GPU-accelerated Multiphysics-based Seismic Wave Propagation Simulation and its Surrogate Model with Machine Learning

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1 INTRODUCTION

Physics-based earthquake simulation is expected to contribute to estimation and mitigation of earthquake damage. However, its computational cost is huge, especially for three-dimensional (3D) domain. To overcome the cost, we have been developing a variety of methods for large-scale 3D earthquake simulation using the finite element method (FEM). In this poster, the GPU-accelerated method for multiphysics seismic wave propagation simulation considering soil liquefaction [1] is presented. By adopting load balancing schemes that consider characteristics of the multiphysics problem, the developed method achieved a 10-fold speedup over the CPU-based method. In addition, with machine learning using the simulation results, a surrogate model was constructed to enable much faster evaluation of earthquake response.

2 GPU-ACCELERATED EARTHQUAKE SIMULATION

The governing equation is the motion equation of the soil:

$$\rho \frac{\partial^2 \boldsymbol{u}}{\partial t^2} - \frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{x}} = \boldsymbol{f}, \tag{1}$$

where $\boldsymbol{\sigma}$ is the stress, $\boldsymbol{u}$ is the displacement of the soil, ρ is the density of the soil, $\boldsymbol{f}$ is the external force, and t is the time. The equation (1) is discretized by FEM and Newmark β method, and a sparse matrix equation with 1 million − 1 billion degrees of freedom (DOF) is obtained. The equation, whose coefficient matrix is updated every time step, is solved over tens of thousands of time steps. The developed method uses the adaptive conjugate gradient method to solve it. Here, a multigrid method and mixed precision arithmetic are used in the preconditioner to reduce the computational cost. The whole analysis is parallelized with MPI and OpenACC. By revising the domain partitioning method and adopting element reordering that consider the characteristics of the multiphysics problem, we developed an algorithm with high parallel efficiency which is suitable for GPU architecture. Also, a 21-bit floating point data type, FP21, is used in the MPI communication in the preconditioner to reduce communication cost. Even though the target multiphysics simulation is complex and could be unstable, the developed method can stably perform it.

In the performance measurement on one compute node of the supercomputer AI Bridging Cloud Infrastructure (ABCI) [2] with four Nvidia V100 GPUs, the developed method was 10 times faster than the method that used only CPUs. The developed method carried out a 30,000-time-step simulation with an 89,146,716-DOF soil structure model using 13 compute nodes on ABCI for 3 h 33 min. When this simulation was performed on a CPU-based supercomputer with Intel Xeon Phi 7250 (Knights Landing) CPUs, it took 14 h 37 min with 128 compute nodes, indicating the developed method drastically reduces necessary computational resources.

More simulation results can be obtained as a result of the simulation speedup. With machine learning using the obtained results, we constructed a neural network surrogate model of earthquake simulation and enabled even faster evaluation of earthquake response.

3 CONCLUSION

We accelerated large-scale earthquake simulation by using GPU. The implementation for one constitutive law was presented in this poster as an example, but the developed method is versatile and is applicable to other constitutive laws. Also, the surrogate model constructed from simulation results enabled even faster evaluation of complex multiphysics earthquake response. It is expected to enable evaluation of earthquake response of large-scale domain for a large number of cases, which is not feasible with physics-based simulation due to the huge computational cost.

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