A Simple Improvement of Gas Simulation Quality

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1 Introduction

For *Alvin and the Chipmunks*, dry ice vapor was simulated for a rock concert sequence. The chipmunks jumped out of a cauldron of vapors, and danced and sang on the lid. Vapors had to flow from the cauldron and interact with the chipmunks throughout the sequence. Because both close up and establishing shots were needed, the simulation was required to be high resolution over a fairly large volume of space. The Rhythm and Hues fluid simulator, Ahab, simulates high resolution smoke well suited for this task. However, the production schedule limited the available simulation time and resources, and the consequent quality of the simulations was not as good. Our solution was to do faster simulations on a relatively coarse grid, and supplement the motion with a step of advecting the vapor through its own velocity field. The additional advection was performed at render time using the Felt volume scripting system developed by Rhythm and Hues. This advection step was a gridless procedure that generated finer flow detail than present in the original simulated vapor density. The process dramatically improved the visual quality of the simulations with minor cost in render speed and memory.

Figure 1: *Chipmunks emerge from a cauldron of simulated vapors.*

2 Vapor Simulation

The Ahab fluid simulator is an Eulerian-grid solver of the Navier-Stokes equations using the minimally dissipative QUICK scheme. Two 250 frame simulations were used in segments for the various shots in the sequence. The vapor was simulated as a gas with positive downward bouyancy (heavier than air). Density was continuously injected along the lip of the cauldron and stirred by forcing objects. This caused the gas to spill out the top and flow down the outer sides of the cauldron. The chipmunks were represented with low polygon count animated models, which Ahab converted to levelsets to handle boundary and momentum conservation constraints.

The simulation volume was represented on a grid of $256 \times 64 \times 192$ points over the volume occupied by the cauldron, lid, and floor immediately around the cauldron. Because rapidly moving chipmunks and complex boundaries constrained the CFL condition, simulation times averaged 22 minutes per frame. The velocity and gas density at each frame was stored on disk for later use in rendering. With this grid size, volume rendering the simulated gas density produced gridded artifacts in the animation.

3 Gridless Advection

We applied a step of gridless advection at render time. In practice, we have found that it solves several problems: (1) gridded artifacts in the density are eliminated, (2) smooth but with well-defined detail and edges are generated in the structure and flow of the density, (3) render-time options for control of the look of a simulated gas after the simulation is completed, and (4) modest additional resources at render time are required. Because gridless advection is a built-in shading function within Felt, it easily fits into the volume rendering pipeline.

Gridless advection uses the formula for semi-lagrangian advection for the transport of density in the velocity field. For any rendering frame, we read from disk the gas simulation gridded density and velocity field $\mathbf{u}$ on the rectangular grid $\mathbf{x}_i$. The volume renderer queried for the density at points $\mathbf{x}$ in space which need not lie on grid points. Instead of interpolating the density at that point, the gridless advection process evaluates the density at the advected position

$$\mathbf{x} - \mathbf{u}(\mathbf{x})\, T$$

where the timestep T is chosen for artistic effect, and in these shots had a value of 0.1 seconds. The value of the density at this position is evaluated by interpolation of the density at surrounding gridpoints. Gridless advection generates features in the density that are finer in scale than the simulation grid, including crisp edges and filaments where the gridded data may have only a soft structure.

4 Volume Render

The volume renderer separately handles ray marching/lighting and the volumetric material that is being rendered. The Felt scripting language functions as the volumetric equivalent of a surface shader, and manages how the density and color are presented to the renderer. The gridless advection is handled by Felt without any special alteration of the ray marcher, other than adjusting the march step size to capture the high resolution detail produced by the advection.

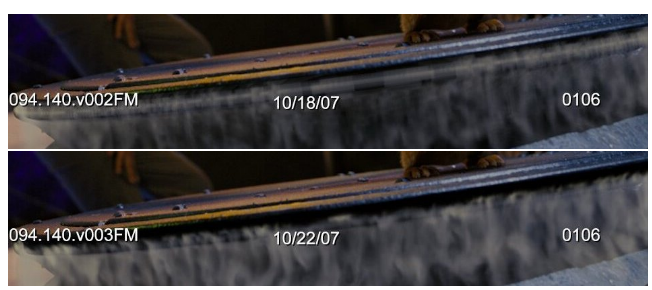

Figure 2: *Simulated vapors (top) without gridless advection, (bottom) with gridless advection.*

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