Recent Developments in Implicit Incompressible SPH

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Incompressible SPH (ISPH) computes a pressure field p by solving a pressure Poisson equation (PPE) of the form $\nabla^2 p = \boldsymbol{s}$ with $\boldsymbol{s}$ being a source term that either encodes the divergence of a predicted velocity field, e.g. [1], a predicted density deviation, e.g. [2], or a combination of both, e.g. [3]. Implicit incompressible SPH (IISPH) is a specific discretization of $\nabla^2 p$, e.g. [4]. It discretizes $< \nabla \cdot < \nabla p > >$ instead of $< \nabla^2 p >$ which allows for a matrix-free solver implementation and seems to have positive effects on the solver convergence. Various boundaries, e.g. pressure mirroring [5] can be easily incorporated into the discretized PPE. Fig. 1 shows an example scenario with up to 500 million samples that has been computed on a well-equipped standard PC with 24 cores and 256 GB of memory. In addition to its efficiency in terms of memory and computation time, IISPH has various other positive properties. First, it is quasi incompressible as the employed density invariance in the source term results in small - typically 0.1% - but more importantly *constant* density deviations over time. Second, the parameterization of IISPH is simple and intuitive. The user specifies a density deviation that the solver preserves during the simulation. While IISPH preserves a high-quality sampling over time, shear-wave-decay scenarios indicate that the computed velocity field suffers from a significant amount of diffusion and dispersion. Diffusion positively affects the stability. Dispersion, however, disturbs the formation of vortices as illustrated in lid-driven-cavity scenarios. Therefore, our group currently investigates various ways to improve the quality of the IISPH velocity field without degrading the quality of the computed sample positions. 1. Shepard filter and kernel gradient normalization. 2. Improving the error order of the time integration which is currently one in IISPH. 3. Solving two PPEs, one for positions, one for velocities, similar in sense to [3] and also combining this idea with the concept of particle shifting. 4. Improving the computation of the predicted density deviation in the source term. 5. Solving for pressure and artificial viscosity in parallel.

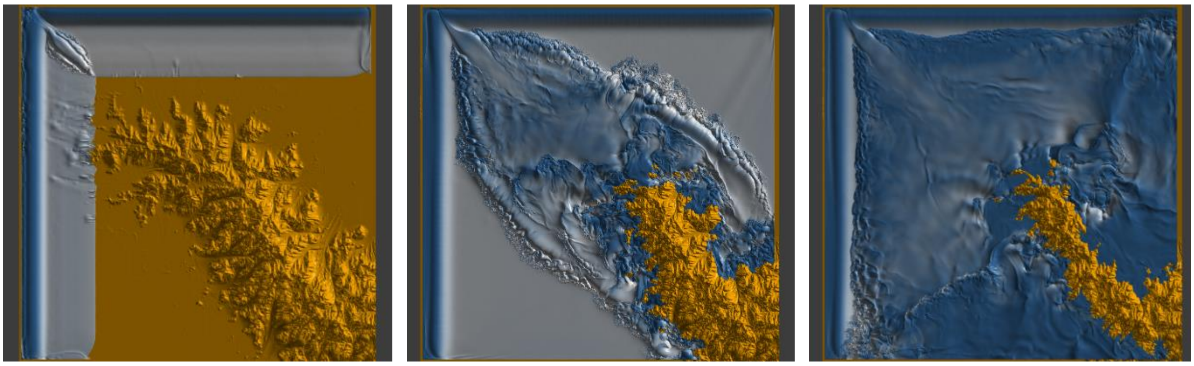

Figure 1: Up to 500 million fluid samples in a free-surface scenario with geometrically complex boundaries. Velocity is color-coded. For the maximum number of samples, one IISPH solver iteration is computed in 15 s on a 24-core PC. Typically, 8 solver iterations are required for a global relative density deviation of 0.1%. Thus, the pressure field is computed in 2 minutes. The maximum memory consumption is 190 GB. The simulation timestep is adaptive and corresponds to a CFL number of 0.5.

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