EARTHQUAKE SIMULATIONS ON THE INTEL XEON PHI PROCESSOR

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What is AWP-ODC-OS?

AWP-ODC-OS

- AWP-ODC-OS (Anelastic Wave Propagation, Olsen, Day, Cui): Simulates seismic wave propagation after a fault rupture
- Used extensively by the Southern California Earthquake Center community (SCEC)

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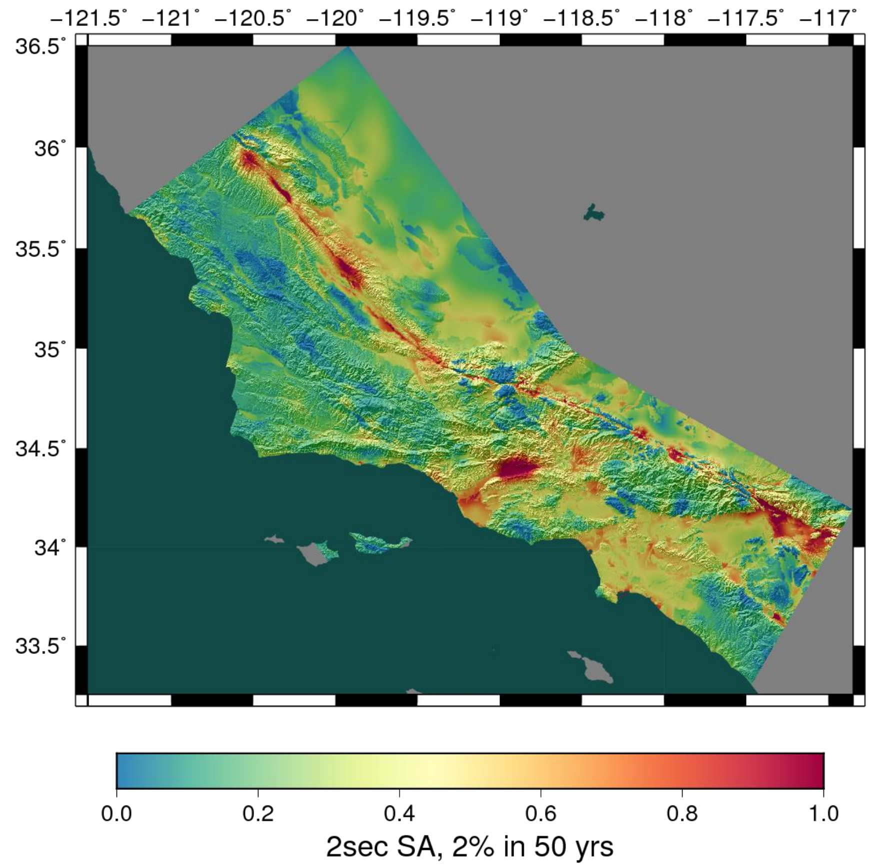


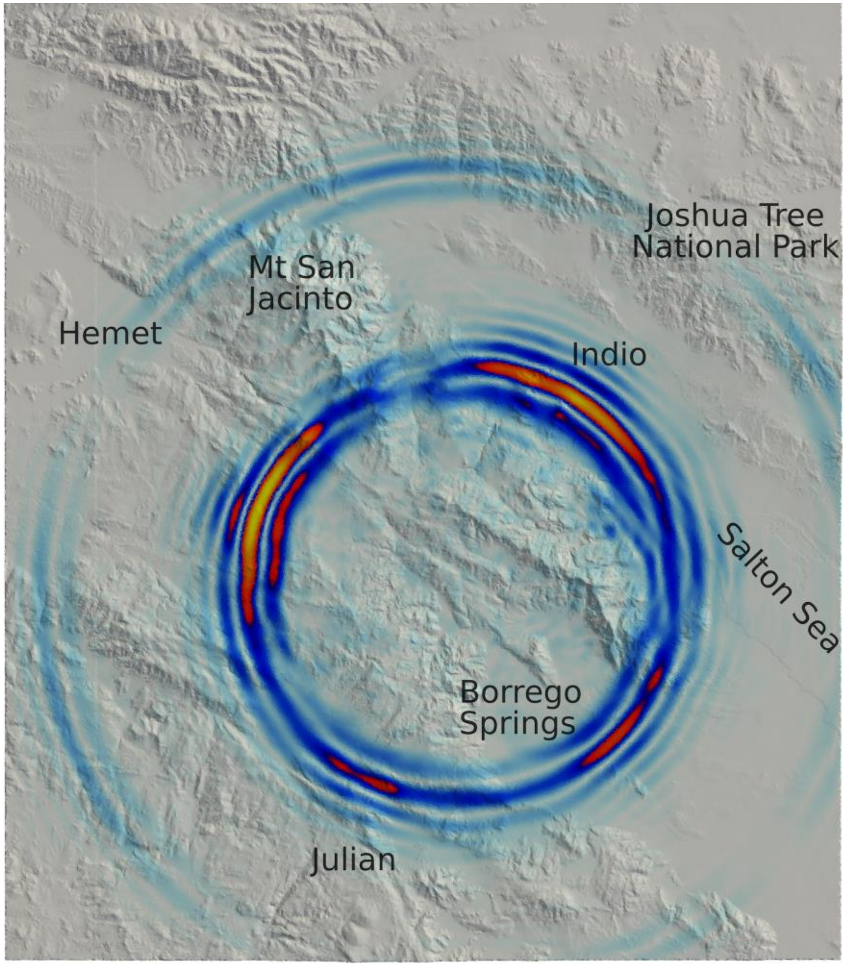
[Combined Hazard map]() of CyberShake Study 15.4 (LA, CVM-S4.26) and CyberShake Study 17.4 (Central California, CCA-06). AWP-ODC simulations are used to generate hazard maps. Colors show 2 seconds period spectral acceleration (SA) for 2% exceedance probability in 50 years.

What is EDGE?

- Extreme-scale Discontinuous Galerkin Environment (EDGE): Seismic wave propagation through DG-FEM
- Focus: Problem settings with high geometric complexity, e.g., mountain topography

- "License": BSD 3-Clause (software), CC0 for supporting files (e.g., user guide)

http://dial3343.org



Example of hypothetical seismic wave propagation with mountain topography using EDGE. Shown is the surface of the computational domain covering the San Jacinto fault zone between Anza and Borrego Springs in California. Colors denote the amplitude of the particle velocity, where warmer colors correspond to higher amplitudes.

Two Representative Codes

AWP-ODC-OS

Finite difference scheme: 4th order in space, 2nd order in time

Staggered-grid, velocity/stress formulation of elastodynamic eqns with frequency dependent attenuation

Memory bandwidth bound

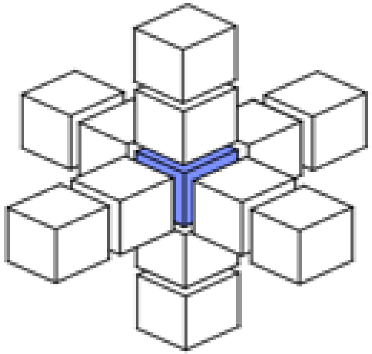
EDGE

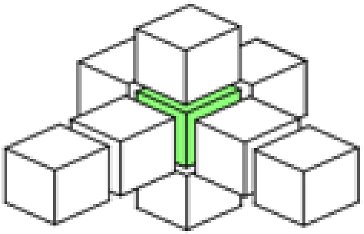
Discontinuous Galerkin Finite Element Method (DG-FEM)

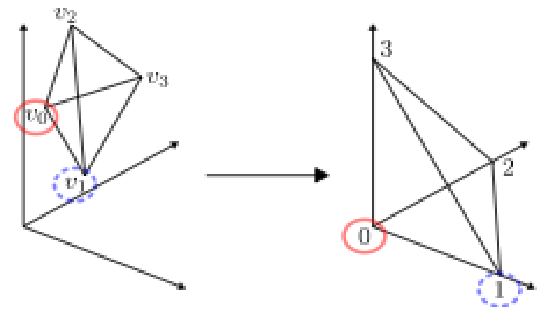
Unstructured tetrahedral meshes

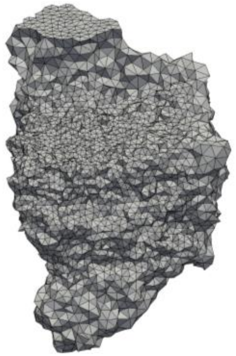
Small matrix kernels in inner loops

Compute bound for higher orders









Boosting Single-Node Performance: Vector Folding

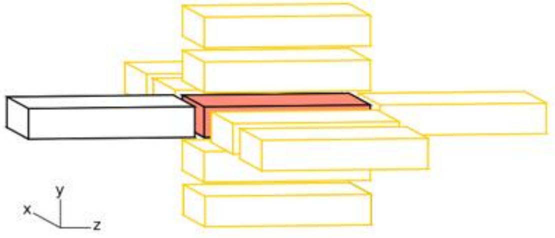
- **Vector folding data layout**
  - **Stores elements in small SIMD-sized multi-dimensional blocks**
  - **Reduces memory bandwidth demands by increasing reuse**
- **YASK (Yet Another Stencil Kernel)**
  - **Open-source (MIT License) framework from Intel**
  - **Inputs scalar stencil code**
  - **Creates optimized kernels using vector folding and other optimizations**

Y*A*S*K

Yet Another Stencil Kernel

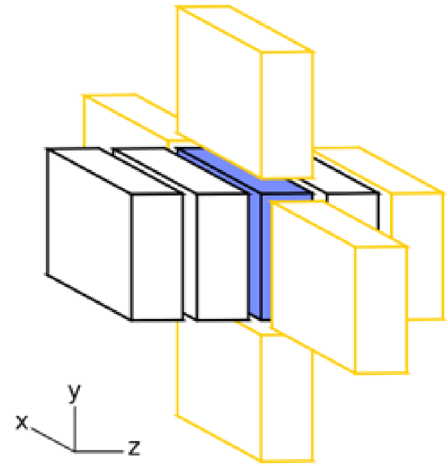
https://github.com/01org/yask

Traditional vectorization



Requires 9 cache loads per SIMD result

Two-dimensional Vector folding

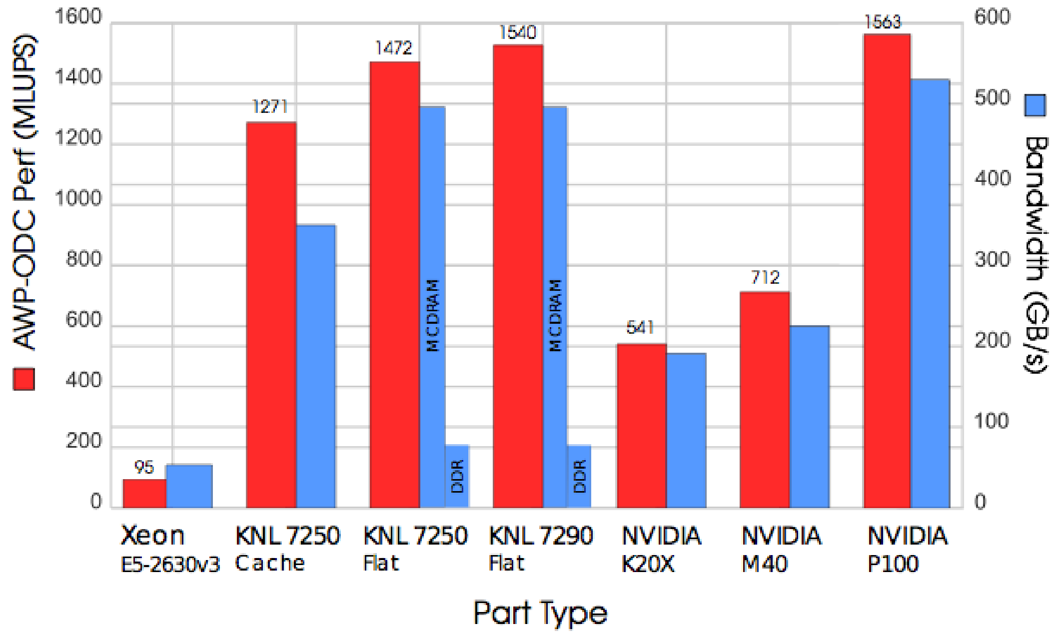


Requires only 5 cache loads

Architecture Comparison

AWP-ODC-OS

- Xeon Phi KNL 7290:
  - 2x speedup over NVIDIA K20X; 97% of NVIDIA Tesla P100 performance
- Memory bandwidth accurately predicts performance of architectures (as measured by STREAM and HPCG-SpMv)

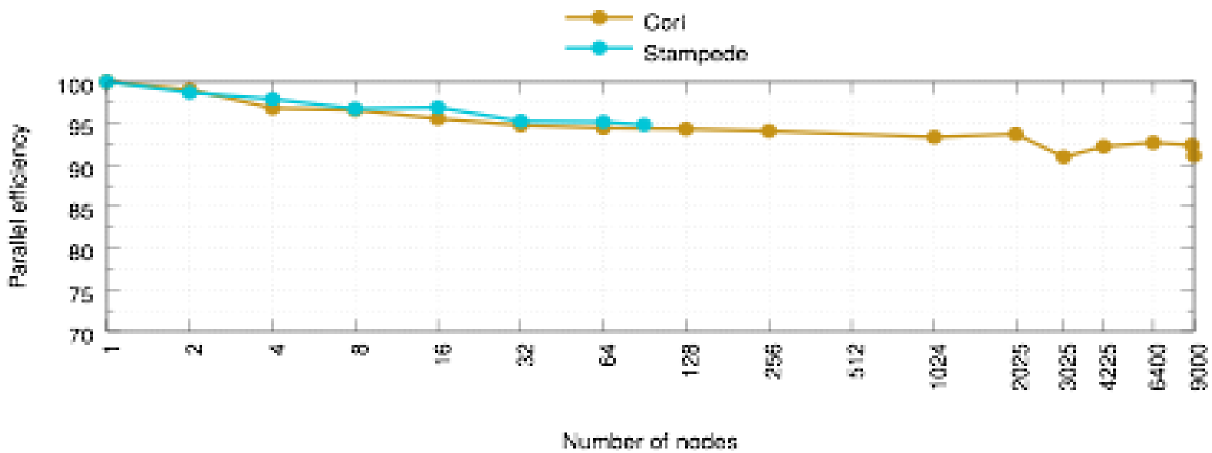


Single node performance comparison of AWP-ODC-OS on a variety of architectures. Also displayed is the bandwidth of each architecture, as measured by a STREAM and HPCG-SpMv [ISC_17_2].

Outperforming 20K GPUs

AWP-ODC-OS

- Weak scaling studies on NERSC Cori Phase II and TACC Stampede Extension
- Parallel efficiency of over 91% from 1 to 9000 nodes (9000 nodes = 612,000 cores)
- Problem size of 512x512x512 per node (14 GB per node)
- Performance on 9000 nodes of Cori equivalent to performance of over 20,000 K20X GPUs at 100% scaling



AWP-ODC-OS weak scaling on Cori Phase II and TACC Stampede. We attain 91% scaling from 1 to 9000 nodes. The problem size required 14GB on each node [ISC_17_2].

EDGE

Fused Simulations

Exploits inter-simulation parallelism:

- Full vector operations, even for sparse matrix operators
- Automatic memory alignment
- Read-only data shared among all runs
- Lower sensitivity to latency (memory & network)

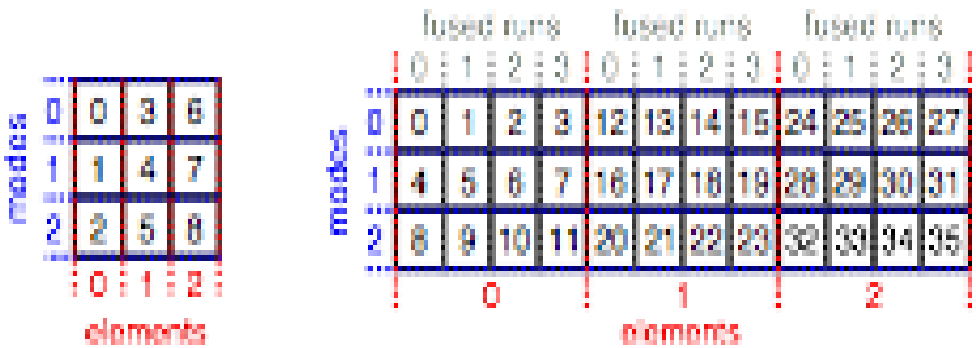


Illustration of the memory layout for fused simulations in EDGE. Shown is a third order configuration for line elements and the advection equation. Left: Single forward simulation, right: 4 fused simulations

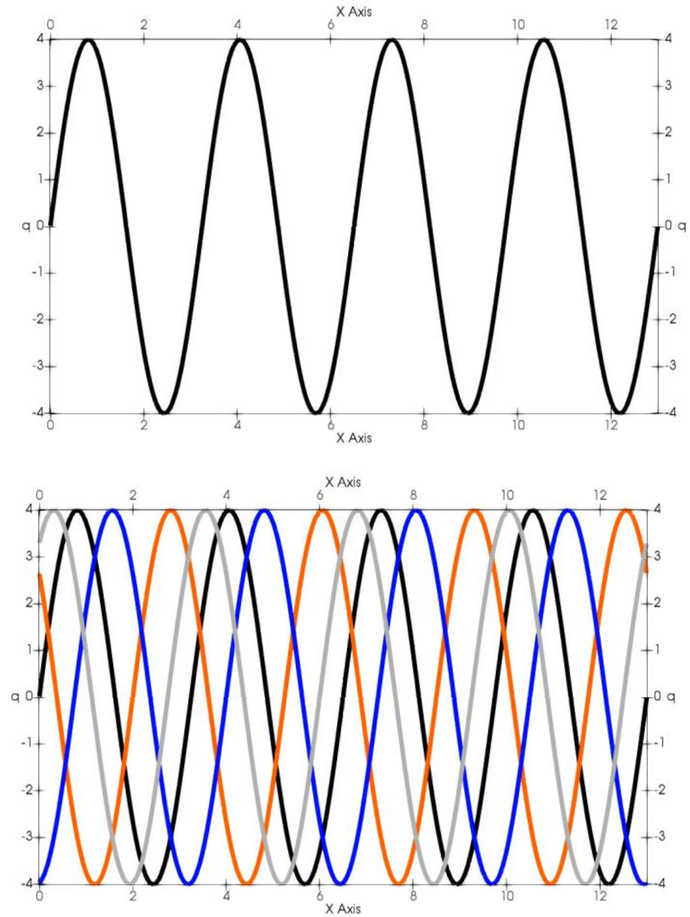
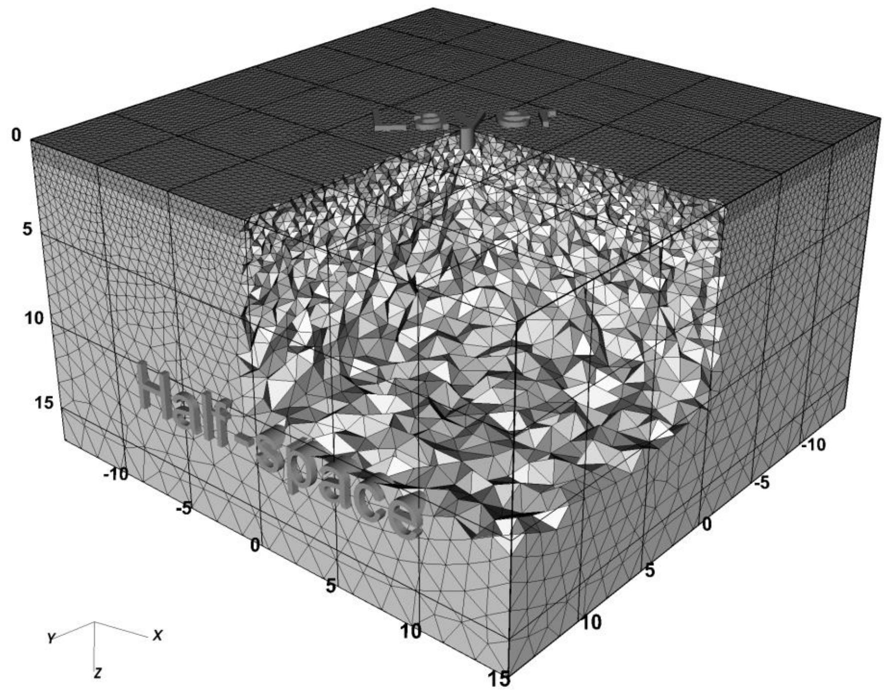


Illustration of fused simulations in EDGE for the advection equation using line elements. Top: Single forward simulation, bottom: 4 fused simulations.

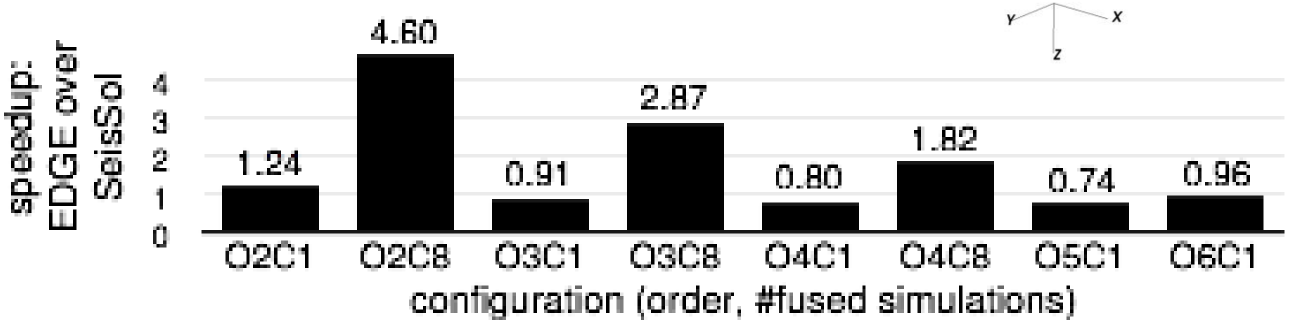
EDGE

Fused Simulations: Performance

- Orders: 2-6 (non-fused), 2-4 (fused)
- Unstructured tetrahedral mesh: 350,264 elements
- Single node of Cori-II (68 core Intel Xeon Phi x200, code-named Knights Landing)
- EDGE vs. SeisSol (GTS, git-tag 201511)
- Speedup: 2-5x



LOH.1 Benchmark: Example mesh and material regions [ISC16_1]

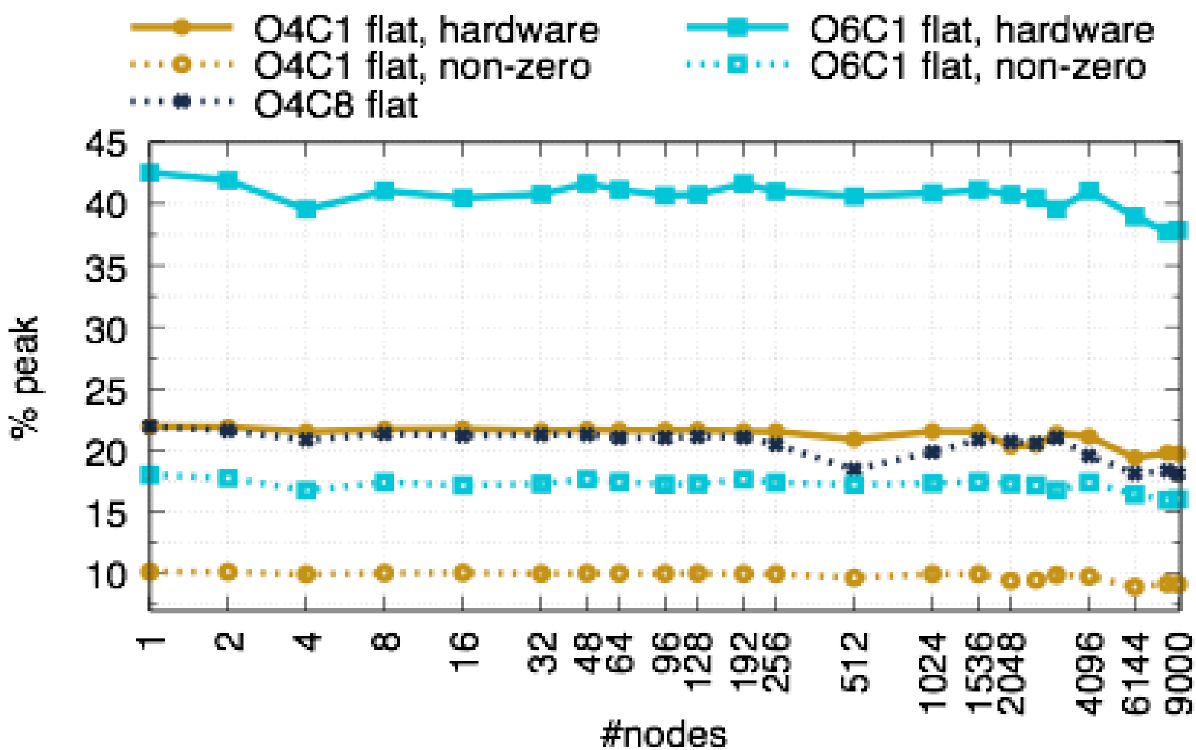


Speedup of EDGE over SeisSol (GTS, git-tag 201511). Convergence rates O2 − O6: single non-fused forward simulations (O2C1-O6C1). Additionally, per-simulation speedups for orders O2−O4 when using EDGE's full capabilities by fusing eight simulations (O2C8-O4C8). [ISC17_1]

Reaching 10+ PFLOPS

EDGE

- Regular cubic mesh, 5 Tets per Cube, 4th order (O4) and 6th order (O6)
- Imitates convergence benchmark
- 276K elements per node
- 1-9000 nodes of Cori-II (9000 nodes = 612,000 cores)
- O6C1 @ 9K nodes: 10.4 PFLOPS (38% of peak)
- O4C8: @ 9K nodes: 5.0 PFLOPS (18% of peak)
- O4C8 vs. O4C1 @ 9K nodes: 2.0x speedup

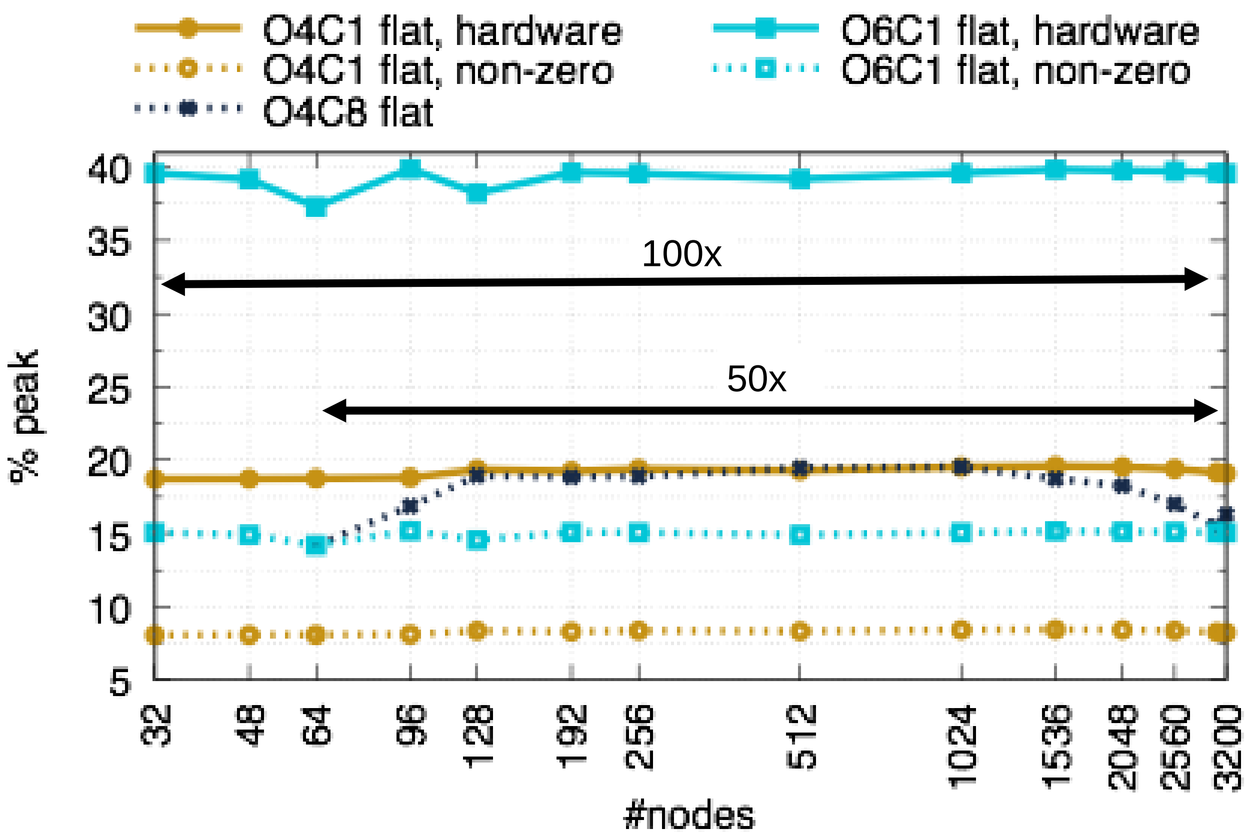


Weak scaling study on Cori-II. Shown are hardware and non-zero peak efficiencies in flat mode. O denotes the order and C the number of fused simulations [ISC17_1].

Strong at the Limit: 50x and 100x

EDGE

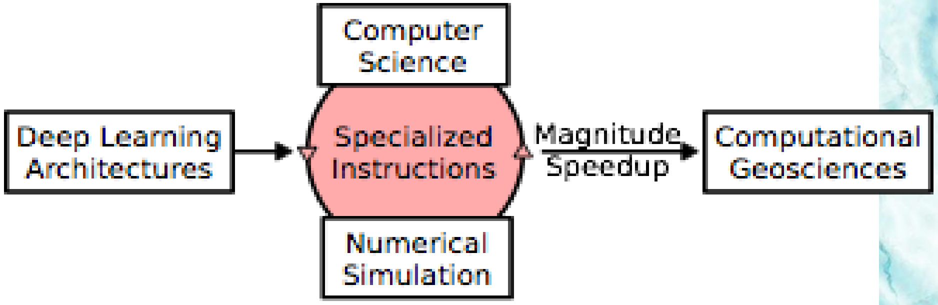
- Unstructured tetrahedral mesh: 172,386,915 elements
- 32-3200 nodes of Theta (64 core Intel Xeon Phi x200, code-named Knights Landing)
- 3200 nodes = 204,800 cores
- O6C1 @ 3.2K nodes: 3.4 PFLOPS (40% of peak)
- O4C8 vs. O4C1 @ 3.2K nodes: 2.0x speedup

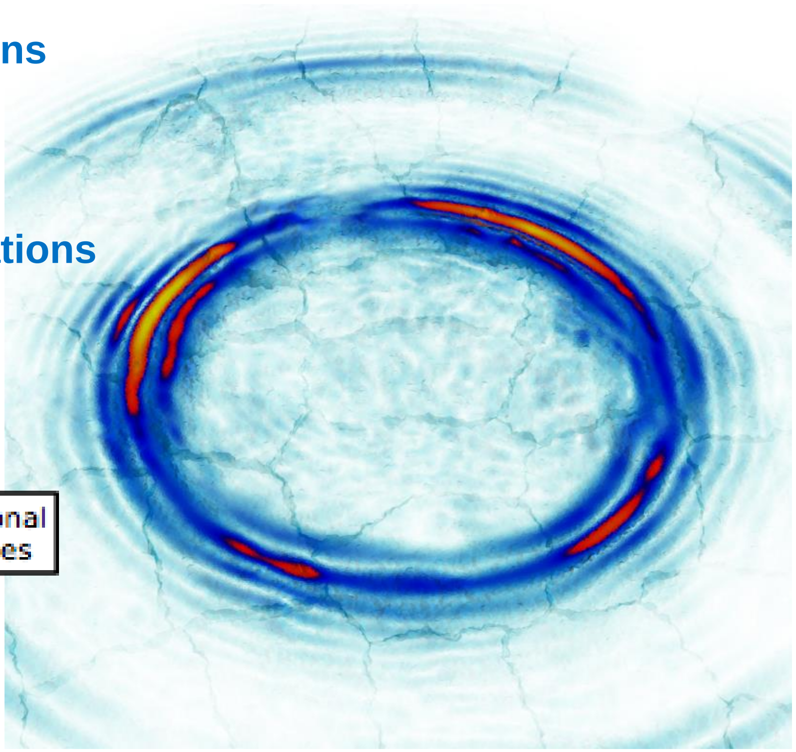


Strong scaling study on Theta. Shown are hardware and non-zero peak efficiencies in flat mode. O denotes the order and C the number of fused simulations [ISC17_1].

Outlook: AI Revolution

- EDGE is a prime candidate for merging traditional HPC and AI
- Work in progress: LIBXSMM for AVX512_4FMAPS (Knights Mill)
- Future work: AVX512_4VNNIW for seismic simulations (Knights Mill)
- Future work: Fused simulations to address high-dimensional parameter spaces (“crunching data”):
  - EDGElearn: (Deep) Learning from seismic simulations
- Future work: LIBXSMM in TensorFlow





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