Implementing Hydrodynamic N-Body Codes on Reconfigurable Computing Platforms

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Abstract: N-Body codes for scientific applications like astrophysical simulations are usually highly demanding in computing power, and even the application of cutting edge computer technologies still doesn't satisfy the need of calculation power for lots of most interesting problems. With our research on FPGA-based reconfigurable computing we try to overcome the limitations of today's computing platforms.

Our current work deals with astrophysical N-Body simulations where hydrodynamical effects are important (e.g. galaxy dynamics). For such systems the smoothed particle hydrodynamics method (SPH) has shown to be a very powerful algorithm with a simple computing structure and nice dynamical behavior of the simulated system. It fits well together with the simulation of self-gravitation for which highly efficient special-purpose computers are applied (GRAPE).

Using general-purpose computing systems for SPH leads to a bottleneck of the overall system. The diversity of SPH-algorithms foils an approach of building a special-purpose processor for SPH. Therefore our approach is to apply a FPGA-based reconfigurable computing platform. The hydrodynamical simulation algorithm has a very simple computation structure where sums of force terms are calculated through the nearest neighbors of a particle. For these loops parallelized special-purpose floating-point calculation units are implemented in the FPGA. To save logic resources of the FPGA, the precision of the arithmetic has been reduced to a significant size of 16 bit. Test calculations confirmed that this precision is sufficient for our application.

We used a prototype system which consists of a PCI plug-in card with a modern off-the-shelf FPGA (Xilinx Virtex-II) and the capability of directly interfacing the GRAPE special-purpose hardware. On this platform we successfully implemented several of the time-critical SPH formulas of a state of the art SPH formulation. With the FPGA-processor we achieved a floating-point performance of 3.9 Gflops which outperforms modern general-purpose workstations by far.

The hybrid system approach with its novel capabilities and design paradigm is presented together with our plans for parallelizing the prototype system to achieve superior computing power in the area of hydrodynamic N-body simulation.

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