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Real-time interactive simulation of smoke using discrete integrable vortex filaments

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Abstract

We present a fluid solver for the real-time interactive simulation of inviscid, ideal fluid flow. The simulation is based on the evolution of discrete vortex filaments, which allow a dramatic increase of detail and performance compared to traditional methods used in Computer Graphics. As a fully lagrangian method the simulation is not restricted to a fixed domain and does not suffer from numerical dissipation. Vortex filaments arise naturally in real flows and thus provide an excellent building block for modelling realistic smoke. We present a GPU-based implementation which allows the interactive experimentation with 3D fluid flow on desktop computers and also in distributed immersive virtual environments.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism—Animation; Computer Graphics [I.3.5]: Computational Geometry and Object Modeling—Physically based modeling

1. Introduction

Real-time simulation of 3D smoke is an important ingredient for virtual environments in general and computer games in particular. Nevertheless computational challanges have so far prevented the widespread implementation of such simulations. While it is possible to achieve realistic and highly resolved 3D smoke animations in extensive offline simulations, real-time applications are still missing the desireable detail and realism.

We describe a 3D method that is highly efficient while allowing a tremendous amount of detail. The method is based on the simulation of the evolution of vortex filaments. Vorticity originates as 2–dimensional vortex sheets that tend to roll up into complicated 1–dimensional structures. The resulting visual complexity easily exceeds the level of detail that can be achieved with real-time grid based methods, as in Figure 1. The use of vortex filaments provides an efficient method to capture the complexity of smoke with very sparse data. The whole fluid velocity field is defined by the vortex filaments and can be used to advect arbitrary marker particles. Besides the application for real-time simulation, the method provides a significant improvement for the workflow of effects artists designing smoke animations. It allows to obtain an immediate preview of the fluid motion. The final animation can then be rendered with an arbitrary number of particles – without affecting the fluid motion at all.

Figure 1: *Comparison of a photograph (left, from [Jef]) with our simulation (right). The* 396^2 *particles are rendered as unshaded transparent GL points.*

2. Related work and contribution

Real-time 3D smoke simulations have so far been restricted to low resolution grid-based Eulerian methods (mostly based on Stam's *Stable Fluids* [Sta99] with vorticity confinement [FSJ01]) or to algorithms based on 2D reductions

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