Streaming Computation for Lattice Boltzmann Method

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Summary

This paper presents a dataflow engine-based acceleration of 2D time-dependent computational fluid dynamics (CFD) using a Lattice-Boltzmann Method (LBM). LBM is particularly suitable in problems with complex boundaries, and/or multiple phases, including bubbles, oil and water, and porous media. Performance on a test problem demonstrates speedup of 2.93x and 2.46x over single-core 3.4GHz Intel Pentium 4 and 2.2GHz AMD Opteron processors, respectively. Performance is limited by the PCI-Express interface available at the time.

The lattice Boltzmann method (LBM) models fluids with fictive particles performing propagation and collision processes over a discrete lattice mesh. Here, we describe the 2D orthogonal 9-speed (2D9V) model. Each grid point has a distribution function f_i for each of the nine particle speeds as shown in *Figure 3*. The propagation and collision are given by the following equation:

$$f_i(x + c_i\Delta t, t + \Delta t) = f_i(x, t) - \frac{1}{\tau}\{f_i(x, t) - f_i^{eq}(x, t)\}$$

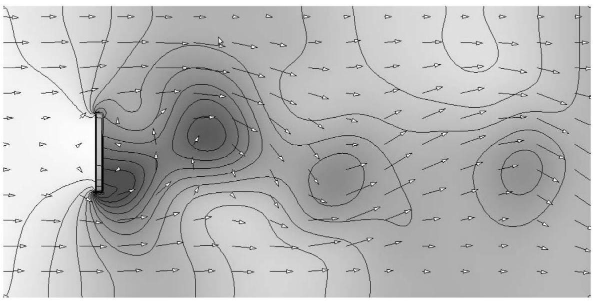

Figure 1: Computational results from the DFE.

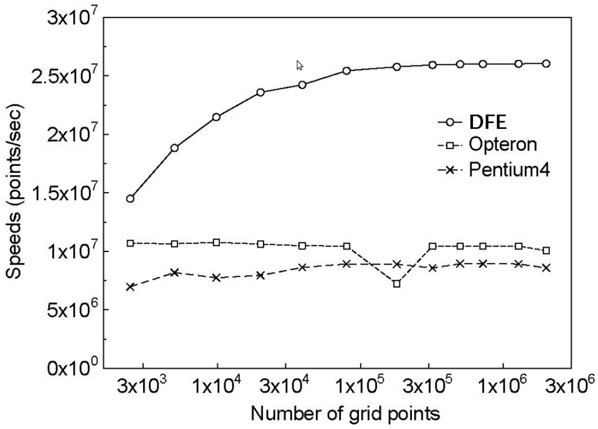

Figure 2: Computing speed comparison.

This is solved by an iterative process, in which particles are propagated, equilibrium distribution functions are calculated, and collisions are evaluated, until convergence. This is repeated for each timestep.

To achieve sharing of compute resources, we design a datapath that is switched according to cycles. This is implemented using a Maxeler MAX-I DFE and a PCI-Express interface with up to x8 transfer rate. *Figure 1* shows results on the 280 x 140 grid at time-step 10001.

Figure 2 shows the number of grid-points processed per second for problem sizes $2.45 * 10^3$ to $2.0 * 10^6$ grid-points. For grids larger than $1.0 * 10^5$ grid points, the DFE achieves the best performance of $2.61 * 10^7$. Since each grid point has to input and output stream data of $9 * 2 * 4 = 72$ Bytes, the PCI-express connection provides the bidirectional bandwidth of 1.8 GB/sec for the best sustained performance, which is almost half of the theoretical peak bandwidth of the x8 transfer mode. This actual bandwidth is limited by the current host system: future systems will offer higher bandwidth, which will translate directly into increased acceleration.

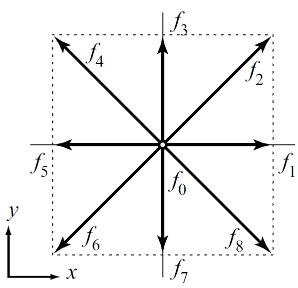

Figure 3: Particle distribution functions.