

地震津波の防災減災のための京コンピュータを用いたシミュレーション研究 Advanced Disaster Simulation Researches on Earthquakes and Tsunamis using High Performance Computing System Kei

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‘Kei’ computer is one of the highest computing system in the world. Using ‘Kei’ computer, we are performing the advanced simulation for disaster mitigation by earthquakes and tsunamis in a project ‘Study for Advancement of Prediction Accuracy on Earthquake and Tsunami’. In this research project, we have three research fields as Earthquake simulation research field, Tsunami research field and Damage estimation research field.

In Earthquake simulation research field, we are developing the scenario simulations of earthquake recurrences on the subducting plate around Japan. As other earthquake simulation researches, we are simulating seismic waves based on the scenarios, and the underground structures using seismographs.

The second research simulation research field on Tsunami hazard, we are developing applications for the simulating tsunami damages at East Japan earthquake 2011. In this research field, not only damage simulations, but also we are developing the early tsunami detection system using simulation and real time data. Finally, we will apply it to the Nankai trough seismogenic zone and etc.

The third research field is the civil engineering research as the advanced civil engineering structural analyses, seismic response analyses on large scale cities, and agent simulation for more precise and practical evacuations.

Finally, we will integrate these research fields in this project for the seismic simulator on disaster mitigation.

キーワード: ハイパフォーマンスコンピューティング, 防災・減災, シミュレーション, 地震, 津波

Keywords: high performance computing, disaster mitigation, simulation, earthquake, tsunami

京コンピュータを用いた地震のシミュレーション Earthquake Simulations running on K computer

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Large-scale high fidelity model can be constructed with recent accumulation of spatial data. Although computational cost of earthquake simulations using such model is huge, supercomputer (e.g. K computer) is now resolving difficulties and creating new frontier in this field. In this presentation, recent illustrative examples (crust deformation, earthquake ground motion, soil amplification, city response etc.) will be shown.

キーワード: シミュレーション, ハイパフォーマンスコンピューティング, コンピュータショナルサイエンス
Keywords: Simulation, High performance computing, Computational science

ハイパフォーマンスコンピューティングにおける流体と粒状体に対する粒子法シミュレーションの進展と社会貢献的利用
Development of high performance particle simulations of fluid and granular dynamics for contributing to human society

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Large-scale parallel computing is important for numerically reproducing actual measurement results and dynamics of phenomena in various science and engineering areas, such as civil engineering, bioengineering, and earth sciences. The computational performance of parallelized software tools plays a critical role in such simulation studies, as these improve the computational accuracy relative to the simulation resolution within a limited computation time. Recent massively parallel computer systems based on shared- and distributed-memory architectures employ various types of arithmetic processors. Current processor designs are known to exhibit totally different computational performance depending on the numerical algorithms and implementation methods employed. Currently, parallel computing generally uses either a multi-core CPU, graphics processing unit (GPU), or many integrated core (MIC) processor. Multi-core CPUs have traditionally been used in high-performance computing, whereas GPUs were originally designed for computer graphics with many arithmetic cores. The common progress of current processor designs is the increase in the number of cores using vector operations such as single-instruction multiple-data (SIMD). In such a situation, the shared-memory parallelization plays a basic but critical role in dealing with the increasing number of arithmetic cores in an efficient manner.

Numerical simulation methods used in science and engineering include the finite difference method (FDM), finite element method (FEM), finite volume method (FVM), boundary element method (BEM), and particle simulation method (PSM). Among these, PSM has a benefit of being mesh-free, allowing the computation of large-scale deformations and fractures of a continuum body without expensive remeshing tasks. As a PSM, smoothed particle hydrodynamics (SPH) is often used for tsunami disaster simulations because of its robustness in free-surface fluid dynamics. The discrete element method (DEM) is one popular PSM for granular dynamics in which geometrical size and shape attributes are provided for each particle. In the most conventional formulation of the DEM, the Voigt model in both the normal and tangential directions is considered at each contact point. In the tangential direction, Coulomb friction is introduced to determine the maximum tangential force and the slip condition. In addition, rolling friction can be considered at the contact points. Therefore, the DEM is attractive to simulate granular materials such as sand, pebbles, and other grains.

However, PSM programs must be implemented carefully to avoid write-access conflicts under shared-memory parallelization, especially when calculating a resultant force. In addition, it is important for distributed-memory parallelization to dynamically balance the computational load between computational nodes. To address these issues, we have proposed parallel algorithms that use the action-reaction law and parallelize the interaction summation with a reference table to avoid memory access conflicts. We have also implemented the algorithm of dynamic load balancing by resizing the domain decomposition region. Our methods were implemented on various parallel processors such as GPU, MIC processor, multi-core CPU on K computer, and vector processor on Earth simulator. In this presentation, we will talk about these parallel algorithms and applications for contributing to human society; Tsunami disaster simulations in consideration of structures-soil-fluid interactions and impact dynamics of ballast particles in rail track are important topics that require a high performance computing resources.

キーワード: 離散要素法, 並列計算, 津波, バラスト軌道, 粒子, SPH
Keywords: DEM, parallel computing, Tsunami, ballast track, particle, SPH

3次元非平面断層解析に適した動的境界要素法の領域分割法による高速化 Efficient Domain Partitioning Method for Dynamic BIEM applicable to Non-planar Faults

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The boundary integral equation method (BIEM) is a powerful tool to analyze the earthquake rupture dynamics on non-planar faults. The non-planar fault analysis requires of the boundary integral equations (BIEs) that they are formulated in the real space and time domain, while those formulate in the spectral domain are limited to the application of the planar fault geometry. However BIEM in the space-time domain has extremely large numerical costs. Due to such large costs particular for the memory requirement, efficient use of the memory storage of the integration kernel have not be possible. In this study, we develop a new method to reduce the calculation time and memory requirement greatly without degrading the accuracy in 3-D. We extend the method proposed by Ando et al. (2007) in 2-D. This method divide the causality cone appealing in the integration kernel to the domains related to the wave fronts, the near-field term and the static term. We implement the algorithm on K-computer, and demonstrate the memory storage of the integration kernel becomes possible on the currently available computational environment owing to the reduced memory requirement. This contributes the efficiency of the numerical analysis considerably. For example, by using the same 6400 nodes, the analysis of the model consisting of 160 thousands fault elements and 1600 time steps took about a half year with the original method, however it is reduced to about two hours with the current efficient method. The current method is also shown to be scalable on distributed memory environment to the scale of these nodes. This method is expected to break through the emerging limitations of the dynamic earthquake rupture simulations with realistic 3-D geometrical models, and will contribute to widen the spectrum of the applicational works using the dynamic simulations.

キーワード: 境界要素法, 境界積分方程式法, 非平面断層, 動的破壊, 領域分割, 高速解法

Keywords: Boundary element method, Boundary integral equation method, non-planar faults, rupture dynamics, domain partitioning, high speed computing

津波シミュレーションの現状と課題 Current status and issues of Tsunami simulation by HPC

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津波シミュレーションでは、波源から遡上までをマルチスケールで連成し、遡上計算部においては3次元シミュレーションを用いて計算する計算や、漂流物との連成計算、構造物の破壊計算との連成計算などの高精細な計算が、京コンピュータを用いてできあがりつつある。本稿では、その現状について整理をするとともに、津波シミュレーションの課題についてまとめるものである。

3次元の高精細シミュレーションにおいては、1m程度の格子間隔で、およそ10億格子数を用いた計算が数万ノードのコンピュータを使用して計算できるようになった。その計算では、実時間の500倍から1000倍程度の計算スピードで計算することが可能となる。また、構造物との連成計算では、津波による防護施設の変形が実験と同じような精度で計算できるようになっている。

そのようななかで、今後の課題としては、被害の想定だけでなく、復旧や復興の事前対策への活用といった社会との連携が必須であるが、そのためには、建築構造物の破壊やがれきの計算ということが必要になってくるが、そのような方向性について課題としてまとめる

キーワード: 津波シミュレーション, ハイパフォーマンスコンピューティング, 津波, 連成計算
Keywords: Tsunami simulation, High performance computing, Tsunami, Coupling simulation

HPCを用いた巨大デジタル岩石内の2相間隙流体シミュレーション Two-phase flow simulation in the large digital rock by using high performance cluster

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A numerical implementation based on a Graphics Processing Unit (GPU) is proposed for the acceleration of the two-phase simulation using Lattice Boltzmann Method (LBM). The LBM yields regular, data-parallel computations; therefore, it is especially well fitted to GPU calculations. This study focuses on the application of the LBM for fluid displacement computations in real rock sample. For this purpose, the digital rock model is reconstructed from the micro-CT scanned images of reservoir sample with a resolution of 2.0 μm . In order to obtain reliable and accurate results from the developed numerical model, the computational domain must be large enough to cover the representative element size (REV) of sample rock. As a result, pore scale LBM simulation of multiphase porous medium systems with sufficient resolution and large grid-number are very computationally challenging. To achieve this extremely large-scale simulation, multi-GPU parallel scheme by using CUDA and MPI is developed. Careful optimizations include sparse storage scheme, efficient domain decomposition and non-blocking communication are desired for algorithm implementation. Finally, we succeeded to perform a two-phase simulation with 10 billion (1000 x 1000 x 1000) mesh sizes using a small-scale GPU cluster. The developed large-scale simulation method enables the direct upscaling from pore scale to core scale which is a very powerful tool for many engineering applications such as enhanced oil recovery (EOR) and Carbon Capture and Storage (CCS).

キーワード: デジタル岩石, 格子ボルツマン法, 2層流シミュレーション, GPU, 二酸化炭素の地下貯留
Keywords: Digital rock, lattice Boltzmann method, two-phase simulation, GPU, CO₂ storage

HPCが拓く固体地球科学の未来：導入 Introduction for Creating future of solid Earth science with HPC

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日本におけるハイパフォーマンスコンピューティング (HPC) は、従来ハードウェア主体で計画が進められてきたが、次世代 HPC 開発では、今後 10?20 年程度の期間で解決すべき社会的・科学的課題への貢献に主眼においた議論が、関連各分野で進められていた。次世代 HPC に向けた重点課題の FS や基本設計が始まっている。一方、京コンピュータの戦略プロジェクトは今年最終年度を迎え、成果の取りまとめが進んでいる。本セッションは、固体地球科学分野における HPC を活用した成果を共有するとともに、HPC の活用が貢献するであろう社会的・科学的課題や課題解決に向けた方向性についての議論を深めることを目的としている。社会的課題としては、地震・津波による災害軽減に資するものを中心とし、また科学的課題としては、観測網の充実を背景とした幅広い時空間スケールでの固体地球モデルの精緻化とそれに向けたビッグデータの高速度処理・解析を中心として、HPC に直接関わる側と、社会的・科学的課題の解決に向けた取り組みを行う側の双方が参加し、社会的・科学的課題に対する HPC の役割について議論を深める。そのための現状についての導入を行う。