# Optimized Free Surface Fluids on Adaptive Grids with the Lattice Boltzmann Method

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### 1 Introduction

Capturing all details of an animation with free surface fluids often requires large resolutions for the underlying simulation. In the following we will present an algorithm to speed up the simulation by adaptively coarsening the computational grid. As shown in e.g. [Losasso et al. 2004] for a Navier-Stokes based fluid solver, the speed up of grid adaptivity for fluid simulations can be significant. For the test cases described below, our method results in a speedup factor of up to three.

The algorithm used to simulate the free surface fluid is based on the Lattice Boltzmann Method (LBM). The free surface tracking is similar to Volume-of-Fluid methods for conventional Navier-Stokes solvers. For the free surface three types of cells are distinguished fluid cells that are treated with the normal LBM, empty cells, that do not require any computations, and interface cells. For these the amount of fluid mass is tracked for each time step, together with appropriate boundary conditions for the fluid gas interface. The algorithm is described in more detail in e.g. [Thürey 2003]. To speed up the simulations we use a modified version of the grid-refinement described in [Filippova and Hänel 1998] together with a method to adapt the grid boundaries according to the free surface movement.

## 2 Adaptive Grids

A series of coarser grids is generated (usually one or two depending on the overall resolution of the domain), each with half the resolution of the previous one. As the grids cover the same domain, this means that the cells of a coarse grid are twice the size compared to the cells of the adjacent fine grid. Furthermore, the time step scales in the same way, while the magnitude of the simulation velocities stay similar on both grids for LBM. Hence, the coarse grid needs to be stepped only once for two steps on the fine grid. On each grid the region of simulated fluid is surrounded by a layer of cells that are used to transfer information to the next coarser and next finer grid. Thus, on the finest grid there is only a boundary layer towards the next coarser grid and the free surface.

We were able to show that for the boundary layers between the grids linear spatial interpolation without temporal interpolation is sufficient to accurately simulate the free surface movement. This allows an efficient adaption of the grid boundaries. On a given grid the boundary regions to the adjacent coarse and fine grids require only

\*e-mail: nils.Thuerey@cs.fau.de †e-mail: Ulrich.Ruede@cs.fau.de a single layer of cells. To adaptively modify the coarsened regions it is now only necessary to check the neighborhood of boundary cells for cells of the other boundary type. For the finest grid the distance to the interface cells representing the free surface is used. Hence, the grid adaption can be performed efficiently and locally for each cell. If a necessary change of the boundary layer is detected, the cell itself and it's neighborhood are re-initialized to represent the moved boundary layer. This might again trigger a change of the boundary layer on the next grid, until a valid boundary layer is re-established.

The accompanying video demonstrates the algorithm using two levels of coarse grids for two different test cases: a drop falling into a basin of fluid, and a breaking dam. For the first test case a simulation without the optimizations explained above is compared to a simulation using the described adaptive grids. Both animations are almost indistinguishable, but the unoptimized simulation requires almost 3 times longer (on average 69 instead of 24 seconds per frame of animation). The second test case is harder for our algorithm, as it exhibits thin layers of fluid that can not be computed on the coarser grids. But while the results with and without optimizations are visually equivalent, the optimized version still requires only half the computational time.

## 3 Conclusions & Future Work

The presented algorithm is able speed up the simulation of LBM free surface animations considerably without sacrificing physical plausibility. This also demonstrates the capabilities of the LBM to perform large-scale free surface simulations. Depending on the size of the fluid volumes in the simulation, the gained speedup can be a factor of two to three, higher speedups being possible depending on the setup of the simulation. In the future we would like to include turbulence models for the LBM simulation, as the coarser grids impose restrictions of the parameterization of the LBM. Also, we hope to further improve our current implementation of the algorithm to achieve even higher speedups.

#### References

FILIPPOVA, O., AND HÄNEL, D. 1998. Grid Refinement for Lattice-BGK models. *J. Comp. Phys. 147*.

LOSASSO, F., GIBOU, F., AND FEDKIW, R. 2004. Simulating water and smoke with an octree data structure. SIGGRAPH Proc..

THÜREY, N., 2003. A Lattice Boltzmann method for single-phase free surface flows in 3D. Masters thesis.