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論 文 要 旨

THESIS SUMMARY

専攻： Department of	創造エネルギー　　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This dissertation titled "Large-scale Global MHD Simulation for Solar Wind Interaction with Magnetosphere on Multi-GPU Systems" consists of 6 chapters.

In chapter 1 "Indroduction", brief introductions to space plasma and MHD simulation, the research background and motivation, as well as GPGPU (General-purpose computing on graphics processing units) and GPU systems are given. The space is closed to our life. Over the past few decades many space exploration missions had been conducted. However, the range of observations is limited and it is costly. Space simulation such as MHD simulation is widely utilized in investigating the phenomenon of the space but it is computational expensive. GPUs used to be the graphics accelerated hardware for boosting up the calculations of computer graphics. GPGPU is the use of GPUs to accelerate the computation such as numerical simulation.

In chapter 2 "GPU Accelerated Space Plasma Simulation", related work of the state of the art GPU accelerated plasma simulations are introduced. The recent development of modern graphics processing units (GPUs) makes the simulation possible to perform them in a more efficient manner. GPUs have been widely utilized in MHD simulations in recent years. However, the data communication and the memory model of the GPUs bottleneck the efficiency of large-scale MHD simulation using GPU supercomputer of cluster.

In chapter 3 "GPU Direct-MPI Hybrid Framework", we present our new developed GPU Direct-MPI hybrid data communication framework for efficient large-scale MHD simulations on distributed multi-GPU systems. In our approach, data communcaitons between GPUs within a computing node is conducted via GPU Direct, while inter-node data communications are conducted via MPI (Message Passing Interface). Large-scale ideal MHD simulation was developed using our framework. Performance measurements of running our simulation on the GPU-rich TSUBAME supercomputer are given and high efficiency are shown.

In chapter 4 "Large-scale Global MHD Simulation", Implementation of large-scale global MHD simulation and practical applications to solar wind interaction with the Earth's magnetosphere are presented. Our simulations with a resolution of 1980x1320x1320 performed 4.38 TFLOPS (Tera-Floating-point Operations Per Second). Features of the magnetosphere such as the polar cusp, the magnetosheath and magnetopause are examined. Application of our simulation to the geomagnetic reversal is also carried out. Asymmetric structures and patterns caused by the IMF (interplanetary magnetic field) and the inclined dipole field of the Earth are found.

In chapter 5 "Advanced Simulation for Solar Wind-Earth's Magnetosphere Interaction", large-sacle MHD simulation including the wide region covered the whole magnetosphere is presented. Our novel block-based structure for efficient AMR on multi-GPU systems and simulations of the whole bow shock are proposed to enlarge the simulation domain to simulate the whole structure of the bow shock. Improvement of boundary condition is also made. Frequent variations of the size of the pole direction (the height) of the bow shock as well as the magnetosphere under slow/fast solar wind is found. On the other hand, the size at the equator plane (the width) doesn't change much. Moreover, our simulation domain includes the Moon's orbit. It is found that the Moon is staying in the magnetosheath longer when the solar wind velocity is lower. But the periods of staying beyond the bow shock are almost the same. In the magnetosheath , the density of the charged particles is lower than outside of the bow shock but greater than the magnetopause, and the planet (the Earth) magnetic field becomes irregular. At the region beyond the bow shock, the Moon is directly contact with the solar wind. Because the Moon doesn't contain a magnetic field to shield the solar wind, the charged particles hit the soil of the lunar surface directly. Therefore, the period of staying in the different properties of the plasma environment is very important in investigation of the evolution of the Moon. It is also improtant to the Lunar orbitors of a Lunar exploration project

In chapter 6, we conclude our work with explain the expectations of the possible future work.

In this dissertation, we developed an efficient data communication framework using GPU Direct 2.0. However, the inter-node data communication is still relied on MPI. We expect to improve the efficiency by using the GPU Direct RDMA for inter-node communication when it is available on the next upgrade of TSUBAME 3.0. By our improvement, the simulation domain not only covers the region of the whole magnetosphere, but also contains the Moon's orbit. Therefore, the whole structure of the magnetosphere under different situations (different solar wind speed, in our tests) are simulated. And the affect to the lunar orbit is also examined. We're looking forward to apply our simulation to other planets and satellites. On the order hand, our want to improve the AMR to make enough for represent the Moon in our simulation domain for simulating the coupling between the Earth's magnetosphere with the Moon.