Realtime GPU-Accelerated Smoothed Particle Hydrodynamics with Rigid Body Interaction

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1 Introduction

Smoothed Particle Hydrodynamics (SPH) is a popular Lagrangian fluid simulation technique. The Lagrangian approach models the fluid as a set of particles exerting pressure forces directly on each other according to a discretized version of the Navier Stokes equations while the alternative Eulerian approach models pressures flowing between cells within a fixed grid. The Eulerian model is a more direct mapping of the underlying equations. This means it simple to measure force and pressures within the grid making it well suited for engineering applications, but it is difficult to capture visually interesting detail such as bubbles, splashing and foam which is easier to do with particle-based Lagrangian methods.

2 Aims

While the fundamentals of SPH are well understood and widely implemented on the GPU a big remaining area of active research is rigid-body interaction. Our primary aim will be to incorporate rigid-fluid coupling into an existing open source system which currently lacks this feature and our secondary aim will be to enhance the performance to as close to realtime as possible.

2.1 Solid-Fluid Coupling

In order to contain a fluid it is necessary to implement boundary conditions, these are generally based on the idea that if a particle crosses the a plane it will have forces applied along the plane normal to push it back out. This technique is sufficient to model interaction with parametric shapes such as walls, spheres, cylinders and boxes but it does not work for arbitrary meshes. While it is possible to implement triangle-based collisions it is difficult to handle complex geometry.

A simpler approach is to pre-process the mesh and represent it as particles. Within the simulation a rigid body will have a mesh-shaped cloud of particles surrounding it and the resultant force will the the sum of these particles interaction with the fluid. The main concern is to ensure that the cloud is sampled at a high enough density that fluid penetration into the solid is prevented.

2.2 Performance

2.2.1 CUDA

The existing implementation does not currently seem to achieve it's full potential speedup due to parallelization. We will investigate and perform any possible tuning.

2.2.2 Neighbour-Search

The most expensive part of SPH is determining which other particles lie within a particular particles sphere of influence. Z-indexing based on radix-sort is an efficient way of doing this.

2.2.3 Incompressibility

The size of the simulation timestep affects water compressbility, with a larger timestep allowing more artefacts to occur. PCISPH (Predictor-Corrector Incompressible SPH) use a solver between simulation steps to correct compressibility artefacts allowing larger timesteps, which should improve simulation performance.