Particulate Flows with a Widely Applicable Lattice Boltzmann Solver

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waLBerla - Fluid Dynamics

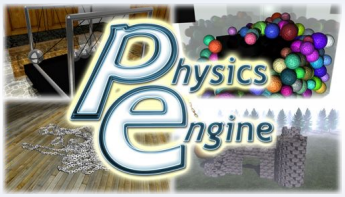
- Widely applicable Lattice Boltzmann solver
- Framework for physically correct fluid simulations
- Suited for various flow applications
- Different fluid models (SRT, MRT, ...)
- Flexibly parametrizable via input file
- Easily adaptable to further extensions

- Large-scale, MPI based parallelization
- Dynamic application switches for heterogeneous architectures and optimization

Largest fluid simulation: 32 billion fluid cells

pe - Rigid Body Dynamics

- Framework for physically accurate and virtual reality multibody simulations
- Several predefined primitive geometries (sphere, box, capsule, ...)
- Joints between rigid bodies (hinge, slider, ...)
- Force generators (spring, gravity, ...)
- Accurate handling of friction during collision



- Massive, MPI based parallelization
- Expression Template based math library
- GPGPU accelerated rigid body simulations

Largest multibody simulation: 2 billion rigid bodies

Simulation of Particulate Flows

Coupling of both Frameworks

- Massively parallel simulation of fluids and particles
- Fluid-particle interaction
- Particle-particle interaction
- Interactions include friction handling
- Fully resolved particles of different shapes

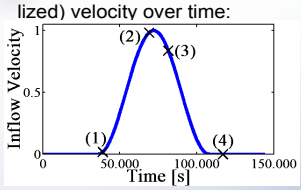
Algorithm of the Coupled Simulation

- Explicit two way coupling between the systems
- Alternating time steps in each system

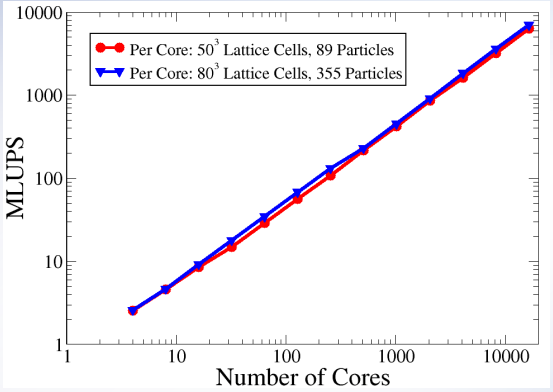
```
1 for each time step do
2 |  map rigid objects to the LBM grid
3 |  update all lattice cells (stream-collide-step)
4 |  add hydrodynamic forces to rigid objects
5 |  synchronize forces between neighboring processes
6 |  calculate collision constraints
7 |  resolve contacts and move objects
8 |  synchronize objects between neighboring processes
9 end
```

Simulation Setup

- Particles in fluid with inflow from below
- Flow with no-slip boundary conditions at walls
- Taking into account gravity, buoyancy and drag
- Particles with same density but different volume
- Inflow according to the (normalized) velocity over time:

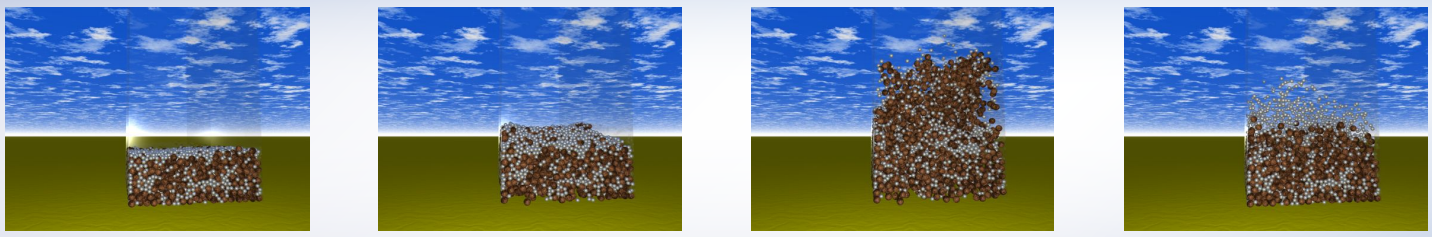


Performance



Weak scaling of fluidization simulations with up to $8.4 \cdot 10^9$ lattice cells and $5.9 \cdot 10^6$ particles on up to 16384 cores on the JUGENE. Each core performs computations on a given number of lattice cells. The average number of particles per core is set to be the same in each simulation. Performance is measured in mega lattice site updates per second (MLUPS).

Results



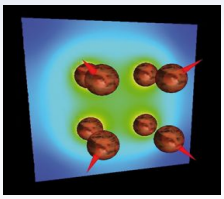
(1) (2) (3) (4)

Applications

Free surfaces

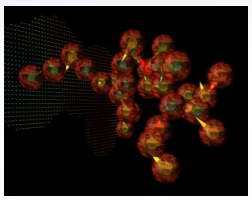
VoF Free Surface Method. Accurate foam simulation including film rupture and disjoining pressure.

Charged colloids



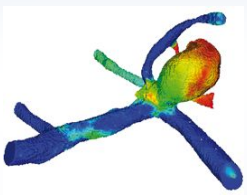
Investigation of agglomeration processes in colloidal suspensions stabilized by electrostatic charges.

Moving obstacles



Simulation of moving obstacles including aggregation and rupture as well as Brownian motion.

Blood flow



Efficient computation of hemodynamic values in blood vessels, especially in stenoses or aneurysms.

Free surfaces and FSI

Sophisticated free surface method with fluid-fluid as well as fluid-structure interaction (FSI).