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Large-Scale High-Performance GPU Computing for Seismology

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Simulation of seismic-wave propagation is essential in modern seismology in order to probe the Earth's and other planets' interiors, to study earthquake sources, and to evaluate the strong ground motions due to earthquakes for the seismic hazard analysis. The modeling of the seismic-waves is a computational challenge because of the effect of the structural heterogeneity and the required large domain size. The effect of the lateral heterogeneity is especially important for the shallow suboceanic earthquakes around Japanese islands where all the heterogeneities such as the steeply varying topography of the trenches, oceanic water layer, thick sediments, crust with varying thickness and subducting oceanic plate, can affect the excitation and propagation of the seismic-waves radiated from the earthquakes (e.g., Okamoto, EPS 2002; Nakamura et al. BSSA 2012). The scale length of the heterogeneity and topography is often small (a few hundred meters or even less than one hundred meters) and we need to use very small grid spacing in the simulation. Also, a very large domain size is often required because the fault size and the affected area can become large especially for the megathrust interplate earthquakes such as the 2011 Tohoku-Oki earthquake of which fault is roughly 200 km wide and 500 km long. Thus for the modeling of the seismic-waves we need all the resources for the high-performance computing, such as large-sized memory system, fast computing devices, fast interconnect network, and high-performance softwares.

In this paper we review our 3-D finite-difference time domain (FDTD) method developed for the simulation of seismic-wave propagation. As the accelerator, we use the GPUs in our simulation (Okamoto et al., 2010; 2013). The GPU (Graphics Processing Unit) is a remarkable device due to its multi-core architectures and high memory bandwidth. The GPU delivers extremely high computing performance at a reduced power and cost compared to conventional central processing units (CPUs): recent GPUs have achieved performaces of about 3.5 to 3.9 TFLOPS in single precision arithmetic at power consumption of 225 to 235 W. Simulation of seismic wave propagation is a memory intensive problem which involves a large amount of data transfer between the memory and the arithmetic units, while the number of arithmetic computations is relatively small. Thus, the simulation can benefit from the high-memory bandwidth of the GPU, and various approaches to adopt GPU to the simulation have been proposed recently (e.g., Abdelkhalek et al., 2009; Aoi et al., 2009; Komatitsch et al., 2009, 2010; Micikevicius, 2009; Okamoto et al., 2010, 2013; Michea and Komatitsch, 2010).

We will show our recent results that were done by using several hundred to more-than one thounsand of GPUs of the TSUBAME supercomputer in Tokyo Institute of Technology from the field of the seismology: the forward wave propagation in realistic 3D structure model for the Japanese islands, the inverse problem for the study of the earthquake sources using 3D Green's tensor waveforms, the computation of the sensitivity kernels for perturbations in the structural parameters of the earth model, and the simulation of scattering of seismic-waves from the moon-quakes as the feasibility study for the future seismic exploration of the moon and other planets. We will also discuss the future direction of the GPU computing in the field of seismology such as the real-time simulation of the wave propagation.

[References]

Okamoto et al. Earth Planets Space, 62, 939-942, 2010.
Okamoto et al, in GPU Solutions to Multi-scale Problems in Science and Engineering, ed. D.A. Yuen et al., Springer, 2013.

Keywords: GPU, seismic-wave propagation, rupture process, structure of the Earth, seismic exploration of planets, hazard analysis