The simulation of particulate flows is important for many industrial applications and natural phenomena, such as sedimentation and fluidization processes. In order to capture the physics of these processes correctly, simulations have to deal with large numbers of interacting particles.

The simulation approach presented on this poster couples a 3D lattice Boltzmann fluid simulation with a multibody dynamics simulation. With this coupled system we are able to simulate up to 37 million geometrically and individually modeled moving objects incorporated in the flow.

The Coupled Simulation System

Algorithm of the Coupled Simulation

Explicit two way coupling between the systems

Alternating time steps in each system

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

Results

Good scaling behavior (74% parallel efficiency) on up to 8192 processor cores

Simulation of individually modeled and geometrically fully resolved rigid bodies

Largest coupled simulation

3.7·10^10 bodies, 6.6·10^10 nodes, 8192 cores

Simulation of 3.7·10^10 spheres with 4608/960/320 nodes on 32/16/16 cores of the HLRB II supercomputer at the Leibnitz Rechenzentrum München.

The Large-Scale Algorithm

1. MPI communication step 1: force synchronization
2. for each body B do
   3. first position half step
   4. first velocity half step
   5. end
3. MPI communication step 2: update of remote and notification of new rigid bodies
4. for each body B do
   5. find all contacts C(B)
   6. find post-collision velocity
   7. select friction response
   8. if B has constraints then
     9. first velocity half-step
     10. first position half-step
     11. add collision and friction constraints to B
     12. end
   13. MPI communication step 3: exchanging constraints on the rigid bodies
      14. for each body B do
         15. calculate collision constraints
         16. move objects
         17. add hydrodynamic forces to rigid objects
         18. synchronize forces between neighboring processes
         19. for each body B do
            20. map rigid objects to the LBM grid
            21. for each violated contact k in C(B) do
               22. synchronize objects between neighboring processes
            23. end
         24. MPI communication step 4: update of remote and notification of new rigid bodies
end

Large-Scale Fluid Dynamics

Simulation Examples

Simulation of a tsunami wave hitting the skyline of a city. The domain for this simulation consists of 2.6·10^8 (880×880×336) lattice cells.

Simulation of 500000 spheres and boxes falling into a well built from 300 fixed boxes. The colors indicate the domains of the 91 MPI processes. Due to the hexagonal setup of the domains, each MPI process has a maximum number of six neighboring processes.

The waBerla Framework

Features

Large-Scale, hybrid parallelization
Dynamic application switches for heterogeneous architectures and optimization
Different fluid models (SRT, MRT, …)
SUITed for various flow applications
Parametrizable via input file

Applications

Particulate Flows/Fluid Structure Interaction
Free Surface/Multiphase Flows
Porous Media Scenarios
Ionized Flows/Charged Colloids
Brownian Motion
Non-Newtonian Fluids (Blood flow, …)

Large-Scale Multibody Dynamics

Simulation Features

Algorithms for physically accurate and virtual reality multibody simulations
Several predefined primitive geometries (sphere, box, capsule, cylinder, and plane)
Compound geometries
Joints between rigid bodies (fixed joints, hinges, ball joints, …)
Force generators (springs, gravity, …)

Implementation Features

Massively MPI based parallelization
Thread based parallelization
Expression Template based math library

Largest multibody simulation

1.1 billion rigid bodies

The Physics Engine

Simulation Features

Expression Template based math library
Thread based parallelization

Non-Newtonian Fluids (Blood flow, …)
Brownian Motion

Large-Scale Coupling of Multibody Dynamics and Computational Fluid Dynamics

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