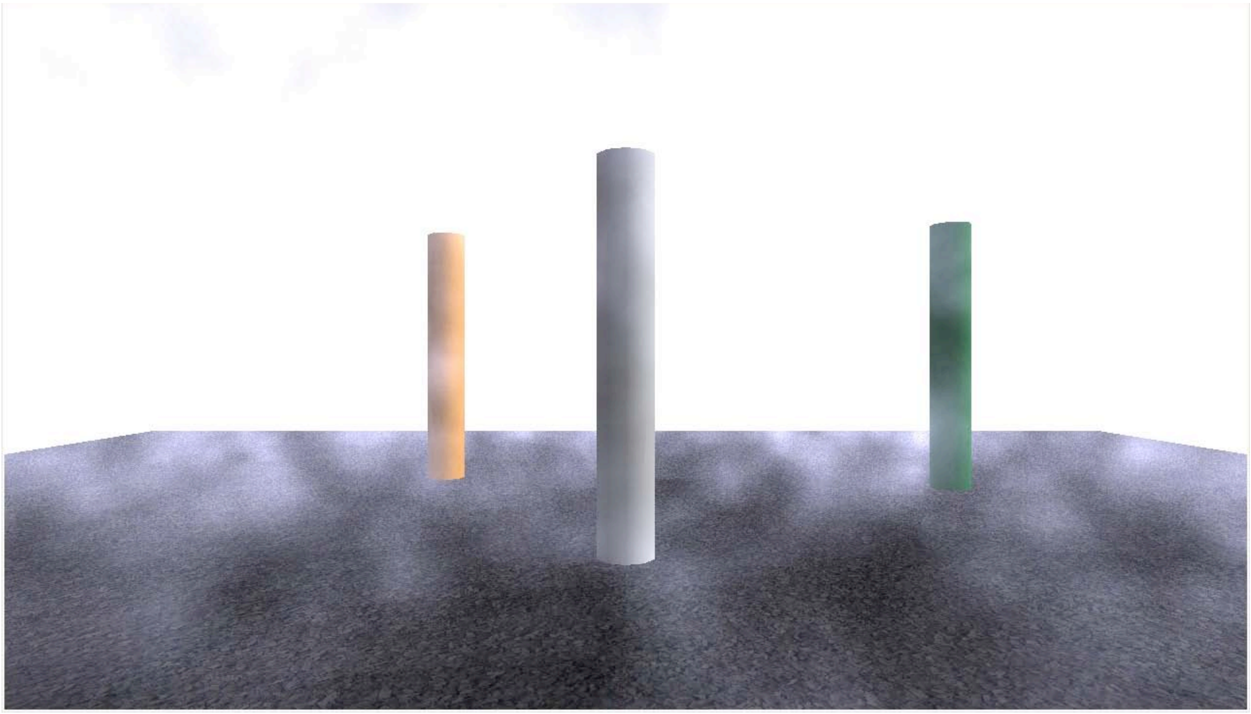

Figure 2.3. Example Snow Cloud

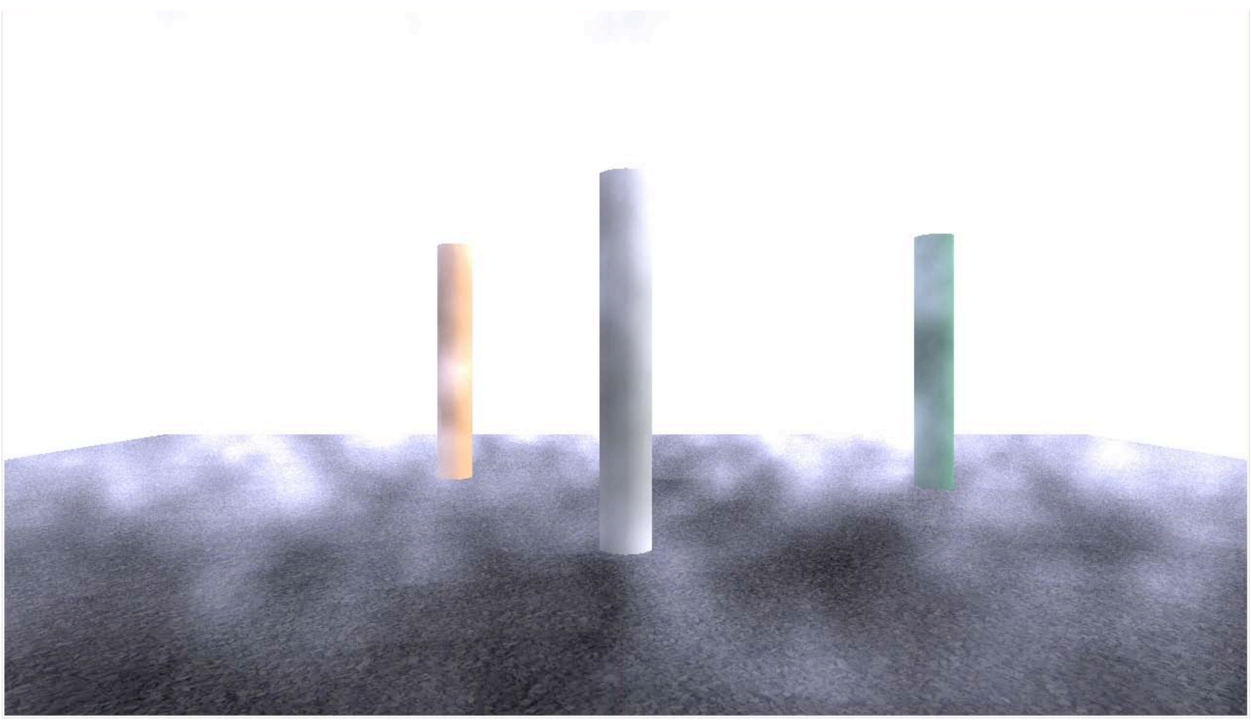

Figure 2.4. Example Snow Cloud

Chapter 3
Conclusions

The long-term goal of this project is to create safer winter driving conditions by reducing the number and the severity of rear-end collisions with snowplows and other vehicles under poor visibility conditions. We hope to achieve this long-term goal by simulating the conditions under which these accidents occur. The objective of this work is to build a real-time virtual environment capable of producing an effective visual simulation of the snow and fog surrounding a snowplow.

Our current efforts have focused on the beginnings of a snow rendering simulation. Future work needs to look at better approximating the manner in which light interacts within a snow cloud. In particular, focusing on the absorption and scattering coefficients will help to make the simulation more realistic. Additionally, increasing the number of particles used to simulate the snow cloud will also help increase the realism of the snow cloud. We plan to focus on these modifications in future work.

One of the expected outcomes of this project is an improved visual rendering of snow that more effectively takes into account the physical interaction between snow particles and light entering the snow cloud. Improving snow rendering for interactive environments will have an impact in the computer graphics field, but will also be of importance to the driving simulation community. The primary application we are focused on is safety with respect to snow plow design and we plan to be able to test the effectiveness of different configurations of snowplow lighting, coloring, and design in low luminance-contrast situations. By focusing snowplow designs around the limits of human perception, we serve to advance knowledge, save lives, and have broad impact across the Northland.

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