INCOMPRESSIBLE FLUID SIMULATION AND ADVANCED SURFACE HANDLING WITH SPH

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ABSTRACT

Particle-based fluid simulations have become popular in computer graphics due to their natural ability to handle free surfaces and interfaces, splashes and droplets, as well as interaction with complex boundaries. However, particle methods have some disadvantageous properties degrading the physical behavior of a simulated fluid and thus the resulting visual quality. Although these problems are present in almost any particle-based fluid solver, this dissertation addresses some of the major problems of the Lagrangian method Smoothed Particle Hydrodynamics (SPH).

This thesis starts by reviewing the standard SPH model and its difficulties to satisfy the incompressibility condition. In the standard model, liquids are typically approximated by compressible fluids where pressures are determined by an equation of state, resulting in undesired compression artifacts. Although incompressibility can be enforced, it represents the most expensive part of the whole simulation process and thus renders particle methods less attractive for high quality and photorealistic water animations. In this thesis, we present a novel, incompressible fluid simulation method based on SPH. In our method, incompressibility is enforced by using a prediction-correction scheme to determine the particle pressures. For this, the information about density fluctuations is actively propagated through the fluid and pressure values are updated until the targeted density is satisfied. With this approach, the costs per simulation update step can be held low while still being able to use large time steps in the simulation.

Next, we shift our attention to the problem of complex interactions between multiple different fluids as well as between fluids and solids. We first focus on

the artifacts caused by standard SPH when simulating multiple fluids with high density ratios. In the standard model, the smoothed quantities of particles near the fluid interface show falsified values and the physical behavior is severely affected, especially if density ratios become large. The artifacts include spurious and unphysical interface tension as well as severe numerical instabilities. In this thesis we derive a formulation which can handle discontinuities at interfaces of multiple fluids correctly and thus avoids the problems present in standard SPH. With our concepts, an animator has full control over the behavior of multiple interacting fluids.

Furthermore, we propose to represent both, fluids and solids, by particles, facilitating the interaction between the different object types. We present a unified simulation model for fluids, rigid, and elastic objects, and show how phase transitions can be modeled by only changing the attribute values of the underlying particles. New effects like merging and splitting due to melting and solidification are demonstrated, and we show that our model is able to handle coarsely sampled and even coplanar particle configurations without further treatment.

Finally, we present a novel point refinement method to achieve a higher visual quality of low-resolution fluids. We introduce new algorithms to efficiently upsample an initial point set given by the physical computation. Our method features the ability to accurately preserve surface details and to reach a uniform point distribution. Another challenge is to reconstruct smooth surfaces from the particles. The visualized fluids typically suffer from bumpy surfaces related to the irregular particle distribution. In order to achieve smooth surfaces, this thesis introduces a new surface reconstruction technique based on the center of mass of the particle neighborhood. We show how artifacts in concave regions can be avoided by considering the movement of the center of mass.