Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **7**, No. 1, pp. 1-12
DOI: 10.4208/aamm.2014.m468
February 2015

Implementation of Multi-GPU Based Lattice Boltzmann Method for Flow Through Porous Media

Changsheng Huang, Baochang Shi*, Nanzhong He and Zhenhua Chai

School of Mathematics and Statistics, Huazhong University of Science and Technology, Wuhan 430074, China

Received 21 January 2014; Accepted (in revised version) 26 June 2014

Abstract. The lattice Boltzmann method (LBM) can gain a great amount of performance benefit by taking advantage of graphics processing unit (GPU) computing, and thus, the GPU, or multi-GPU based LBM can be considered as a promising and competent candidate in the study of large-scale fluid flows. However, the multi-GPU based lattice Boltzmann algorithm has not been studied extensively, especially for simulations of flow in complex geometries. In this paper, through coupling with the message passing interface (MPI) technique, we present an implementation of multi-GPU based LBM for fluid flow through porous media as well as some optimization strategies based on the data structure and layout, which can apparently reduce memory access and completely hide the communication time consumption. Then the performance of the algorithm is tested on a one-node cluster equipped with four Tesla C1060 GPU cards where up to 1732 MFLUPS is achieved for the Poiseuille flow and a nearly linear speedup with the number of GPUs is also observed.

AMS subject classifications: 65Y05, 76M28

Key words: Lattice Boltzmann method, GPU computing, CUDA, porous media, MPI.

1 Introduction

Recently, GPU (graphics processing unit) computing is becoming rapidly popular, especially after the emergence of new programming languages like compute unified device architecture (CUDA) [1]. This is mainly due to the tremendous computing power and superior memory bandwidth of the GPU architecture. For this reason, the GPU computing has also been viewed as a cost-efficient tool to overcome the performance bottleneck. Up

*Corresponding author.
Email: hcshust@163.com (C. Huang), shibc@hust.edu.cn (B. Shi), nzhe@hust.edu.cn (N. He), hustczh@hust.edu.cn (Z. Chai)

to now, many applications have achieved a significant speedup by exploiting the GPU processing power.

The lattice Boltzmann method (LBM) [2,3] is one of such algorithms that is perfectly suitable for running on the GPU. As a kinetic based approach in modeling fluid flows, the lattice Boltzmann method has been successfully applied in various fields. In order to achieve a desirable performance, several researchers implemented the LBM on a single GPU [4–7], and reported some satisfactory accelerations.

To gain a higher performance for complex problems with a large scale, the multi-GPU based LBM has been developed, and studied preliminarily in some previous works [8–14]. In these works, although almost a linear speedup was achieved, only the GPU based LBM for fluid flow in a simple geometry is investigated. Recently, Bernaschi et al. implemented multi-GPU based lattice Boltzmann method for flows in complex geometries by utilizing sparse lattice representation technique [15,16], which only stores fluid nodes and could achieve high performance when the volume fraction of the fluid phase is quite small. However, for porous media with a high porosity, the full matrix mode is a better choice and can achieve a higher performance than the sparse matrix mode. In this paper, based on the full matrix mode, we present an alternative multi-GPU based LBM algorithm for fluid flows through porous media, in which message passing interface (MPI) technique is adopted for GPU management.

The rest of this paper is organized as follows. In Section 2, we will present a brief overview on the lattice Boltzmann method. In Section 3, an improved multi-GPU based lattice Boltzmann algorithm is proposed, and then, a detailed analysis on the performance of the algorithm is given in Section 4. In the next Section, as an application, the present algorithm is used to predict permeabilities of three types of porous medium, and finally, some conclusions are summarized in Section 6.

2 The lattice Boltzmann method

The lattice Boltzmann method can be viewed as a discrete scheme of the continuous Boltzmann equation. For every time step, particles collide at each node and then propagate to neighboring sites along discrete directions. A popular class of lattice Boltzmann models is the so-called lattice Bhatnagar-Gross-Krook (BGK) model with a single relaxation time approximation. In this model, the evolution equation reads

$$f_i(\mathbf{x}+\mathbf{c}_i\delta t,t+\delta t)-f_i(\mathbf{x},t)=-\frac{1}{\tau}\left[f_i(\mathbf{x},t)-f_i^{(eq)}(\mathbf{x},t)\right], \tag{2.1}$$

where τ is the dimensionless relaxation time, $f_i(\mathbf{x},t)$ is the density distribution function for the particle moving with velocity $\mathbf{c}_i$ at position $\mathbf{x}$ and time t, $f_i^{(eq)}(\mathbf{x},t)$ is the local equilibrium distribution function. In this paper, a three-dimensional lattice Boltzmann model with nineteen velocities (D3Q19 model) [17] is used, and the corresponding equilibrium