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Interactive Flow Simulation with FPGA-based acceleration of 2D Lattice Boltzmann Method

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ABSTRACT

Interactive simulation of flow fields has the high potential to be a useful tool for exploring the design space of aerodynamic machines with complex influences upon the surrounding flow fields. However, the required computational power and the dynamically changeable objects have been the major obstruction to achieve the interactive simulation. For smooth interactive operation by users, such a frame rate as 10 to 30 frames per second is necessary including computation and visualization. We need a higher computing performance than general computers in order to achieve both enough frame rates and accepted computational accuracy.

Towards the interactive flow simulation, we are developing the FPGA-based accelerator for the lattice Boltzmann method (LBM) with the immersed boundary method (IBM) [1]. FPGA (Field-Programmable Gate Array) is a semiconductor device where any electrical circuits can be reconfigured by users. With FPGAs, we can implement a custom computing machine (CCM) tailored for a target application to obtain better performance than conventional microprocessors. We design the streaming circuit of LBM [2, 3], which has good features for hardware implementation; regularity and parallelism.

This paper reports our preliminary implementation of the real-time and interactive flow simulation based on 2D LBM. Figure 1 shows the system overview of the interactive flow simulation. LBM computation is performed by a CPU and an FPGA, and then the flow field is visualized by GPU. A user can move and rotate an object in the flow field. When the object is changed, its boundary geometry information is computed for the immersed boundary method.

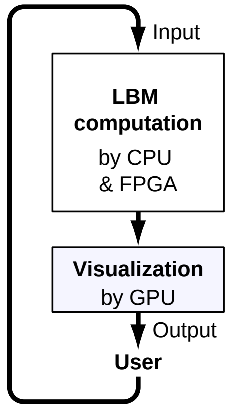

Fig. 1 System overview.

The FPGA-based acceleration of LBM is achieved as follows. The computation of LBM is composed of *Macroscopic value calculation, Equilibrium distribution function calculation, Collision, Translation* and *Boundary computation*. Among these stages, the first three stages can be accelerated by

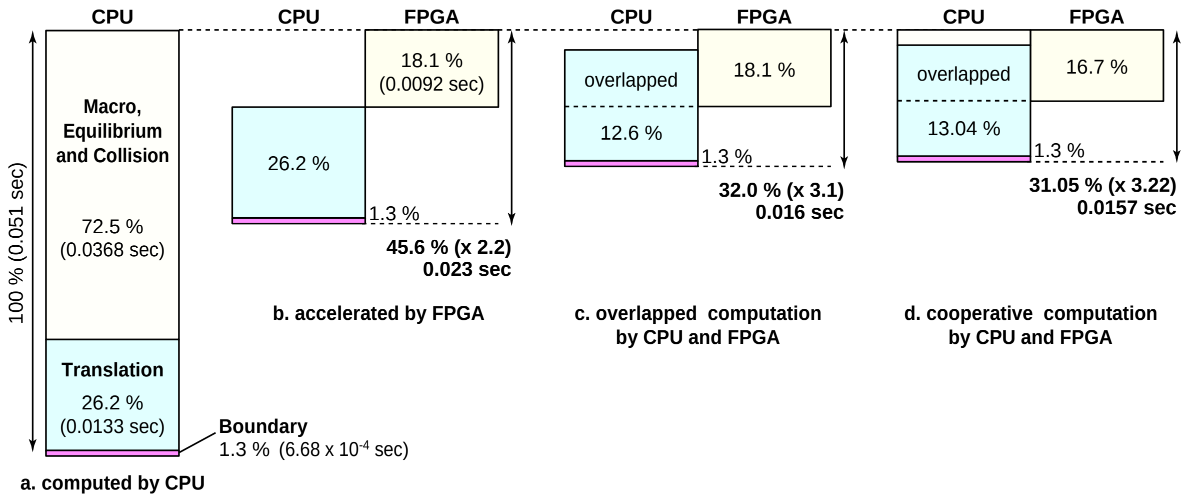

Fig. 2: Speedup by the cooperative computation with CPU and FPGA.

streaming computation with a CCM on an FPGA because of their regularity and parallelism [2, 3]. The pipelined CCM provides the performance scalable to the data bandwidth. Figure 2 shows the speedup by the FPGA acceleration for 600 x 400 grid points. Here we use the CPU of AMD Athlon64 running at 2.2GHz and the FPGA of Xilinx Virtex4 XC4VFX100, which is connected to the CPU with the PCI-Express x8 mode. For each time step, the total computing time only by CPU is 0.051 sec, where the translation, the boundary computation and the other part take 26.2%, 1.3% and 72.5%, respectively. Here we exclude the visualization time that is very small compared to the total time because visualization is performed every 10 time steps.

By using FPGA, the computation of the Macro, Equilibrium and Collision becomes four times faster. Since the remaining part still has 27.5% of the total time given only by CPU, however, the total speedup is restricted to 2.2. To improve the speedup, we exploit the parallel processing capability of CPU and FPGA. The half of the translation can be performed before the whole data are output by FPGA, and therefore we overlap the half with the streaming computation on FPGA. As a result, the total speedup was 3.1 as shown in Figure 2c. We also improve the speedup slightly with cooperative computation of the streaming part. In Figure 2d, the CPU and the FPGA take charge of 8% and 92% of the whole streaming computation, respectively. This reduces the unutilized CPU time, and therefore better performance is obtained. Finally we achieved about 6 frames per second with visualization of 600x400 grid points every 10 time steps, for time-independent flow with arbitrary shape of a 2D objects computed by IBM. As future work, we will further improve the FPGA acceleration and implement the 3D LBM computation with CPU and FPGA.

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