Interactive Physically-Based Cloud Simulation

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Abstract

Artificial clouds play an important role in the computer generation of natural outdoor scenes. Realistic modeling and rendering of such scenes is important for applications in games, military training simulations, flight simulations, and even in the creation of digital artistic media. We propose a model for simulating cloud formation based on an efficient computational fluid solver. We combine the fluid solver with a model of the natural processes of cloud formation, including buoyancy, relative humidity, and condensation. This allows us to simulate the formation and growth of clouds at interactive rates.

1 Introduction

In this work, we focus on the simulation of physical processes that contribute to the formation of clouds in our atmosphere. By simulating these physical processes we are able to more accurately model the structure of a cloud that forms under given atmospheric conditions.

Traditionally, cloud structure has been generated by either procedural or fractal methods[3]. While these methods may at times produce visually compelling results when coupled with complex rendering techniques, these structures are essentially random and are difficult to modify or control interactively for creating different cloud types. Our method allows the user to interact with a physically-based simulated environment in order to produce the desired cloud formation. All the user needs is a basic understanding of the fundamental processes involved in cloud formation: buoyancy, relative humidity, and condensation.

2 Atmospheric Model

In order to model the physical process of cloud formation, we simulate the fluid flow of air within our atmosphere. Atmospheric air flow is based on a number of environmental factors, including large-scale wind motion and buoyancy of air due to local temperature differences. We have developed a fluid simulator based on the work of Jos Stam[5], however our fluid simulator accounts for buoyancy and convection currents created by a dynamic heat distribution, as well as relative humidity and condensation. We record the velocity, temperature, humidity, and condensation at each grid point. More detailed information on our simulation method can be obtained from our technical report[4].

The fluid solver, for computational ease, assumes that pressure is constant in the system, which is certainly untrue over the atmospheric scale. In order to make the fluid model account for the variation in atmospheric pressure in the vertical dimension, we make two low-level modifications to our solver. Specifically, we modify the velocity field at each step to account for the expansion of rising air and the conservation of momentum. Although these effects tend to be minor (velocities in our typical simulation are modified by less than 5%), the effects are not negligible over the scale of the simulation. While the resulting motion is not a completely accurate model of fluid flow in the atmosphere, it does capture the primary differences from a constant-pressure simulation.

3 Creating Different Cloud Types

Currently our simulation focuses only on two main cloud types—cumulus clouds and stratus clouds. Cumulus clouds are formed by vertical air movement caused by thermal currents over land. Stratus clouds, on the other hand, are formed by horizontal wind currents over oceans or other large bodies of cold water.

3.1 Creating Cumulus Clouds

We form cumulus clouds by defining a plume of humidity and a heat source at ground level. The incoming heat
raises the temperature of the air and buoyancy causes the humid air to rise. The heat source pattern can be tailored to fit the approximate cloud shape desired. As the humidity rises and begins to condense, latent heat is released, increasing the upward buoyant force and producing a predominantly vertical cloud growth pattern. In our simulation we have included wind to help shape the cloud as well. A global wind defines the drift pattern of the cloud, while local crosswinds introduce turbulence into the environment. Figure 1A shows an example of cumulus cloud formation. Figure 2 shows examples of off-line renderings of our cumulus clouds using the Skyworks rendering engine presented by Mark Harris[1].

3.2 Creating Stratus Clouds

Stratus clouds are formed slightly differently than cumulus clouds. Stratus clouds usually form over cold terrain such as ocean water, where there is little or no vertical air movement. Contrary to the cumulus cloud set-up, for stratus clouds we do not define any heat source for our environment and our source of humidity is outside our simulation region, carried in on a horizontal cross-wind. The user can define the direction and altitude of the cross-wind and also the amount of humidity carried in by the wind. This gives us humidity traveling horizontally instead of vertically. When any of the water vapor condenses, the latent heat released causes some buoyancy and therefore we see wispy streaks of cloud, interspersed horizontally around the dew point. Figure 1B is an example of stratus cloud formation.

4 Conclusions

We have developed an efficient physically-based simulation of cloud formation which can be run interactively on a standard desktop PC. This model provides a basis for interactively modeling physically-based clouds in 3D using a computational fluid solver, and can be used with any grid-based fluid solver. Also, our model is one of few to date which has addressed more than one type of cloud — others include the recent work of Miyazaki et al.[2]. We believe that the proposed model is a significant improvement over previous models of cloud formation in the field of Computer Graphics and hope to improve this model in the future. For additional details, please refer to our technical report[4].

Figure 2. SkyWorks Rendering.

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References