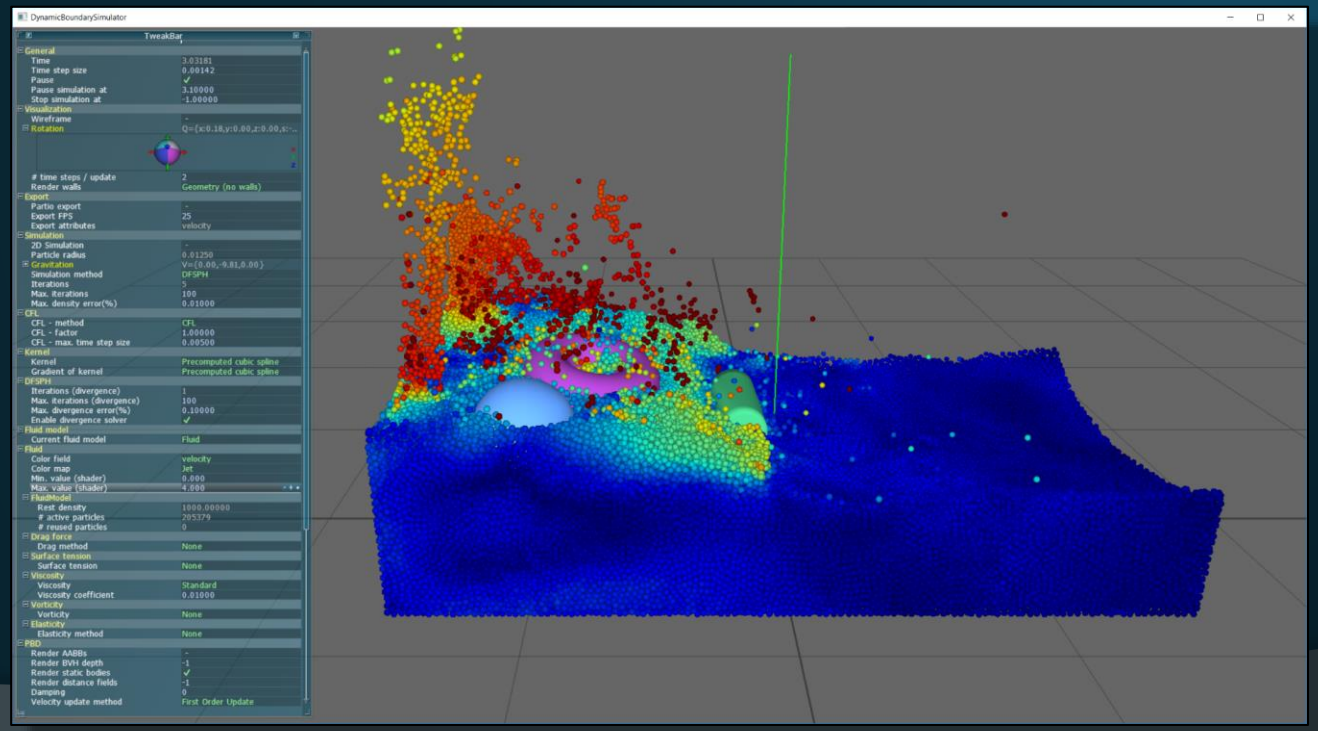
Smoothed Particle Hydrodynamics Techniques
for the Physics Based Simulation of Fluids and Solids

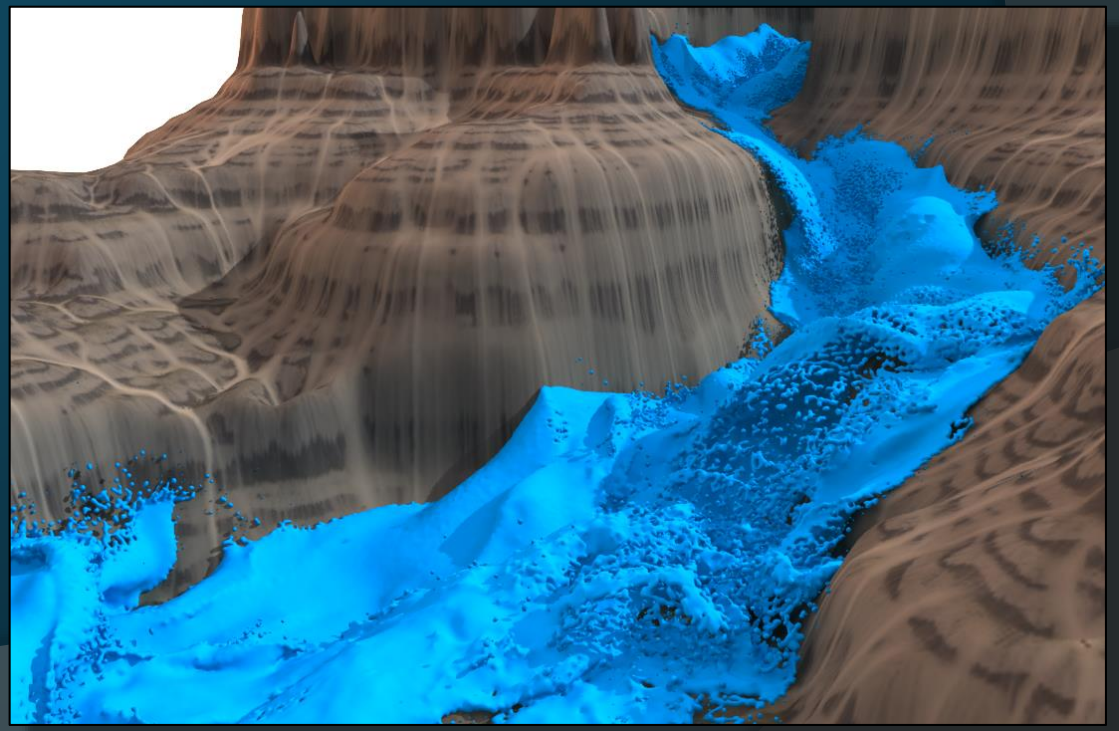
Dan Koschier Jan Bender Barbara Solenthaler Matthias Teschner

UCL RWTH AACHEN UNIVERSITY ETH zürich UNI FREIBURG

What is SPlisHSPlasH

- Open-source SPH library for the simulation of fluids and solids (MIT License) for Windows and Linux
- https://github.com/InteractiveComputerGraphics/SPlisHSPlasH

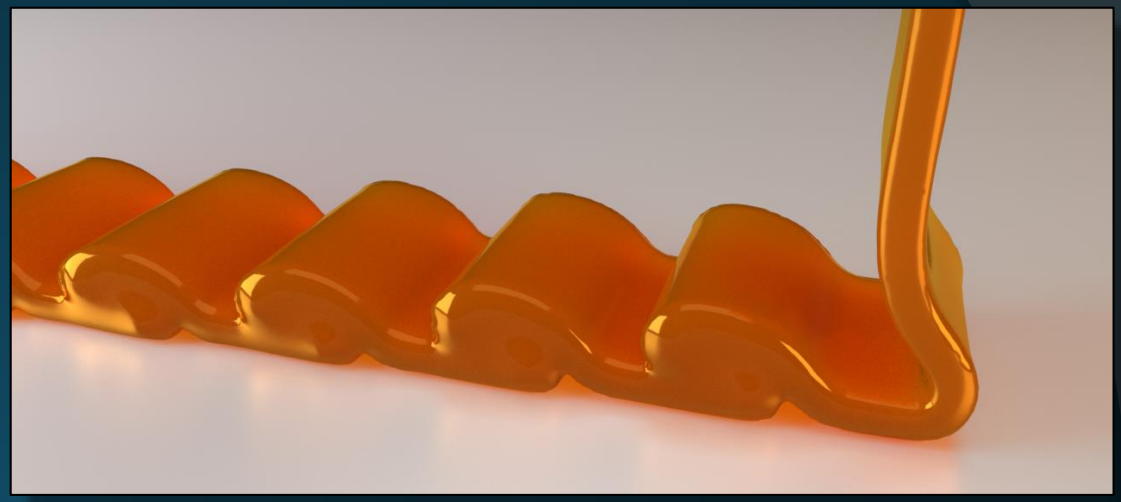




Features

- Explicit Pressure Solvers
  - Weakly compressible SPH for free surface flows (WCSPH)
- Implicit Pressure Solvers
  - Predictive-corrective incompressible SPH (PCISPH)
  - Position based fluids (PBF)
  - Implicit incompressible SPH (IISPH)
  - Divergence-free smoothed particle hydrodynamics (DFSPH)
  - Projective Fluids (PF)

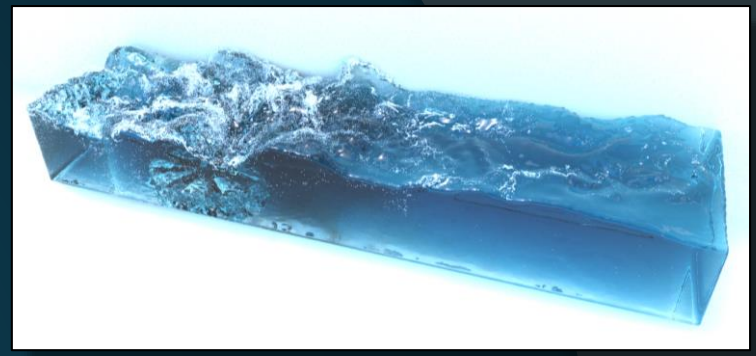
Features

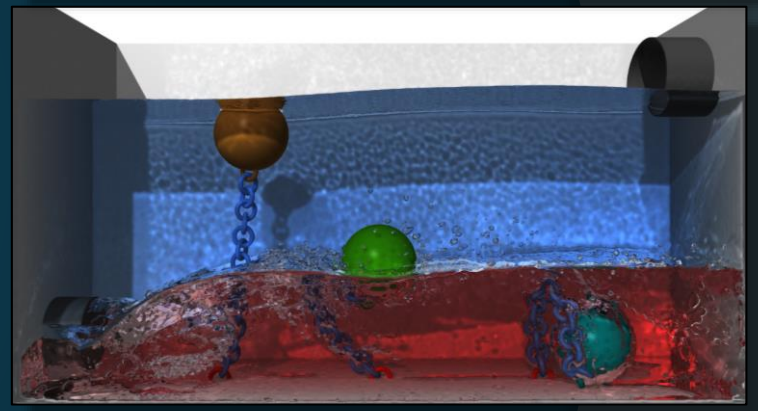


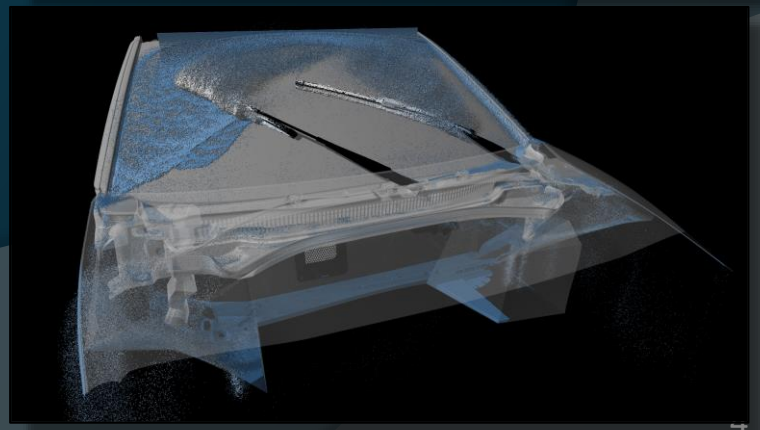
- Explicit Viscosity
  - XSPH
  - Laplacian formulation [Monaghan1992]
- Implicit Viscosity
  - Takahashi et al. *Implicit Formulation for SPH-based Viscous Fluids*. CGF 2015
  - Peer et al. *An Implicit Viscosity Formulation for SPH Fluids*. TOG 2015
  - Peer & Teschner. *Prescribed Velocity Gradients for Highly Viscous SPH Fluids with Vorticity Diffusion*. TVCG 2016.
  - Bender & Koschier. *Divergence-free SPH for incompressible and viscous fluids.* TVCG 2017
  - Weiler et al. *A Physically Consistent Implicit Viscosity Solver for SPH Fluids*. CGF 2018

Features

- Vorticity
  - Macklin & Müller. *Position based fluids*. TOG 2013
  - Bender et al. *Turbulent Micropolar SPH Fluids with Foam*. TVCG 2018
- Multi-Phase Fluid Simulation
  - Solenthaler & Pajarola. *Density Contrast SPH Interfaces*. SCA 2008
- Drag Forces
  - Macklin et al. *Unified Particle Physics for Real-Time Applications*. TOG 2014
  - Gissler et al. *Generalized Drag Force for Particle-based Simulations*. CAG 2017

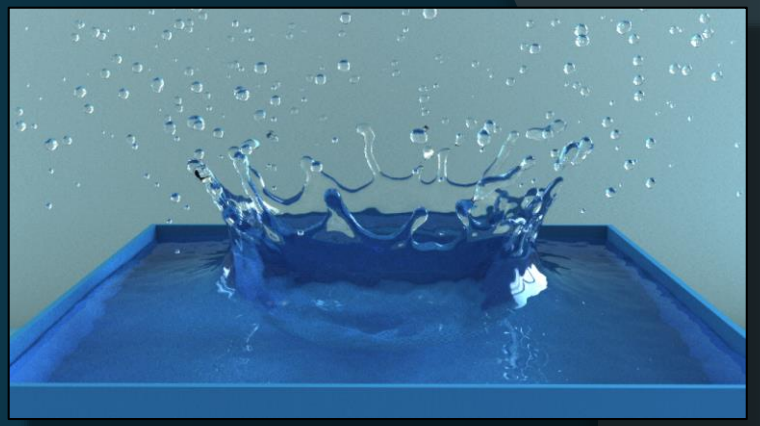






Features

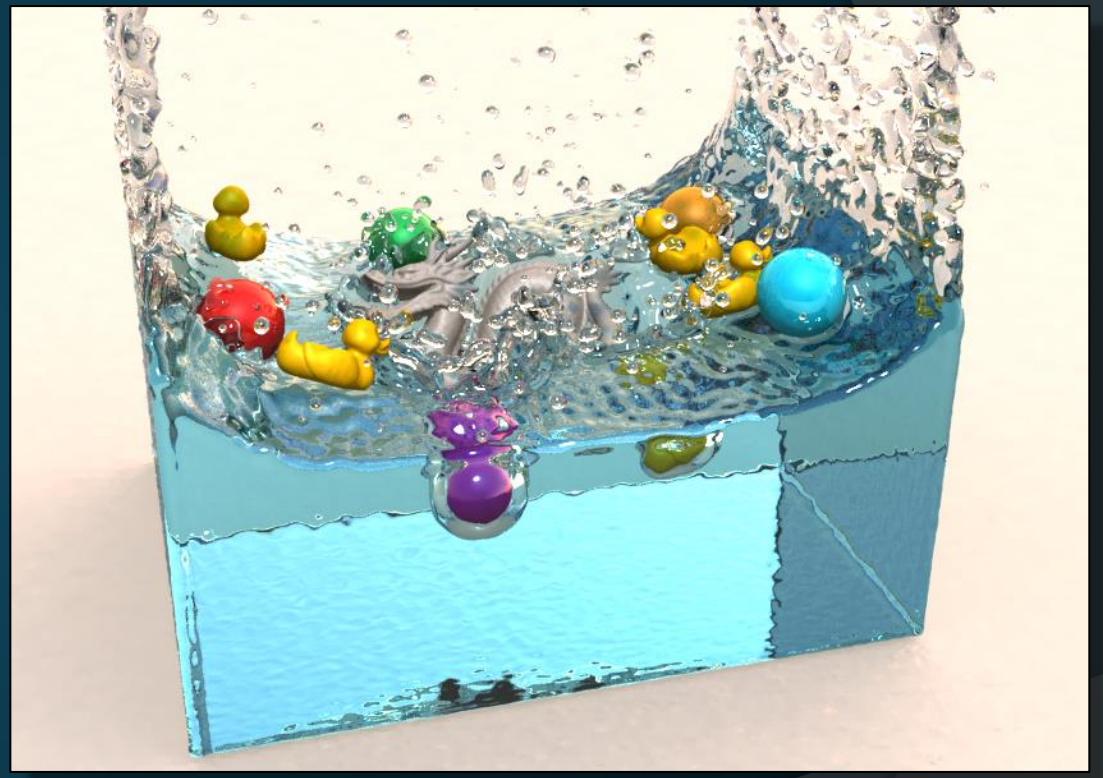
- Surface Tension
  - Becker & Teschner. *Weakly compressible SPH for free surface flows*. SCA 2007
  - Akinci et al. *Versatile surface tension and adhesion for SPH fluids*. TOG 2013
  - He et al. *Robust simulation of sparsely sampled thin features in SPH-based free surface flows*. TOG 2014



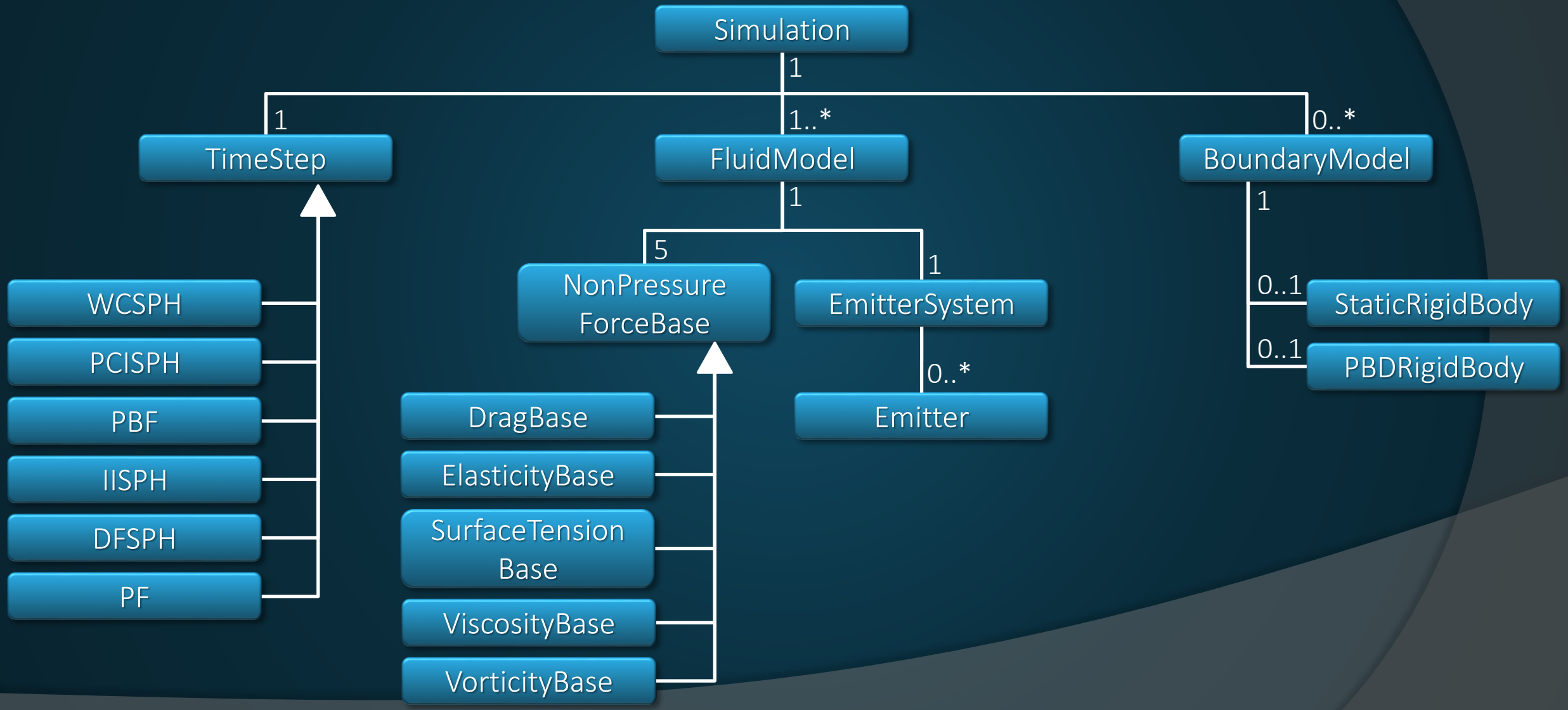
- Elastic Forces
  - Becker et al. *Corotated SPH for deformable solids*. Natural Phenomena 2009
  - Peer et al. *An Implicit SPH Formulation for Incompressible Linearly Elastic Solids*. CGF 2017

Features

- Miscellaneous
  - Rigid-fluid coupling with static and dynamic bodies
  - Fluid emitters
  - Adaptive time stepping (CFL)
  - A json-based scene file importer
  - Automatic surface sampling
  - Volume sampling of closed geometries
  - Partio file export of all particle data
  - Maya plugin to import partio data



Simulator Classes



Code Example: XSPH

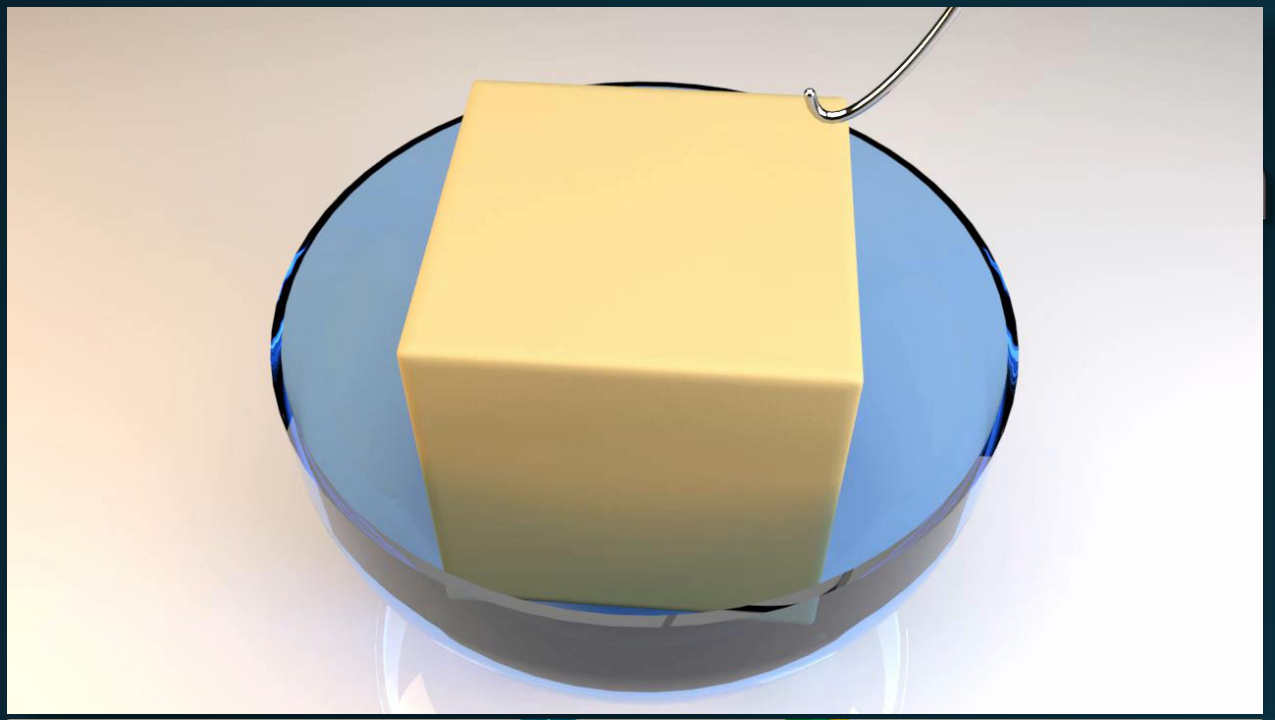
```
void Viscosity_XSPH::initParameters()
{
   NonPressureForceBase::initParameters();
   VISCOSITY_COEFF = createNumericParameter("viscosity", "Viscosity coeff.", &m_viscosity);
   setGroup(VISCOSITY_COEFF, "Viscosity");
   setDescription(VISCOSITY_COEFF, "Coefficient for the viscosity force computation");
}
```

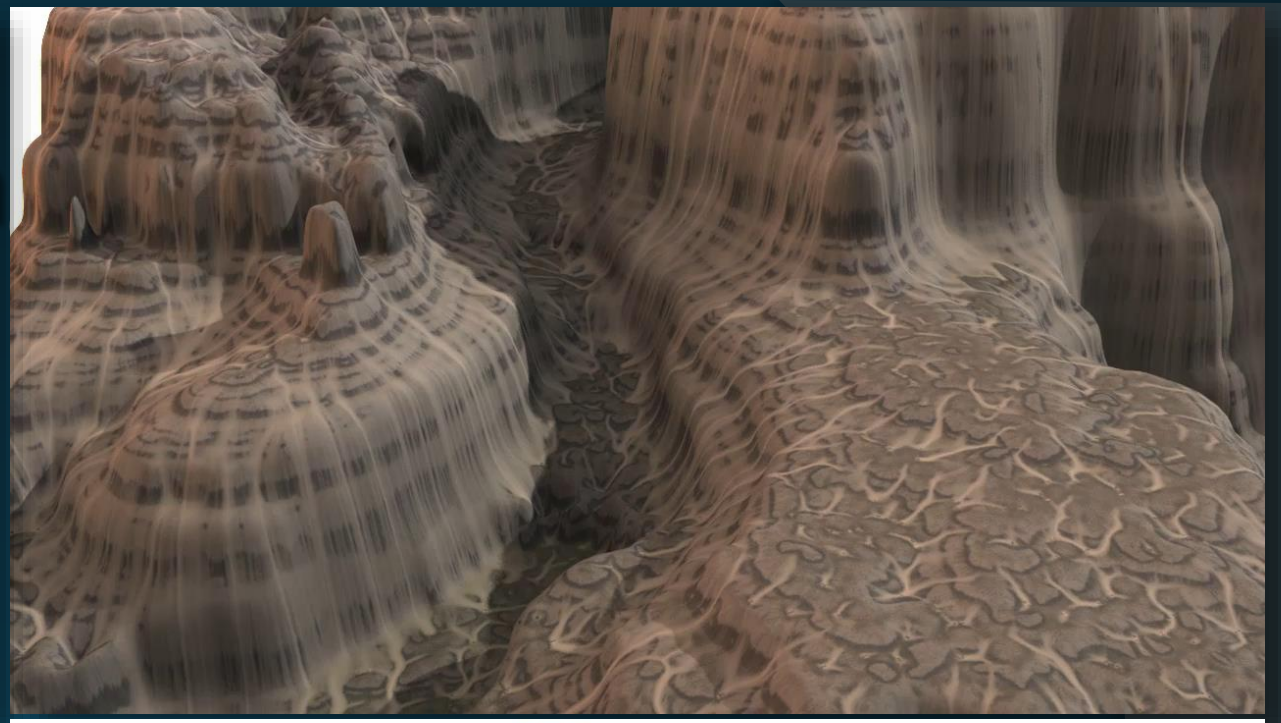
Code Example: XSPH

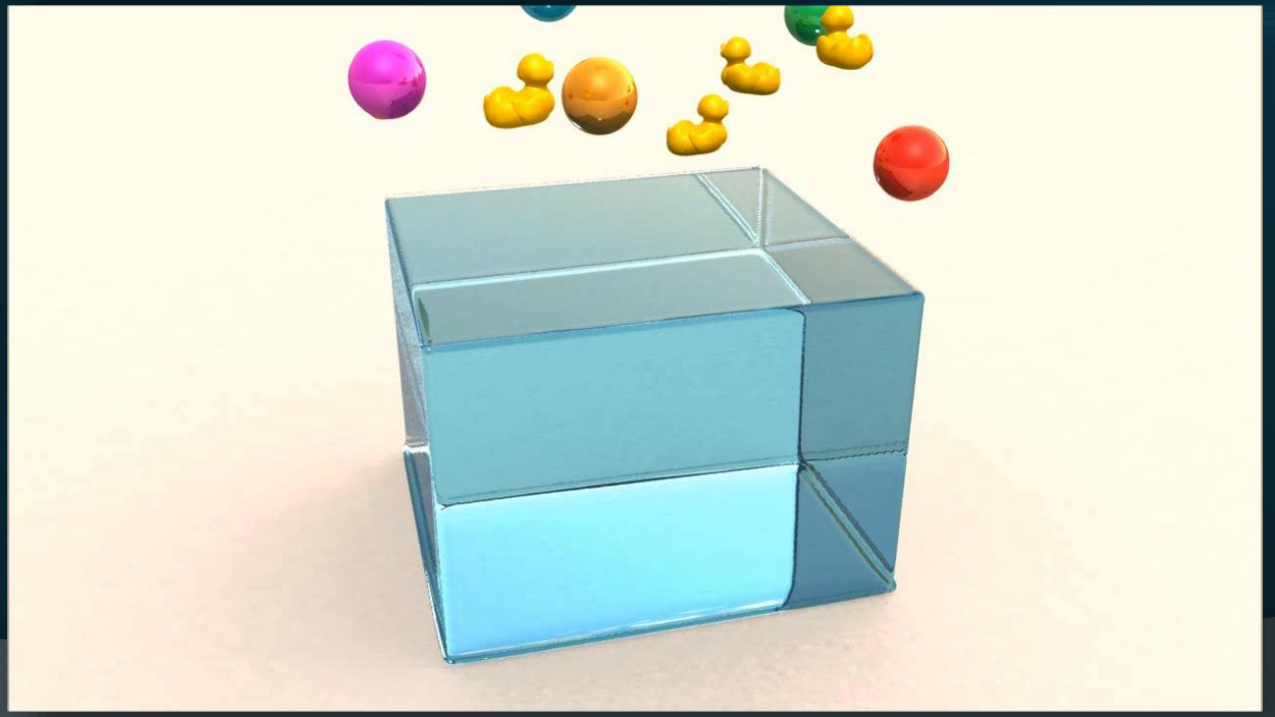
```
void Viscosity_XSPH::step()
{
   …

   #pragma omp parallel for
   for (int i = 0; i < numParticles; i++)
   {
      const Vector3r &xi = m_model->getPosition(i);
      const Vector3r &vi = m_model->getVelocity(i);
      const Real density_i = m_model->getDensity(i);
      Vector3r &ai = m_model->getAcceleration(i);

      forall_fluid_neighbors_in_same_phase(
         const Vector3r &vj = m_model->getVelocity(neighborIndex);
         const Real density_j = m_model->getDensity(neighborIndex);
         ai -= m_viscosity/h * (m_model->getMass(neighborIndex) / density_j) *
               (vi - vj) * sim->W(xi - xj);
      );
   }
}
```



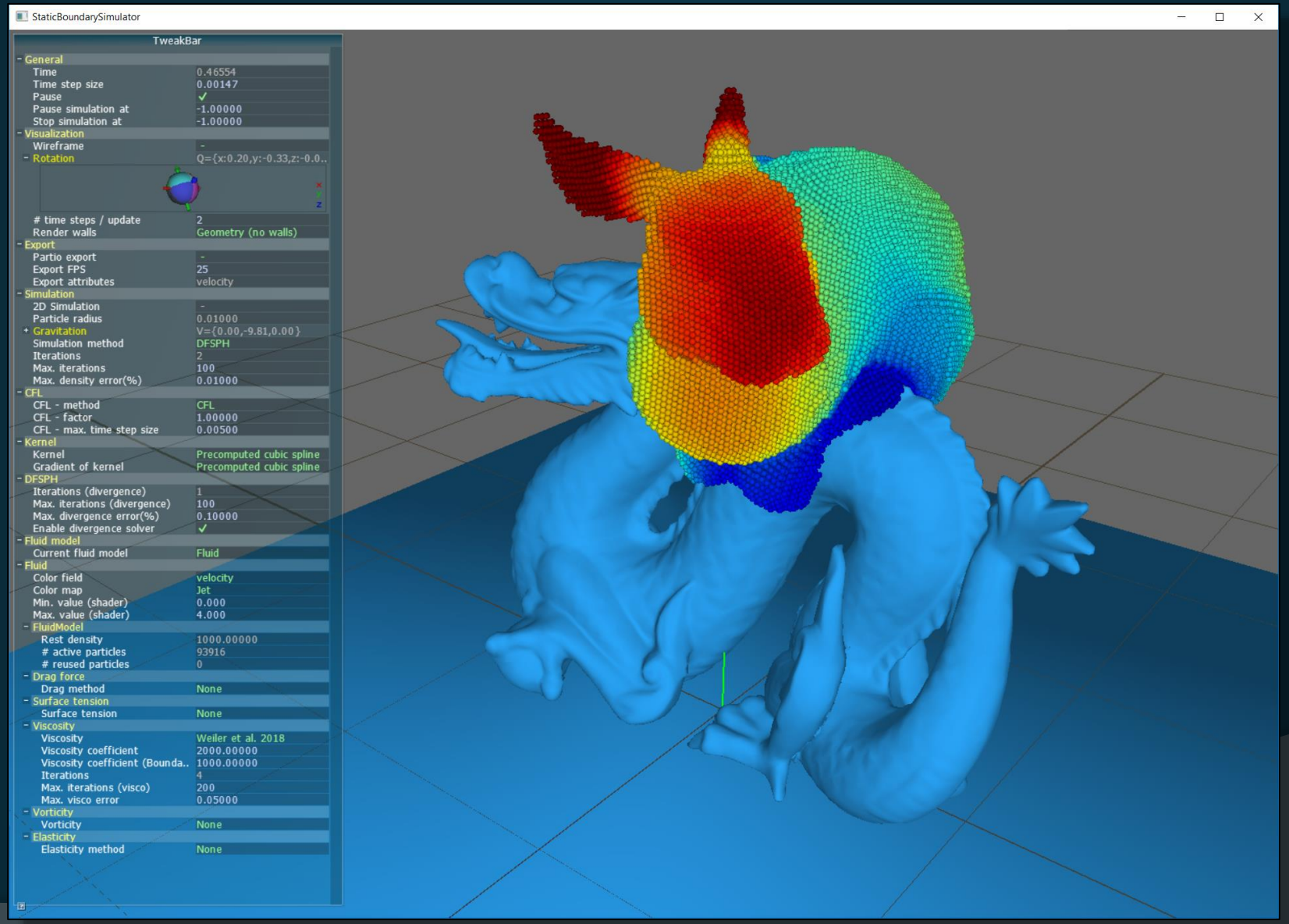




Roadmap

- Available soon:
  - GPU neighborhood search
  - AVX support for the pressure solver
  - Foam generation tool
  - Boundary handling with density maps
- Work in progress
  - Tool for surface reconstruction
- Future
  - GPU-based pressure solver
  - Integration in Blender

Demo


StaticBoundarySimulator
TweakBar
General
Time 0.46554
Time step size 0.00147
Pause ✓
Pause simulation at -1.00000
Stop simulation at -1.00000
Visualization
Wireframe -
Rotation Q={x:0.20,y:-0.33,z:-0.0..
time steps / update 2
Render walls Geometry (no walls)
Export
Partio export -
Export FPS 25
Export attributes velocity
Simulation
2D Simulation -
Particle radius 0.01000
Gravitation V={0.00,-9.81,0.00}
Simulation method DFSPH
Iterations 2
Max. iterations 100
Max. density error(%) 0.01000
CFL
CFL - method CFL
CFL - factor 1.00000
CFL - max. time step size 0.00500
Kernel
Kernel Precomputed cubic spline
Gradient of kernel Precomputed cubic spline
DFSPH
Iterations (divergence) 1
Max. iterations (divergence) 100
Max. divergence error(%) 0.10000
Enable divergence solver ✓
Fluid model
Current fluid model Fluid
Fluid
Color field velocity
Color map Jet
Min. value (shader) 0.000
Max. value (shader) 4.000
FluidModel
Rest density 1000.00000
active particles 93916
reused particles 0
Drag force
Drag method None
Surface tension
Surface tension None
Viscosity
Viscosity Weiler et al. 2018
Viscosity coefficient 2000.00000
Viscosity coefficient (Bounda.. 1000.00000
Iterations 4
Max. iterations (visco) 200
Max. visco error 0.05000
Vorticity
Vorticity None
Elasticity
Elasticity method None