Parallel Simulations of Modelica models using GPU's

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January 21, 2015

Background

During simulations it can be beneficiary to be able to make interactions with the simulations by e.g. changing boundary conditions or geometry, as this would allow for faster prototyping of new ideas. *Dassualt Systémes* wants to deliver this as a part of their future products. In order for useful interaction to be possible, the simulations needs to be computed in real time, so that the user can see the effects of their interactions. Many such simulations exists today, but often the physical accuracy is sacrificed in order to achieve better visual results. *Dassualt Systémes* wants to deliver reliable simulations, where physical accuracy comes first.

In some cases the problem can be diveded into several simpler subproblems. If formulated properly, such a problem can beneficiary be simulated on the GPU. Examples of such problems are fluid dynamics and discrete element simulations. The scope of this master thesis is to develop and implement methods to simulate such problems on the GPU.

Specifics

The scope of the thesis can be divided into two main parts. The first is to implement a solver on the GPU for the Navier-Stokes equations as a possible extension to the *Modelica* language. Here equations stated in *Modelica* will have to be generated as code for the GPU, possibly *OpenCl*. The solver method will be implemented in *C* and/or *C++* with some parts in a GPU language. The solver will work with a fix grid. A possible application is the air flow in an aircraft compartment. What method to use is not decided. Some simple visualization routines will be needed in order to be able to check the results and compare them with results from a CFD solver, e.g. *COMSOL*.

The second part will be to perform Discrete Element Method (DEM) simulations, also here using the GPU and code generation from *Modelica*. This can be divided into two cases. The first, which is the more simple of the two, is where many particles with a simple geometry is considered, e.g. spheres. This to simplify the contact mechanics. A typical application for this would be to simulate the flow of granulate. In the other case fewer objects with a more complex geometry will be considered. Here the focus will be on the contact mechanics. Constructive Solid Geometry may be used to determine the intersection volume, which is of huge importance

when calculating the contact forces. This technique can be of use when e.g. modeling the dynamics of a mechanical wristwatch.

In the beginning of the project most of the time will be spent on research. Mainly about CFD methods like the Finite Volume Method and on practical issues concerning the GPU programming. Then the idea is that the work more or less should follow in the order things where brought up in the sections above, with a lot of research along the way.

Disciplinary foundation

Discussion about solving Navier-Stokes Equations on GPU:
GPU Gems: Chapter 38. Fast Fluid Dynamics Simulation on the GPU
http://http.developer.nvidia.com/GPUGems/gpugems_ch38.html

The basic principles are given in:
Jos Stam: Real Time Fluid Dynamics for Games
http://www.dgp.toronto.edu/people/stam/reality/Research/pdf/GDC03.pdf

A comprehensive discussion of Discrete Element Method is given in:
JIAN CHEN: Discrete Element Method for 3D Simulation of Mechanical Systems of Non-spherical Granular Materials
http://ir.lib.uec.ac.jp/infolib/user_contents/9000000625/9000000625.pdf

A nice and clean implementation of Constructive Solid Gemoetry operations is given in JavaScript:
http://evanw.github.io/csg.js/

Our contribution

This project could contribute to the knowledge in:

- Reformulating problems and methods to run on a GPU, in order to achieve faster simulations.
- Integrating interactive realtime fluid simulations with existing physics simulation software.
- Integrating advanced contact mechanics in DEM simulations with complex geometries.

Resources

The master thesis will be carried out at the department of Computer Graphics at LTH, and will begin on the 26th of january 2015 and preliminary last to the 28th of august 2015.

Most of the working time will be spent at the office of *Dassault Systémes*. Computers will be provided, with the software needed from *Dassault Systémes*. Possibly experiments will be carried out on more powerfull machines/GPU's. If this would done at the department of Computer Science or at the company is not yet decided. If *COMSOL* will be used for result comparison, we have access to that with our student licences.

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