Adaptive Liquid Simulation for Computer Graphics

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This thesis aims to develop an adaptive fluid simulation framework for computer graphics. The thesis consists of three chapters: Prerequisites, Preserving Fluid Sheets, and Highly Adaptive Liquid Simulations for FLIP.

The prerequisites chapter introduces the Navier-Stokes equation that describes the motion of a fluid. The equation consists of advection term, pressure term, and viscosity term. In the computer graphics, it is common practice to employ Operator Splitting to decompose the equation into the individual terms. This thesis sketches the Operator Splitting to this end. The hardest part in the solver is computing pressure. This chapter also illustrates a Poisson equation and its boundary condition for solving for pressure, in addition to FLIP which the grid and particle hybrid method to solve for fluid. Finally, we will go through the adaptive simulations methods.

Preserving Fluid Sheets chapter introduces a method for preserving fluid sheets for particle-based liquid simulations with an adaptively sampled FLIP method. In this method, we preserve fluid sheets by filling the breaking sheets with particle splitting in the thin regions, and by collapsing them in the deep water. To identify the critically thin parts, we compute the anisotropy of the particle neighborhoods, and use this information as a resampling criterion to reconstruct thin liquid surfaces. Unlike previous approaches, our method does not suffer from diffusive surfaces or complex re-meshing operations, and robustly handles topology changes with the use of a mesh-less representation. We extend the underlying FLIP model with an anisotropic position correction to improve the particle spacing, and adaptive sampling to efficiently perform simulations of larger volumes. Due to the Lagrangian nature of our method, it can be easily implemented and efficiently parallelized. The results show that our method can produce visually complex liquid animations with thin structures and vivid motions.

Highly Adaptive Liquid Simulations for FLIP chapter introduce a new method for efficiently simulating liquid with extreme amounts of spatial adaptivity. Our method combines several key components to drastically speed up the simulation of large-scale fluid phenomena: We leverage an alternative Eulerian tetrahedral mesh discretization to significantly reduce the complexity of the pressure solve while increasing the robustness with respect to element quality and removing the possibility of locking. Next, we enable subtle free-surface phenomena by deriving novel second-order boundary conditions consistent with our discretization. We couple this discretization with a spatially adaptive Fluid-Implicit Particle (FLIP) method, enabling efficient, robust,
minimally-dissipative simulations that can undergo sharp changes in spatial resolution while minimizing artifacts. Along the way, we provide a new method for generating a smooth and detailed surface from a set of particles with variable sizes. Finally, we explore several new sizing functions for determining spatially adaptive simulation resolutions, and we show how to couple them to our simulator. We combine each of these elements to produce a simulation algorithm that is capable of creating animations at high maximum resolutions while avoiding common pitfalls like inaccurate boundary conditions and inefficient computation.