Correcting Low Frequency Impulses in Distributed Simulations

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1 Introduction

Level set fluid simulations are a common approach for simulating liquids. Their regular grid sampling make it straightforward to apply incompressibility constraints through a velocity projection. However, the high resolutions needed for fine detail result in large memory requirements and long computation times. Distributing liquid simulations across multiple machines can address these problems.

Incompressibility is an intrinsically global constraint. [Irving et al. 2006] exchange boundary data during each iteration of the projection, but this requires large data transfers for 3D fluids. The approach we take closely matches that of [Lentine et al. 2010]; our contribution is to use a padded grid that avoids the need for a separate surface pressure solve to preserve detail.

We divide the fluid simulation box into equal-sized slices, one per machine. Because most stages of a fluid simulation only require local knowledge of the simulation grids, we pad our slices by a band of voxels. The size of the band can be computed from a CFL-like condition. After each time step, neighboring slices exchange their padded data.

Our reference test is designed to focus on a simple fluid impulse. We divide a \(400^3\) fluid box by quadrants into four slices and then drop a slice-centered sphere of liquid into a standing pool.

2 Previous Method

We originally used a frame delayed method that solved the projection locally on each slice. Closed boundary conditions were used to prevent the fluid from draining into adjacent slices. Boundary cells velocities were overwritten every frame by the padding exchange. Each slice thus reacted to a frame delayed version of its neighbors.

The frame delayed boundaries introduce two artifacts: they delay the transfer of fluid impulses and introduce a reflection at the internal slice boundaries. Our padding ensured we accurately represent the neighborhood of every voxel, so the naturally more local in nature high frequency fluid detail would be preserved. Low frequency detail, on the other hand, has to propagate across the entire fluid in a single time step.

This approach is effective for smoke and fire simulations where the error is often masked by artist induced turbulence in the system. Liquid simulations are more problematic. Although turbulent and fast moving fluid can produce usable results by breaking up the error, when low frequency impulses dominate the system, the result is clearly erroneous.

3 New Method

We adopted a multi-resolution technique to address the low frequency errors in liquids. Each slice is reduced to quarter resolution and exchanged with the other machines. A full size, low resolution, version of the simulation can then be built and quickly solved.

3.1 FLIP Update

We first coupled the low and high resolution simulations with a FLIP update. We computed the change in velocity caused by the low resolution solve and added it directly to our high resolution velocity. This delta update informed the high resolution simulation of the global state and avoided diffusion of fine detail.

Consequently, low frequency errors were eliminated by the FLIP update. Computation time for each slice was also reduced because most of the work for the high resolution pressure projection was already done. However, we also lost high resolution detail - the low resolution simulation would incorrectly cancel out surface waves that fell below its sampling frequency.

3.2 Border Update

Since the low resolution correction factor was damping the detail, our next approach was to minimize its use. [Lentine et al. 2010] note the key step was to update only the fine cells that lie on coarse boundaries. In the projection stage, this implied that the only important velocity values to update were those on the slice boundaries. Correcting closed boundary conditions with the low resolution deltas provided the high resolution projection a close approximation of the values we expected it to have computed if it had access to the full simulation. Our padding of the slices caused the localized error due to the low resolution approximation to be erased in the border exchange stage.

References


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