

Multi-GPU Based Lattice Boltzmann Method for Hemodynamic Simulation in Patient-Specific Cerebral Aneurysm

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Received 30 October 2013; Accepted (in revised version) 12 June 2014

Abstract. Conducting lattice Boltzmann method on GPU has been proved to be an effective manner to gain a significant performance benefit, thus the GPU or multi-GPU based lattice Boltzmann method is considered as a promising and competent candidate in the study of large-scale complex fluid flows. In this work, a multi-GPU based lattice Boltzmann algorithm coupled with the sparse lattice representation and message passing interface is presented. Some numerical tests are also carried out, and the results show that a parallel efficiency close to 90% can be achieved on a single-node cluster equipped with four GPU cards. Then the proposed algorithm is adopted to study the hemodynamics of patient-specific cerebral aneurysm with stent implanted. It is found that the stent can apparently reduce the aneurysmal inflow and improve the hemodynamic environment. This work also shows that the lattice Boltzmann method running on the GPU platform is a powerful tool to study the fluid mechanism within the aneurysms and enable us to better understand the pathogenesis and treatment of cerebral aneurysms.

AMS subject classifications: 65Y05, 76Z05, 76M28

Key words: Lattice Boltzmann method, GPU computing, MPI, cerebral aneurysm, blood flow.

1 Introduction

Cerebral aneurysms are localized dilation or ballooning of the brain blood vessel, usually caused by disease or weakening of the walls. They are particularly dangerous because their rupture often leads to subarachnoid hemorrhage, which is associated with

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high morbidity and mortality. Although the mechanisms responsible for the formation and rupture of cerebral aneurysms are not fully understood, hemodynamic factors are thought to play an important role in the pathogenesis and treatment of cerebral aneurysms [1].

A novel therapy to treat cerebral aneurysm is to implant a porous stent across the neck of the aneurysm, which has been viewed as a promising and minimally invasive treatment modality. The placement of the stent could change aneurysmal hemodynamic environment, reduce the inflow into the aneurysm, and prevent the further growth of the aneurysm. For this reason, many different methods, including experimental study, clinical observation, and numerical simulation, have been developed to investigate the effect of the stent on hemodynamic characteristics. Among them, the numerical simulation has been proved powerful and efficient [2–6]. As a mesoscopic numerical approach, the lattice Boltzmann method (LBM) [7–9], has been widely used to investigate the hemodynamics of cerebral aneurysm for its distinct advantages [10–16], including easy implementation, intrinsic parallelism, and capability in treating complex boundary conditions. However, most of the previous work, which assessed the effect of stent deployment on hemodynamics within the aneurysm, are only limited to the two-dimensional or idealized aneurysm models. In this work, we will consider a patient-specific cerebral aneurysm model which is reconstructed from medical image.

At the same time, GPU (graphics processing unit) computing, which is a novel and popular parallel computing technology, has also attracted increasing attention in the area of lattice Boltzmann modeling and simulation. Several researchers implemented the LBM on GPU platform and reported rather remarkable performance [17–22]. Besides, their results also show that the LBM is very compatible with GPU computing. However, the multi-GPU based lattice Boltzmann algorithm has not been studied extensively, especially for fluid flows in complex geometries. In this paper, an algorithm designed for multi-GPU platform is proposed, where the message passing interface (MPI) technique is adopted for GPU management. Considering the complex structure of the blood vessel, the sparse lattice representation [23] is also utilized to reduce memory consumption and improve performance of the algorithm. Then the proposed algorithm is used to study the effect of the stent on the hemodynamics of cerebral aneurysm.

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, a multi-GPU based lattice Boltzmann algorithm and its performance analysis are presented. In the next section, the proposed algorithm is used to study the effect of the stent on hemodynamic characteristics of blood flow in a patient-specific cerebral aneurysm, and finally, some conclusions are summarized in Section 5.

2 The lattice Boltzmann method

The lattice Boltzmann method can be viewed as a discrete scheme of the continuous Boltzmann equation [24]. For each time step, particles collide at each lattice site and