I Love It When A Cloud Comes Together

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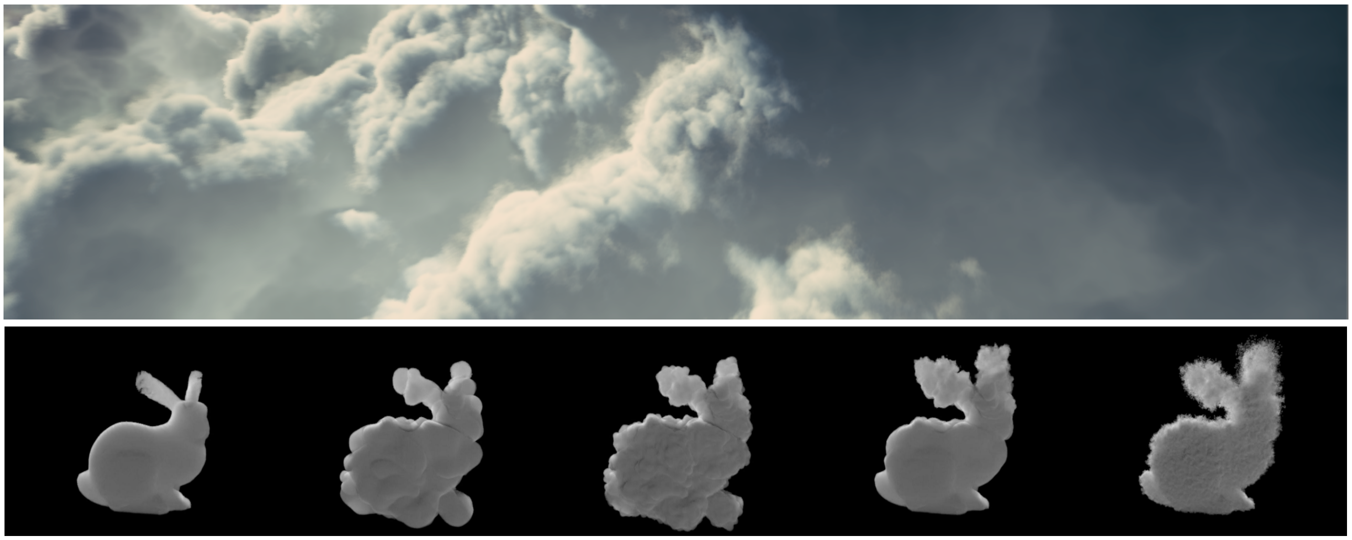

Figure 1: *Top: 3D cloud environment for a scene from* The A-Team*. Bottom: Progression of cloud modeling techniques in* Cumulo*. From left to right: bunny cloud base shape; bunny cloud with one layer of pyroclastic displacement; bunny cloud with two layers of displacement; bunny cloud with three layers of displacement and field control of displacement amplitude; bunny cloud with three layers of displacement, field control and render-time advection.*

1 Introduction

One of the action sequences in the film *The A-Team* takes place within a growing system of storm clouds. The story plot required the creation of a fully 3D environment of clouds covering tens of kilometers of evolving storm, modeled and simulated at high resolution because the camera and story elements are embedded within it. The cloud system covered approximately $20 \times 10 \times 5$ kilometers, at a resolution as small at 0.1 meters. A variety of clouds types were modeled, corresponding to the different cloud taxonomies in different regions of a storm supercell. Individual cloud structure was controlled and directed down to arbitrarily fine spatial detail. This talk discusses the software tools developed to model, simulate, and render this complex, high resolution cloud system.

2 Cumulo

One of the major cloud features needed was the puffy cauliflower-like structure in cumulus clouds. The pyroclastic noise method[1] exhibits the kind of features of interest, but for a cumulus cloud we needed to apply pyroclastic displacements onto arbitrary shapes, and to apply multiple layers of them. Also, cumulus cloud pyroclastic structures clear the displacement noise out of the valleys between major puffs. To accomplish these aspects, our *Cumulo* tool converts modeled base cloud shapes into levelsets and applies displacement noise, and generates a new levelset for pyroclastically displacement geometry. *Cumulo* iteratively applies multiple generations of noise to create displacements on top of displacements, puffs on top of puffs. Clearing between puff structures happens by modulating each layer of displacement with scaled versions of the previous layers.

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[1] Alan Kaplar, "Avalanche! snowy FX for XXX", Siggraph 2003 Sketch.

3 Advection

Cumulo displacement of base shapes produces hard-edged cloud structures. A few steps of advection by vector noise was used to soften the edges and create small, ragged, separated pieces of cloud near the larger cloud. Advection was applied during cloud modeling, where it would be "burned into" the density grid after the *Cumulo* process. It was also applied at render time independent of gridding so that very fine sub-grid detail was created.

4 Field Controls

No two clouds are alike. Individual clouds have large amounts of structual variation within them. To reproduce this, the parameters driving the *Cumulo* displacements and advection velocity had to be controllable from point to point on the cloud. Parameters were controlled by the artists as point attributes on the surface of the cloud base shape. These point attributes were transfered to a volumetric field control. Field controls were also built procedurally, sometimes driven by animations and simulations. This approach allows complete freedom to control the cloud structure with arbitrary precision, and facilitates modifying existing cloud structure locally without altering the rest of the cloud.

5 Volume Render

Cumulus and storm clouds are participating media which have relatively little absorption (the single scatter albedo is between 0.95 and 0.999), and large amounts of multiple scattering (number of scattering lengths frequently in excess of 100). Ideally, rendering would employ a robust multiple scattering method which handles many orders of scattering. We employed several techniques in different parts of the sequence, including multiple light sources, internal glow lights, and new yet-to-be-published multiple scattering algorithms.