Porting a 2D Unstructured CFD code from the CPU to the GPU

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ABSTRACT

Traditionally, scientific computations are performed on Central Processing Units (CPUs) either in sequential or parallelized computing strategies. However, the recent appearance of powerful and massively parallel Graphics Processing Units (GPUs) is decisively contributing to its adoption in highly intensive scientific computations with concomitant reductions of computation times. It is known that GPUs are not as versatile as CPUs, but the recent availability of accessible programming tools and of GPUs able to operate in double precision create an opportunity for a leap forward in massively parallel computations [1]. Even though the most suitable applications for GPUs are those that feature high data parallelism with regular patterns to memory accesses, irregular patterns are not uncommon. Thus, this work explores the capabilities of GPUs to accelerate an unstructured 2D cell-centered finite volume computational fluid dynamics (CFD) code, which features irregular patterns arising from the unstructured grid.

The linear momentum (1) and the continuity (2) equations are solved numerically for Newtonian fluids in isothermal incompressible flow conditions with a finite volume method based on unstructured meshes and a cell-centered arrangement, in which all variables are stored at the centre of the control volume [2].

$$\rho\left(\frac{\partial v}{\partial t}+v\cdot\nabla v\right)=-\nabla p+\mu\nabla^2 v \tag{1}$$

$$\nabla\cdot v=0 \tag{2}$$

In order to solve the governing equations, the SIMPLE algorithm proposed by Patankar [2] was employed to ensure the solution of the linear momentum and mass conservation equations, and to address some nonlinearities of the problem. Furthermore, the coupling between the velocity and pressure fields was achieved by using an interpolation scheme based on the Rhie and Chow [3] scheme to estimate the cell face fluxes. The methodology employed is valid for Newtonian and

generalized Newtonian fluids, where the shear viscosity depends on the shear rate via some function, as the Bird-Carreau model. Due to performance requirements, in the GPU code all the steps comprising the SIMPLE algorithm were fully ported to the graphics device.

This investigation comprises the performance comparison between CPU and GPU CFD codes for two benchmark problems: the lid-driven cavity flow, for Newtonian fluids, and Poiseuille channel flow, for Newtonian and inelastic Generalised Newtonian fluids.

A performance analysis based on mesh refinement scalability was carried out with the purpose of evaluating the benefits of running large dimensional problems on the GPU, since graphics cards are suitable for massive parallel algorithms with high data parallelism. The computations were carried out on an Intel i7-2600 (CPU) and a NVIDIA GTX 580 (GPU).

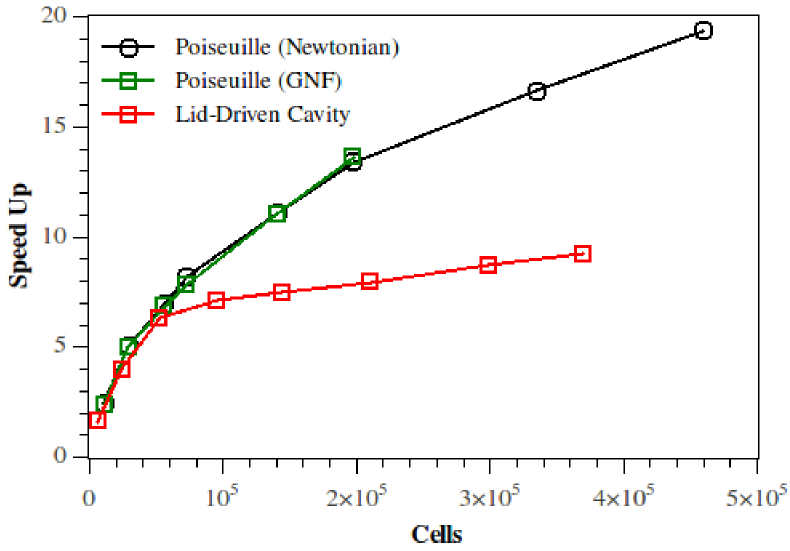

Figure 1: Speed-ups for both benchmark problems.

Considering the GPUs availability, cost and easiness to program, the results obtained are an indication that the full exploitation of the capabilities of these devices can be very useful for future CFD computations.

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