Constraint based particle fluids on GPGPU

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ABSTRACT

We present a fluid simulation method adapted for stream parallelism on general purpose graphics processing units (GPGPU). In this method the equations of Navier and Stokes are discretized using particles and kernel functions as in Smoothed Particle Hydrodynamics (SPH), but rather than using penalty methods or solving for a divergence free velocity field, incompressibility is enforced using holonomic kinematic constraints [1]. We use one constraint for each smoothed particle stating that the local density should be kept constant. Other constraints are used for boundary conditions and multiphysics coupling. We also present a viscosity model in which the shear rate at each pseudo particle is constrained to satisfy a given constitutive law. The computation of the constraint forces, namely, the pressure and the stresses, requires the solution system of linear equations which have a sparse, saddle point structure. These are solved using the Uzawa method of preconditioned conjugate gradients (CG) applied directly to the symmetric indefinite matrix. The overall simulation method has its roots in a discrete variational principle and the SPOOK time stepping scheme for constrained mechanical systems [2]. The SPOOK method is second order accurate on the positions and constraints violations, and is stable at large time-steps, thus often allowing several orders of magnitude larger timesteps in our method compared to in traditional SPH methods. The numerical implementation on GPGPU that is the main result of this paper consists of the following components: particle neighbour searches based on spatial decomposition; summation of kernel densities; construction of Jacobians representing the constraints on the density, boundary conditions, viscosity and multiphysics couplings; a Uzawa CG solver for the system of linear equations; and finally, discrete time stepping of velocities and positions. The CG solver is particularly suitable for stream computing since it is based on matrix-vector multiplications. The sparse system data is stored in a compressed matrix format and the algorithms operating on this data on GPGPU are implemented in CUDA and OpenCL. Our simulation results include performance measurements, and validation of the method for benchmark problems. We achieve up to two orders of magnitude speed-up from the GPGPU over traditional processors and together with the increased timestep efficiency of our method we arrive at interactive performance for systems with up to two million fluid particles representing an incompressible fluid.

REFERENCES

[1] K. Bodin, C. Lacoursière, M. Servin, “Constraint Fluids”, Preprint, accepted for IEEE Transcations on Visualization and Computer Graphics, vol. 99 (2011).

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