Data-driven Fluid Simulations using Regression Forests

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Figure 1: *The obtained results using our regression forest method, capable of simulating millions of particles in realtime. Our promising results suggest the applicability of machine learning techniques to physics-based simulations in time-critical settings, where running time matters more than the physical exactness.*

Abstract

Traditional fluid simulations require large computational resources even for an average sized scene with the main bottleneck being a very small time step size, required to guarantee the stability of the solution. Despite a large progress in parallel computing and efficient algorithms for pressure computation in the recent years, real-time fluid simulations have been possible only under very restricted conditions. In this paper we propose a novel machine learning based approach, that formulates physics-based fluid simulation as a regression problem, estimating the acceleration of every particle for each frame. We designed a feature vector, directly modelling individual forces and constraints from the Navier-Stokes equations, giving the method strong generalization properties to reliably predict positions and velocities of particles in a large time step setting on yet unseen test videos. We used a regression forest to approximate the behaviour of particles observed in the large training set of simulations obtained using a traditional solver. Our GPU implementation led to a speed-up of one to three orders of magnitude compared to the state-of-the-art position-based fluid solver and runs in real-time for systems with up to 2 million particles.

CR Categories: I.3.3 [Computer Graphics]: Computational Geometry and Object Modeling: Physically based modeling; I.2.6 [Artificial Intelligence]: Learning;

Keywords: fluid simulation, data-driven, regression forest

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1 Introduction

Computing high-resolution fluid simulations with traditional state-of-the-art approaches is very challenging, as they require tremendous computational resources to compute a scene with millions of particles. The main bottleneck is the severe restriction on the time step size needed to guarantee stability, and thus simulation times are typically in the range of hours to days on high-end computers, making it impossible to achieve high-resolution fluids in real-time.

The standard Smoothed Particle Hydrodynamics [Lucy 1977] (SPH) method approximates continuous quantities in the Navier-Stokes differential equations using discrete particles with appropriate smoothing kernel and replaces a continuous advection by an advection of particles. The approach does not deal with the incompressibility constraint directly, which causes significant visually unpleasant artifacts.

Recent work has addressed this problem and either enforce a density invariance condition or a divergence-free velocity field. A predictive-corrective scheme has been introduced where pressure values are iteratively updated to satisfy the zero compression constraint [Solenthaler and Pajarola 2009]. The performance has been further improved by discretizing and iteratively solving the pressure Poisson equation [Ihmsen et al. 2013]. Most recently, a position based fluid (PBF) approach has been presented [Macklin and Mueller 2013], where first all particles are advected, and then projected to the manifold of feasible solutions by iteratively correcting positions of particles to satisfy the incompressibility constraint. PBF allows to use a larger time step compared to its counterparts. A density invariance condition has also been combined with a multi-scale scheme [Horvath and Solenthaler 2013] to further speed-up the computation. Despite all these improvements, high-resolution fluids are still computed offline.

An alternative to particle-based approaches are grid-based methods that approximate continuous quantities on a discrete regular grid [Enright et al. 2002]. Incompressibility is enforced on the grid by solving the Poisson's equation, making the velocity field divergence-free. To speed up grid-based simulations, the solution space can be restricted to simpler topology [Chentanez and Müller 2010; Chentanez and Müller 2011]. To avoid discretization artifacts of grid-based methods, the hybrid FLIP model [Zhu and Bridson

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