Parallel Scalability of OpenSees on NeSI HPC for 2D/3D Site Response Analysis

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Parallel Analysis using OpenSees

OpenSees is a finite element analysis platform largely used in structural and geotechnical earthquake engineering.

Two parallel programs have been developed from this platform:

OpenSeesSP

- Master process runs the main interpreter and domain partitioning
- Sub-processes solve individual partitions
- Master process assembles output and moves to next step

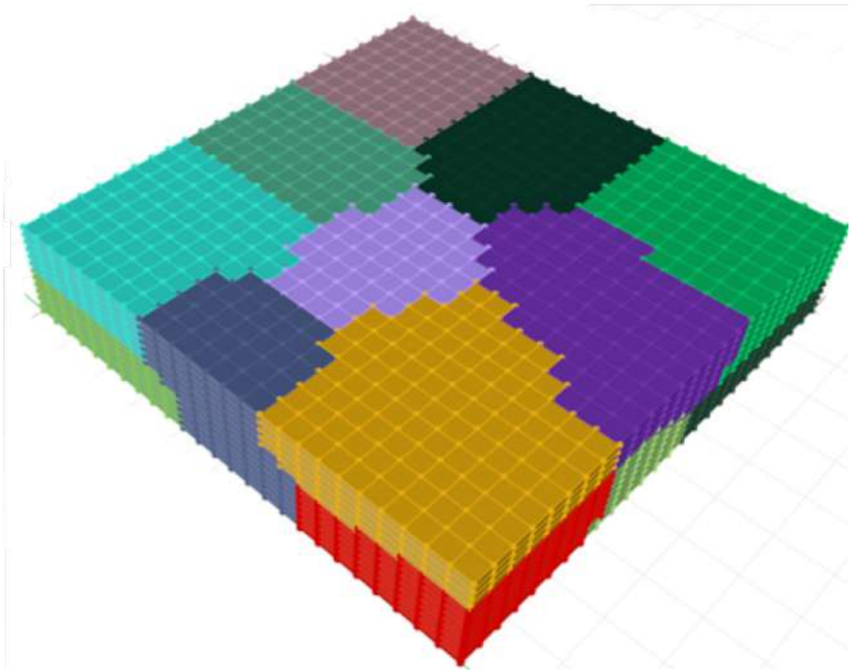
OpenSeesMP

- Each process is explicitly assigned a particular portion of the domain
- Requires pre-partitioning and bespoke model file
- No master process to assemble results during runtime

Models and Analyses

This study considers a linear elastic domain with simple boundary conditions analysed for 1000 steps in free vibration under constant element body forces.

2D and 3D models with **7500, 15000, 30000, 60000, 120000, 2400000, and 480000** elements are examined.



Models and Analyses

All analyses were completed on the **NeSI Mahuika HPC**, which is a Cray CS400 cluster with Intel Xeon Broadwell nodes.

The 2D and 3D models were analysed using both OpenSeesSP and OpenSeesMP with **1, 2, 4, 8, 16, 32, and 64 parallel cores**.

Total execution time was recorded for the purposes of examining the strong and weak parallel scaling behavior of the two programs.

Due to memory demands and the configuration of the Mahuika nodes, it was necessary to run the 32 and 64 core analyses across more than one compute node. All other cases were restricted to a single node.

Strong Parallel Scaling – Amdahl's Law

Strong scaling measures the parallel performance of a program when the size of the problem is held fixed but the number of cores in the parallel analysis is increased.

Amdahl's Law states that the speedup in strong scaling

$$S_s = \frac{1}{1 - p + \frac{p}{n}}$$

Where **n** is the number of cores and **p** is the parallelized portion of the job, with **p + s = 1** where **s** is the serial portion of the job.

Amdahl's law is fit to the strong scaling results to estimate the parallel/serial portion of the OpenSees analyses.

Strong Parallel Scaling Results – 2D

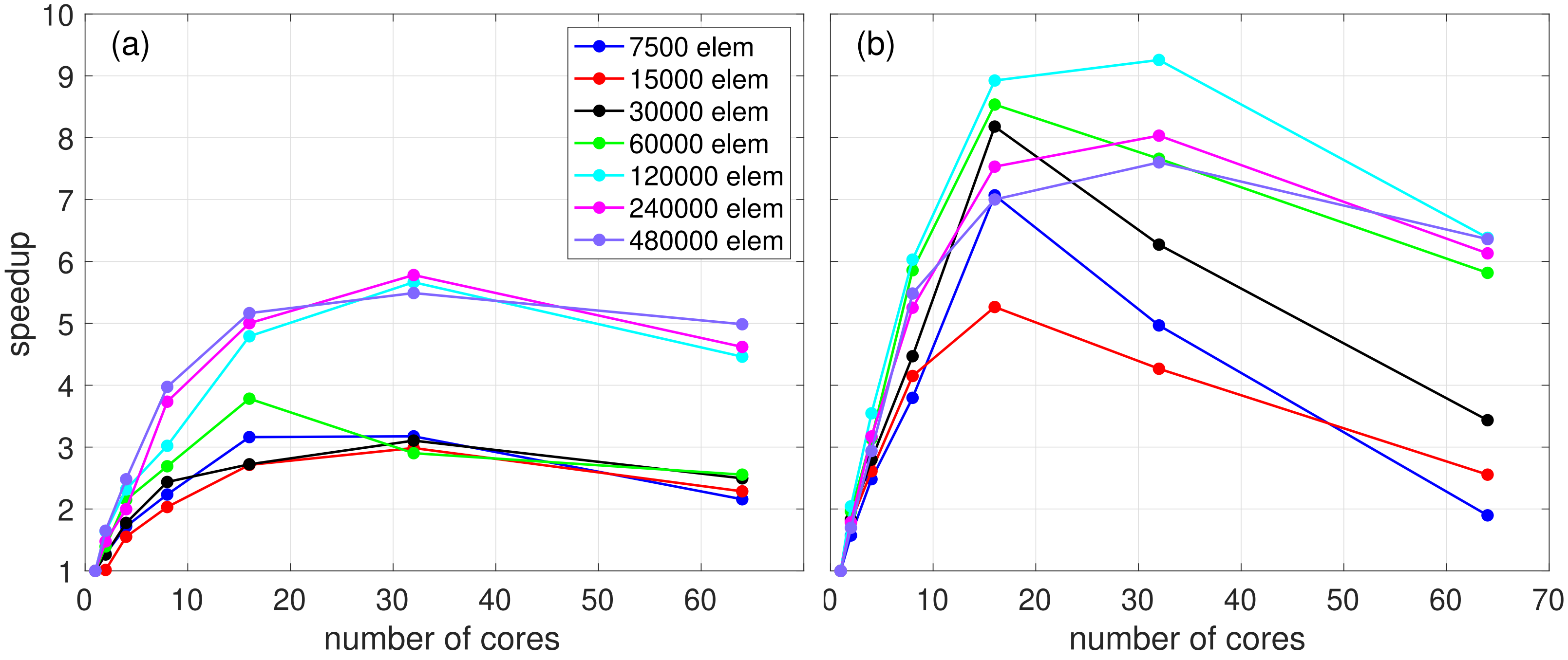
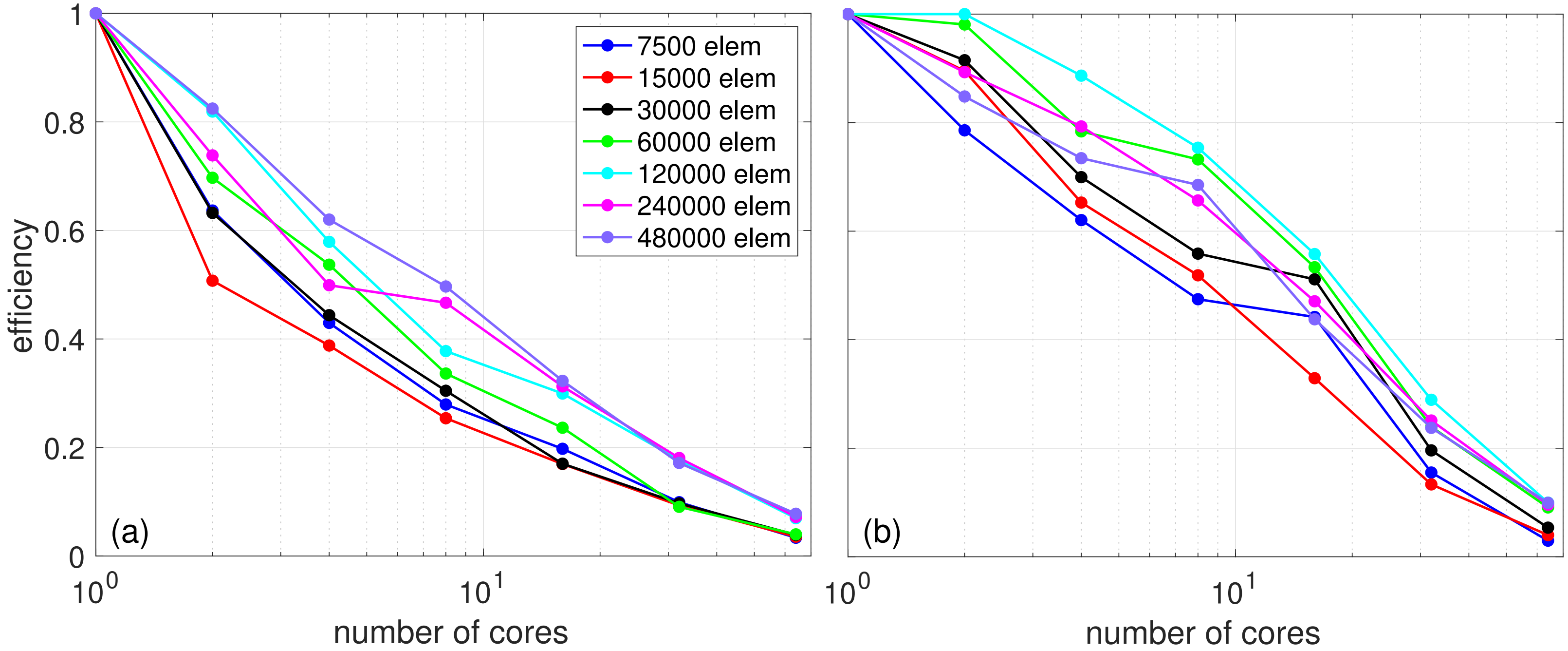


Table 1: The parallelized portion of analysis from fitting Amdahl's law to 2D model results.

Program	7500 ele	15000 ele	30000 ele	60000 ele	120000 ele	240000 ele	480000 ele
OpenSeesSP	0.68	0.62	0.66	0.74	0.82	0.84	0.85
OpenSeesMP	0.87	0.84	0.90	0.92	0.93	0.91	0.90

Strong Parallel Scaling Results – 2D



Strong Parallel Scaling Results – 3D

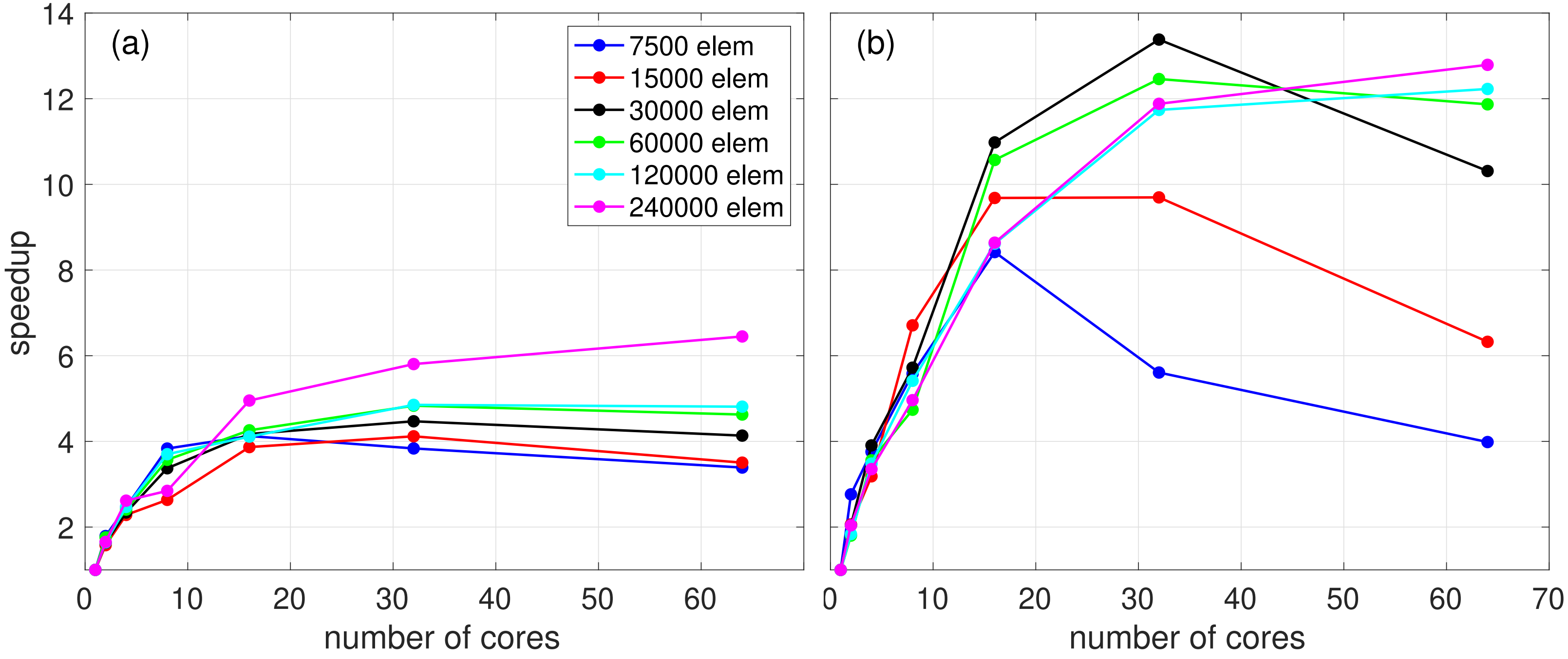
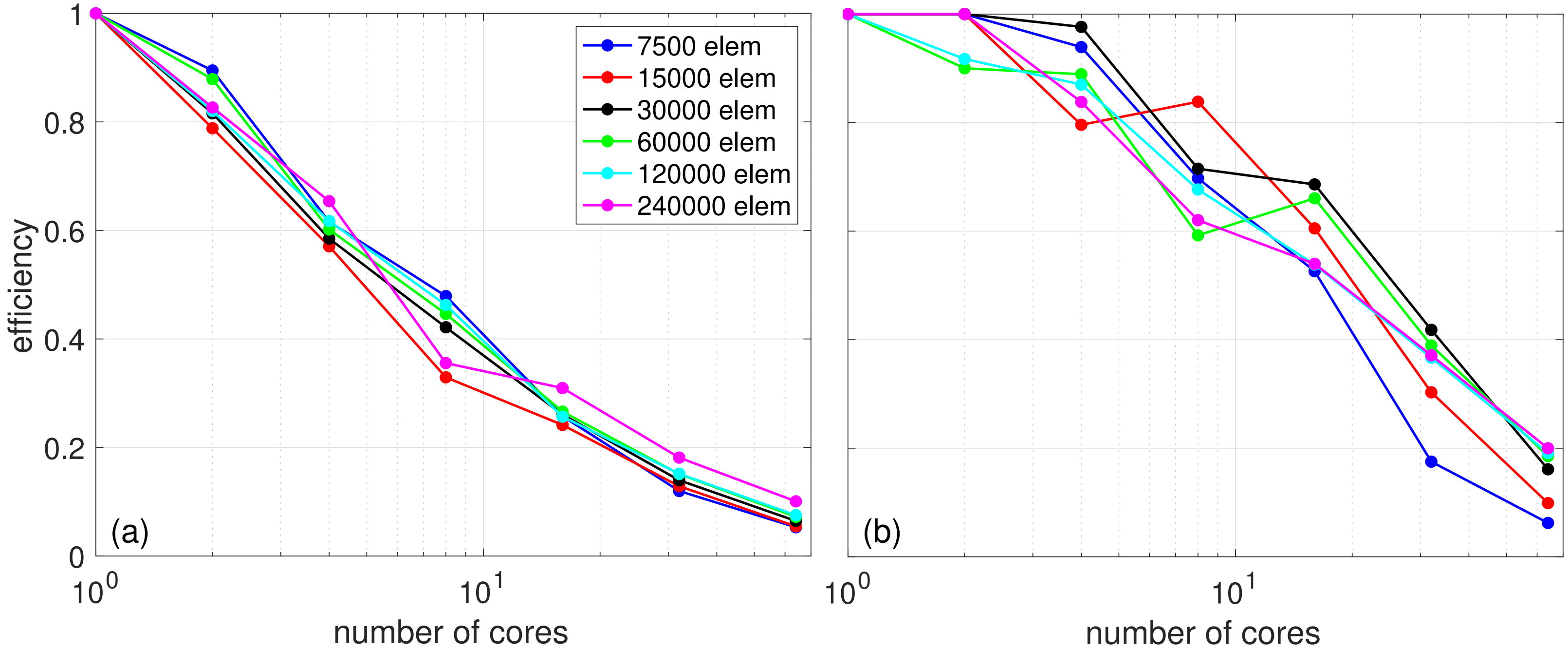


Table 2: The parallelized portion of analysis from fitting Amdahl's law to 3D model results

Program	7500 ele	15000 ele	30000 ele	60000 ele	120000 ele	240000ele
OpenSeesSP	0.77	0.76	0.79	0.81	0.81	0.85
OpenSeesMP	0.86	0.91	0.94	0.94	0.94	0.94

Strong Parallel Scaling Results – 3D



Weak Parallel Scaling – Gustafson’s Law

Weak scaling measures the parallel performance of a program when the size of the problem is increased in proportion to the increase in the number of cores. In this manner the portion of work assigned to each core is constant.

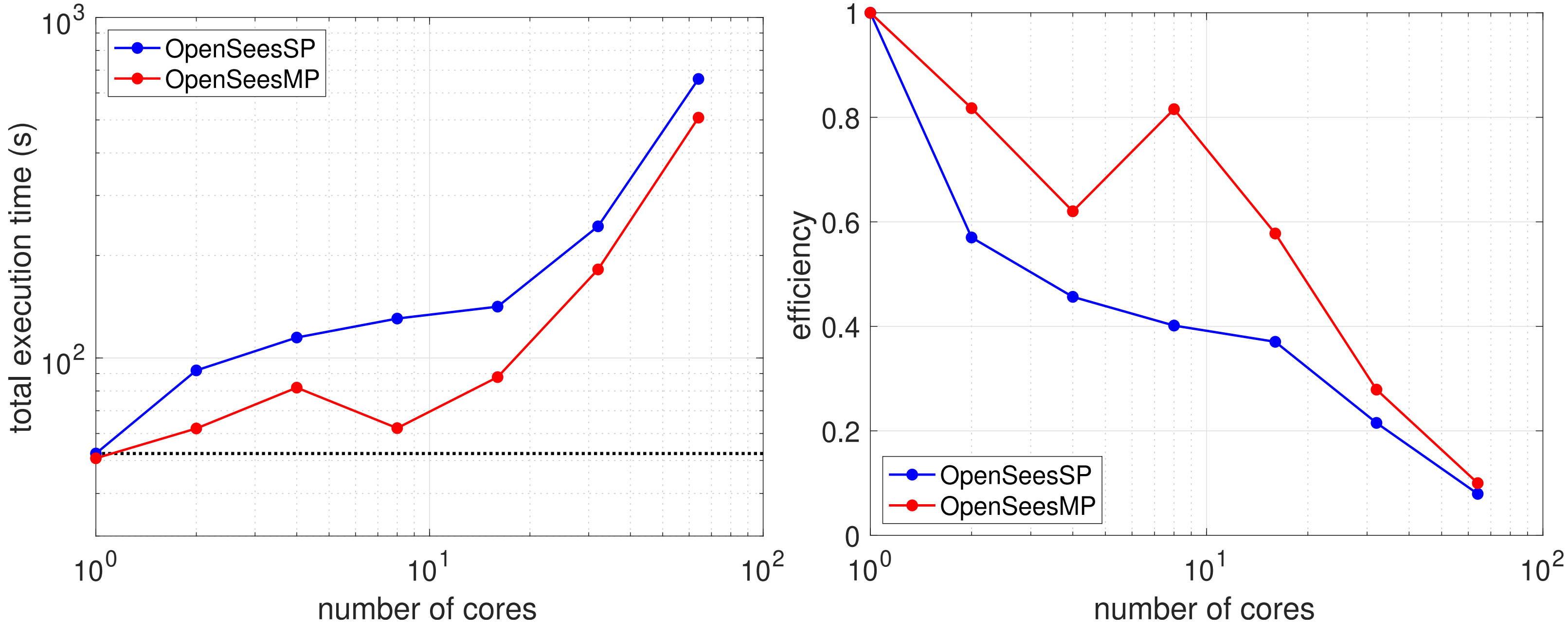
Gustafson’s Law states that the speedup in strong scaling

$$S_w = n + s(1 - n)$$

Where **n** is the number of cores and **s** is the serial portion, with **p + s = 1** where **p** is the parallel portion of the job.

Gustafson’s law is fit to the weak scaling results to estimate the parallel/serial portion of the OpenSees analyses.

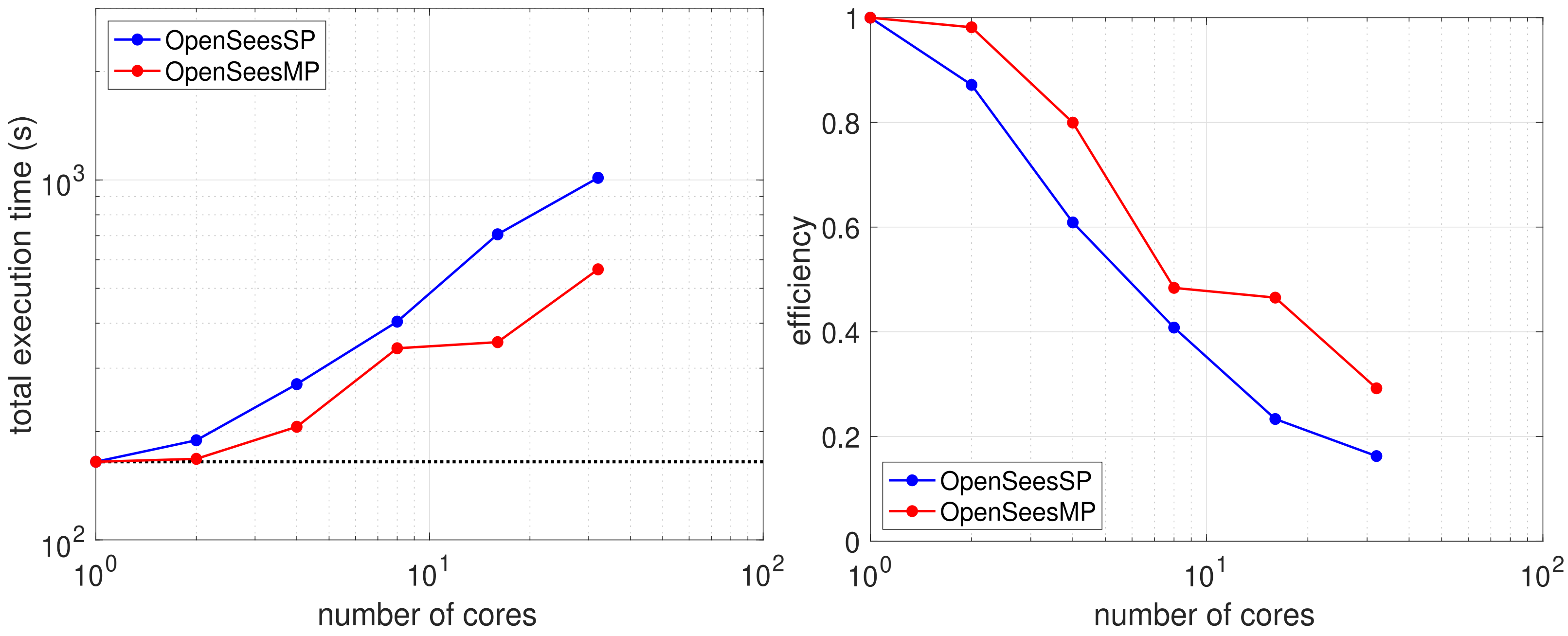
Weak Parallel Scaling Results – 2D



OpenSeesSP: p = 0.83

OpenSeesMP: p = 0.86

Weak Parallel Scaling Results – 3D



OpenSeesSP: p = 0.83

OpenSeesMP: p = 0.93

Miscellaneous Observations

Analysis choices make a bigger impact than parallel analysis approach

Runtimes of 2D model with 7500 elements and 1 process:

- Newton algorithm: 171 s
- Linear algorithm: 90 s
- Linear –factorOnce: 36 s (this is 4.75 times speedup!)

Implicit integrators matter, but not as much

Several implicit integrators were assess (e.g. Newmark, TRBDF2). Modest runtime differences were observed, but no consistent trends.

System-to-system variance is quite high

Runtimes of 2D model with 7500 elements and 4 processes (OpenSeesMP):

- Mahuika HPC: 20.5 s
- iMac (3.6 GHz Intel Core i7): 13.5 s

Questions?

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