A Fast Implicit Solver with Low Memory Footprint and High Scalability for Comprehensive Earthquake Simulation System

Key Ideas and Innovations

- **High convergence with a low-memory footprint:** communication avoiding inexact LU preconditioning used for coarse problem, the preconditioning matrix preconditioner in an inexact conjugate gradient (CG) method.
- **Fast computation with low-memory footprint:** a SIMD buffering and multi-core coloring method developed for efficient memory-safe matrix-vector multiplication (the element-by-element (EBE) method).
- **Highly scalable:** the on-the-fly EBE method circumvents load imbalance from difference in memory access patterns in the unstructured computation.

Comprehensive Earthquake Simulation System

- **We are developing a comprehensive earthquake simulation system designed to model all phases of an earthquake disaster.**
- **Large-scale forward modeling of wave propagation and soil amplification enabled by a fast, unstructured finite-element simulation (e.g., Ichimura et al. SC14 [Gordon Bell Finalist], SC15 [Gordon Bell Finalist]).**
- **The next step is physics-based earthquake forecasting via assimilation of observational data and multiple crust-deformation analyses.**

Comprehensive Earthquake Simulation System

- **Earthquake footprint simulation:** need of fast and scalable implicit solver with low memory footprint.
- **Complete earthquake simulation system:** modeling, as shown above: most important core technology for 1 data and physics unstructured.

Earthquake Simulation System

- **Maximum surface response computed with 133 billion degrees of freedom and 33 billion element soil model:** Maximum response of 328,006 buildings computed with nonlinear frame models.

Shock wave propagation

- **Efficient coloring for multi-core computation of an EBE kernel:** Good load balance, high locality, and fewer colors.

Performance Measurement Results

- **Performance on the K computer:**
  - High DOF/memory attained: 2.36 T-DOF problem solved using the full K computer with 1.3 PB memory (Hori et al., 2012)
  - High performance for unstructured FEM: 1.21 PFLOPS (11.4%) attained for the whole solver.

Performance on the K computer

- **Performance portability:**
  - Hardware peak double precision FLOPS: 4.90 TFLOPS
  - Hardware peak memory bandwidth: 2.77 TB/s

Performance portability

- **Efficiency of the mixed-precision algorithm:**
  - Double precision speedup attained by use of a mixed precision algorithm: inner fine and inner coarse loops accelerated by use of single precision.

Efficiency of the mixed-precision algorithm

Summary and Future Prospective

- **Fast, scalable and portable solver with low-memory footprint developed for a comprehensive earthquake simulation system.**
- **Short-time-to-solution attained by using a load on the compute units, cache, and memory; the effective use of all of these units is required for high-performance.**
- **This system running on the next generation of supercomputers is expected to enable 10^5 times crust-deformation simulation and will be key to developing a dramatic reduction in seismic loss.**
- **Also useful for non-seismic applications where appropriate modeling of geometry is essential.**

Acknowledgements

- **Results are obtained using the K computer at the RIKEN Advanced Institute for Computational Science (Proposal numbers: hp160221, hp150175, hp150127, hp160160, hp160221).**
  - See also the RIKEN Advanced Institute for Computational Science ( Proposal numbers: hp160221, hp150175, hp150127, hp160160).
- **We acknowledge support from Japan Society for the Promotion of Science (15H05510, 16H04409, 16H02564), and the FOCUS Establishing Supercomputing Center of Excellence.**
  - We thank the Operations and Computer Technologies Division of RIKEN Advanced Institute for Computational Science and the help desk of High Performance Computing Infrastructure support concerning the use of the K computer system. We used the crust data of Japan from the J-USGS National Research Institute for Earth Science and Disaster Prevention.