Real-Time Cartoon Rendering of Smoke (poster_0067)

Morgan McGuire* Brown University
Andi Fein† Brown University
Colin Hartnett‡ Brown University

Abstract

We render amorphous shapes like smoke, clouds, and fluids with two-tone shading, self-shadowing, and silhouettes, in the style of a cartoon. Our method operates directly on a particle system without ever forming a surface mesh. It renders only five polygons per particle and executes primarily on the GPU. It can be extended to isosurfaces and volume data sets, and has applications in games, animation, and visualization. Our implementation renders thousands of particles at 30 fps and never reads the frame buffer.

1 Introduction and Related Work

Selle et al. [2004] demonstrate a system for rendering particle smoke in a cartoon style at about 1 fps. They render the body of each particle with a large, unshaded "smoke puff" texture and draw outlines by reading back the depth buffer and applying depth differences. In implementing this, we increased performance and added new features, extending their method in three ways.

First, our puff textures include normal maps, which we use to compute shading on the GPU. Second, we describe a new way to draw outlines using two billboards that addresses the limitations of depth differences, which require significant fill rate, are limited to 1-pixel outlines, and can stall the pipeline while the outline pass waits for the output of depth rendering. Third, we use hardware optimized stenciled shadow volumes to produce self-shadowing. To create cloud-shaped shadow boundaries from square billboards, we extend shadow volumes with Schaufler's nailboards (billboards-with-depth) [1997].

1.1 Pre-processing

We pre-render a normal map and depth map for a single smoke puff using a bundle of random spheres as our geometric model. For variation, we repeat this process four times, and then pack the results into a single texture map (Figure 2). The 3D geometry is then discarded; only billboards are used for real-time rendering.

Each particle in the smoke simulation is permanently assigned one of the four puff textures, providing diversity and frame coherence.

1.2 Two-tone Shading

The body of each particle is rendered as a billboard parallel to the image plane. The pixel processor performs diffuse shading using the normal map, and then quantizes the result to two tones using a dependent read against a 1D texture.

We have also implemented a fixed-function variant for directional lights that pre-shades four two-tone sprite textures every frame.

*e-mail: morgan@cs.brown.edu
†e-mail: afein@cs.brown.edu
‡e-mail: cphartne@cs.brown.edu

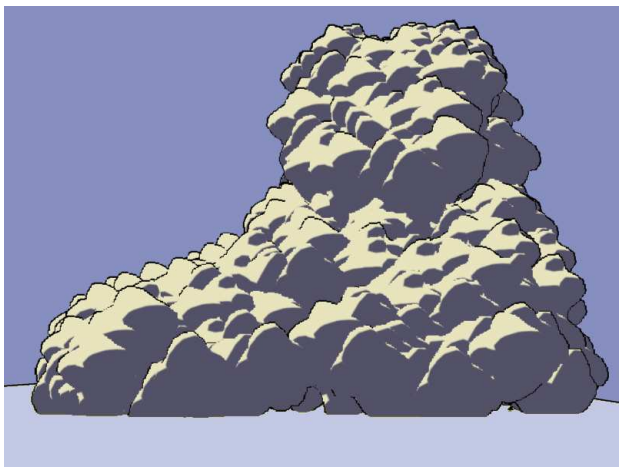

Figure 1: Shading reveals the billowing shape of cartoon smoke.

1.3 Outlines

To produce black silhouettes and some internal contour lines for shape we add a second billboard behind each particle. The second billboard is slightly larger, shaded entirely black, and offset along the view vector by a small distance, d. The thickness of the outline increases with the relative size of the black billboard. The number of internal contours drawn decreases as d increases; a reasonable value for d is the world-space width of the billboard.

1.4 Self-Shadowing

Thick smoke exhibits self-shadowing, a particularly striking effect when the smoke is between the viewer and the light source so that only the fringes of the smoke receive illumination.

We use a special case of Crow's shadow volume method and extend it with nailboards. For each smoke puff, we create the shadow volume that would be cast by a viewer-facing cube. This shadow volume contains only one front and one back polygon, aligned so that they exactly overlap in image space. These shadow volumes meet the billboards at straight boundaries, revealing the billboard shape. To create a wavy intersection, we modify the depth value of each billboard and shadow-volume pixel using the pre-rendered smoke puff depth map.

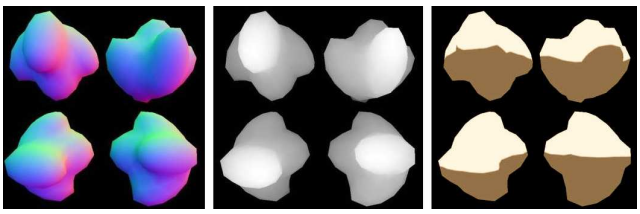

Figure 2: Normal map, depth map, and final toon-shaded puffs

References

SCHAUFLER, G. 1997. Nailboards: A rendering primitive for image caching in dynamic scenes. In *Proc. of Eurographics*, Springer Wien, New York City, NY, 151–162.

SELLE, A., MOHR, A., AND CHENNEY, S. 2004. Cartoon rendering of smoke animations. In *Proc. of NPAR*, ACM Press, 57–60.