Tsunami run-up and inundation simulations using LexADV_EMPS solver framework on Fujitsu FX100

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ABSTRACT
In this research, we describe applications of the LexADV_EMPS solver framework to tsunami run-up and inundation simulations on the Fujitsu FX100. To achieve high performance of particle-based simulations, the LexADV_EMPS framework supports hierarchical domain decomposition, halo exchange pattern of communication, and dynamic load balancing on the distributed-memory parallel computers. By using our framework, we have been successfully performed large-scale tsunami simulations with hundreds of millions of particles for the purpose of the tsunami impact assessment.

CCS Concepts
• **Computing methodologies→Massively parallel and high-performance simulations.**

Keywords
LexADV_EMPS; Open source software; MPS method; Particle method; Tsunami; ParMETIS; Distributed memory parallel, Domain decomposition and Dynamic load balancing

1. INTRODUCTION
We have been developing the open source CAE software, called ADVENTURE [1], which is a general-purpose parallel finite element analysis system and can simulate the large-scale analysis model with various supercomputers. Moreover, we have been also developing an open source software library, named LexADV [2], which is for large-scale numerical simulations of continuum mechanics in the exascale era. The aim of this research is to develop scientific libraries of the particle methods of the continuum mechanics.

We adopted the moving particle simulation (MPS) method [3] which is the well-known particle method as target solver and have been developing the LexADV_EMPS solver framework based on the explicit MPS method. The LexADV_EMPS is especially useful for the 3-dimensional fluid flow analysis involving free surfaces such as tsunami run-up simulations on the parallel computers [4][5][6].

The Fujitsu Supercomputer PRIMEHPC FX100 consisting of 2.2GHz SPARC64 XIfx processor was installed in Nagoya University, Japan. From a user viewpoint, the main features of the FX100 are 32 computer cores per processor, 256-bit SIMD, a high memory bandwidth of 480GB/s, and the Tofu interconnect 2. In this research, we ported the LexADV_EMPS to the FX100, and then performed large-scale tsunami run-up and inundation simulations with hundreds of millions of particles as an application of the LexADV_EMPS to the tsunami impact assessment.

2. LEXADV_EMPS
The LexADV_EMPS has been developed as the open source software, and the latest version is 0.1.2b released on December 2014. The target problem in size is 10 million to 1 billion particles, or more. The main features of the LexADV_EMPS are the explicit MPS method solver, two-level domain decomposition, halo exchange pattern of communication, dynamic load balancing on the distributed-memory parallel computers.

To achieve high parallel efficiency of the particle methods, an efficient data management by adopting three-level bucket structure is implemented. Figure 1 shows strong scaling efficiency of the LexADV_EMPS using the K computer at RIKEN and the FX100. The number of particles are 1 billion for the K computer and 500 million for the FX100. As can be seen in the figure, we achieved about 87 % of parallel efficiency both on the K computer and on the FX100.

To improve the accuracy of the numerical method, the higher order spatial derivative scheme of the least squares moving particle semi-implicit (LSMPS) method based on the Taylor expansion [7] is adopted for gradient and Laplacian. As shown in Figs.2-3, the LexADV_EMPS got better performance out of the FX100 and successfully calculated gradient and Laplacian with LSMPS scheme in actual time.

3. TSUNAMI RUN-UP AND INUNDATION SIMULATIONS
Tohoku area was severely damaged by the tsunami of the Great East Japan Earthquake on 2011. To simulate tsunami effects on coastal area, we have analyzed tsunami inundation area of Kesennuma city, Ishinomaki city, and Fukushima Daiichi Nuclear Power Station. In this research, to analyze target area efficiently, we used results of the 2-dimensional shallow-water analysis for the area of about 1000 km^2 as boundary conditions of coastal area. Figure 4 show a result of tsunami run-up simulation with a 330-ton fishing vessel at Kesennuma.

In case of Kesennuma city, tsunami run-up analysis of 130 million particles (1-meter particle spacing) has been done in about 6 days using 192 nodes of the FX100. On another case, tsunami run-up simulation of Fukushima Daiichi Nuclear Power Station with 250 million particles has been successfully performed in about 150 hours using 192 nodes of FX100. Since solving same problem on

K computer used computer resources of multiplying of 12,000 nodes by 30 hours, we succeeded in reduction of required computer resources drastically by using the LexADV_EMPS on the FX100. Besides, computational simulations agreed well with real-world observations.

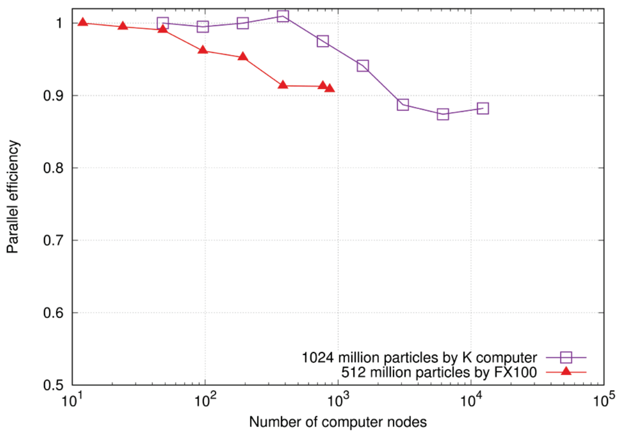

Figure 1 Strong scaling efficiency of LexADV_EMPS using 1 billion particles on the K computer and 500 million particles on the FX100.

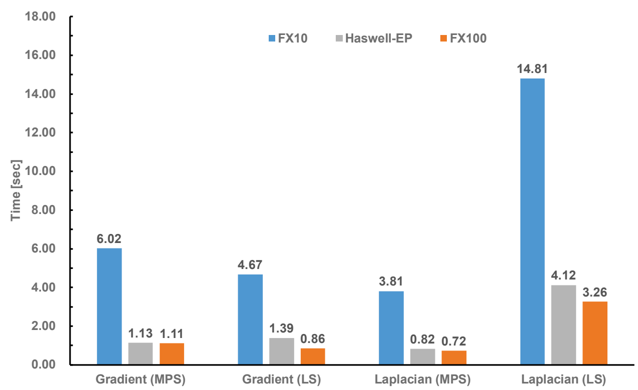

Figure 2 Computation time of gradient and Laplacian with different spatial derivative scheme using 16 million particles on 12 nodes of FX10, Haswell-EP, and FX100.

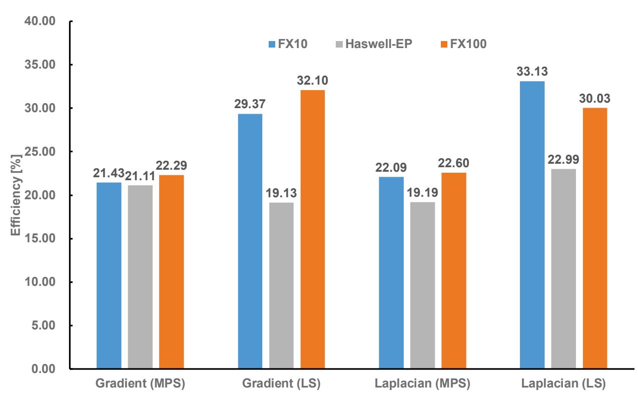

Figure 3 Computational efficiency of gradient and Laplacian with different spatial derivative scheme using 16 million particles on 12 nodes of FX10, Haswell-EP, and FX100.

Figure 4 A tsunami run-up simulation with a 330 ton fishing vessel.

4. ACKNOWLEDGMENTS

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