

# Pushing the Limits of the Maya Cluster

UMBC REU Site: Interdisciplinary Program in High Performance Computing

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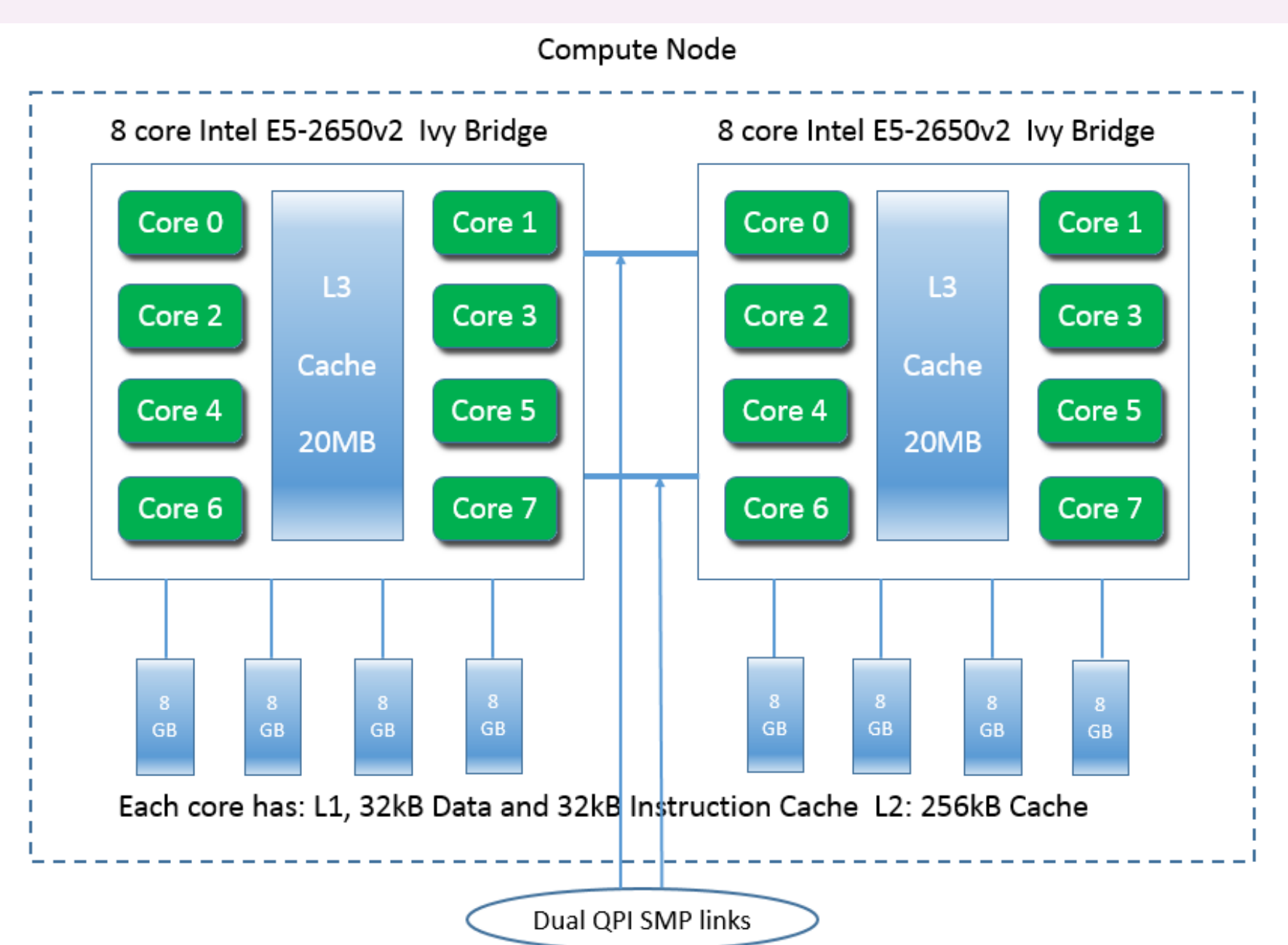
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## Benchmarking

Maya is the 240-node supercomputer in the UMBC High Performance Computing Facility ([www.umbc.edu/hpcf](http://www.umbc.edu/hpcf)).

- The 72 newest nodes have two eight-core Intel E5-2650v2 Ivy Bridge CPUs, making a single node capable of running 16 processes/threads simultaneously.



- The nodes are connected by a high-performance quad-data rate (QDR) InfiniBand interconnect.

⇒ The new hardware requires testing and benchmarking to give insight into its full potential.

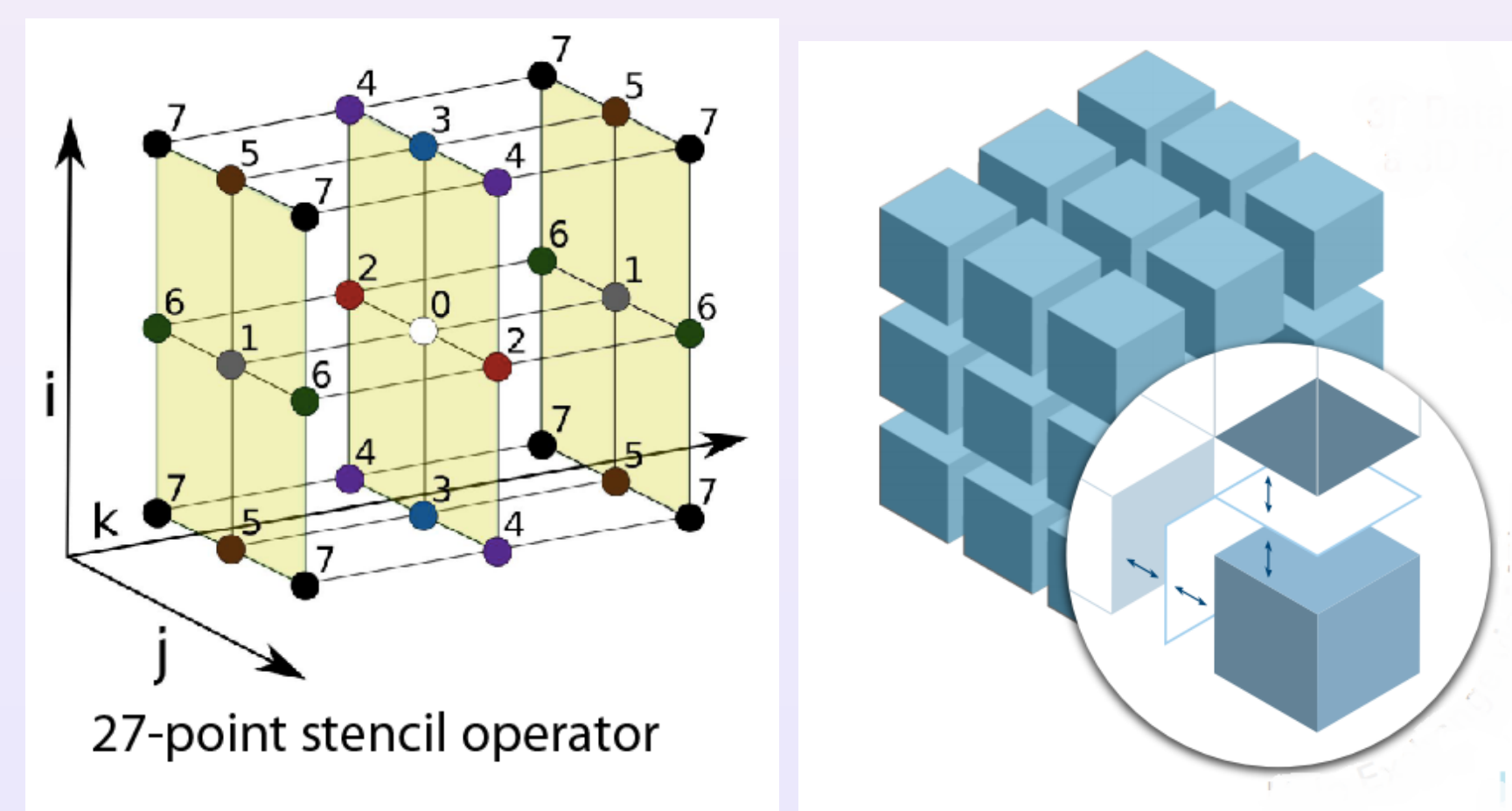
We report here on the High Performance Conjugate Gradient (HPCG) Benchmark developed by Sandia National Laboratories.

## References

- Sandia HPCG Benchmark: <https://software.sandia.gov/hpcg/>
- For complete details and additional tests of maya, see report HPCF-2014-14 at [www.umbc.edu/hpcf](http://www.umbc.edu/hpcf) > Publications.

## HPCG Benchmark

The HPCG benchmark solves the Poisson equation  $-\Delta u = f$  on a three-dimensional domain  $\Omega \subset \mathbb{R}^3$ . A discretization on a global grid with resolution  $N_x \times N_y \times N_z$  with a 27-point stencil at each grid point generates a system of linear equations with a large, sparse, highly structured system matrix. This is more relevant to many applications than the dense system matrix of the LINPACK benchmark.



The benchmark utilizes a preconditioned conjugate gradient method to iteratively solve the system.

## Experimental Design

The HPCG benchmark uses a 3-D grid of  $P = p_x \times p_y \times p_z$  parallel MPI processes. We consider  $P = 1, 8, 64, 512$  in our experiments.

Each process hosts a local subgrid of size  $n_x \times n_y \times n_z$ . Thus,  $N_x = n_x p_x$ ,  $N_y = n_y p_y$ , and  $N_z = n_z p_z$  and the total number of unknowns  $N_x \times N_y \times N_z$  scales with the number of processes.

For  $P = 512$  processes, the global grid ranges from millions to billions of unknowns:

$n_x \times n_y \times n_z$	$N_x \times N_y \times N_z$
$16 \times 16 \times 16$	2,097,152
$32 \times 32 \times 32$	16,777,216
$64 \times 64 \times 64$	134,217,728
$128 \times 128 \times 128$	1,073,741,824

## Results

Observed GFLOP/s for HPCG Revision 2.4 with execution time 60 using the Intel C++ compiler and MVAPICH2. Local subgrid dimensions  $n_x \times n_y \times n_z$  and fixed  $P = 512$  parallel MPI processes ( $N$  nodes with  $p_N$  processes per node) and  $n_t$  OpenMP threads per MPI process. Possible combinations are  $N = 32$  nodes with  $p_N = 16$  processes per node and  $n_t = 1$  thread per process or  $N = 64$  with  $p_N = 8$  and  $n_t = 1, 2$ :

$n_x = n_y = n_z = 16$	$n_t = 1$	$n_t = 2$
$N = 32$ $p_N = 16$	45.58	N/A
$N = 64$ $p_N = 8$	113.50	112.36
$n_x = n_y = n_z = 32$	$n_t = 1$	$n_t = 2$
$N = 32$ $p_N = 16$	170.03	N/A
$N = 64$ $p_N = 8$	209.92	211.84
$n_x = n_y = n_z = 64$	$n_t = 1$	$n_t = 2$
$N = 32$ $p_N = 16$	223.92	N/A
$N = 64$ $p_N = 8$	209.62	238.82
$n_x = n_y = n_z = 128$	$n_t = 1$	$n_t = 2$
$N = 32$ $p_N = 16$	233.98	N/A
$N = 64$ $p_N = 8$	210.94	230.42

- Larger problems allow for better performance, as calculation time dominates communication time.
- Increasing the number of threads per MPI process may increase computational throughput as delays in memory access are masked by process switching.
- Optimal performance is achieved using all 16 cores per node, whether via MPI processes or via OpenMP multi-threading.

## Acknowledgments

- REU Site: [www.umbc.edu/hpcreu](http://www.umbc.edu/hpcreu)
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