Stony Brook University

Comparing OpenMP Implementations With Applications Across A64FX Platforms

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Exascal lab
Exascale Programming Models Laboratory

Motivation

- A64FX processor is relatively new -- limited studies on it
- Most reports established reproducibility of experiments compared to Fugaku-based reports
- OpenMP: had not been studied on the A64FX processor to our knowledge
- Opportunity to cover new ground and show subset of its behavior on the A64FX processor and how compilers may influence that performance

Agenda

- Ookami and Fugaku
- A64FX Processor
- Applications
  - PENNANT, SWIM, Minimod
  - Results of experiments following each application
    - Timings
    - Relative speedups
    - Insights from profiling
- Conclusions and future work

What is Ookami (“baby Fugaku”)?

- Test bed for NSF and US researchers
- First open deployment of the Fujitsu A64FX Post-K processor in US
  - ARM64 + SVE (scalable vector extensions)
  - High-bandwidth (HBM2) memory
- Possibly revolutionary new path to exascale emphasizing scientific productivity, performance, and energy efficiency
- New processor & very high-bandwidth memory promise performance of GPUs with programmability of CPUs

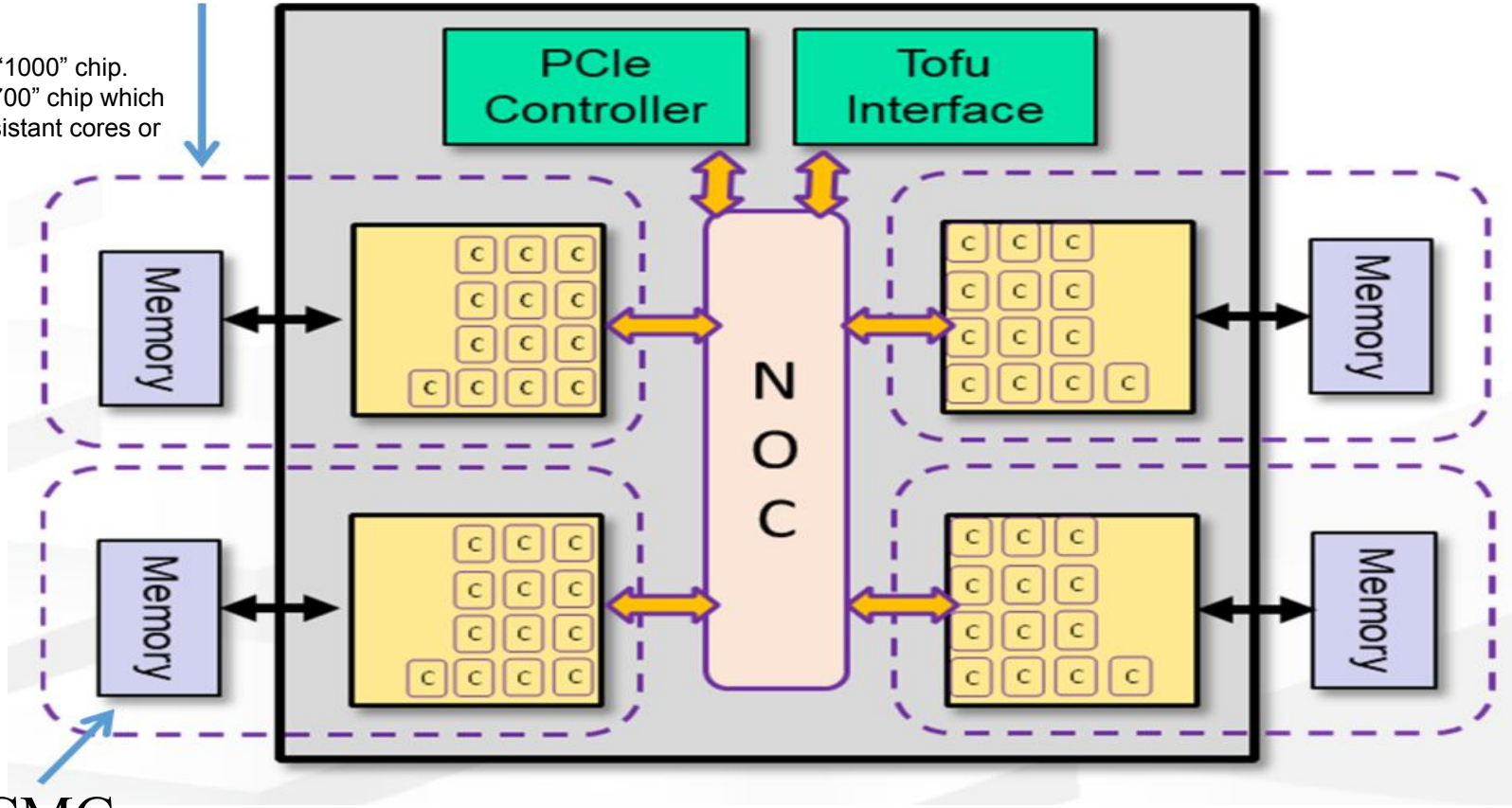
Ookami (狼) means wolf in Japanese --- an homage both to the origin of the processor and the Stony Brook seawolf mascot.

Ookami and Fugaku

- Ookami
  - First A64FX cluster to exist outside of Japan (@ Stony Brook University)
  - **174 A64FX nodes**, Intel Skylake, ThunderX2, AMD Milan nodes for other purposes
  - **FX700 chip (48 cores, 4 Core Memory groups/CMG's)**
- Fugaku
  - Current #1 on Top500
  - Almost 160,000 A64FX Nodes
  - **FX1000 chip (48 + extra cores for OS communication, 4 CMG's)**

A64FX NUMA node architecture

Diagram is of the “1000” chip. Ookami has the “700” chip which does not have assistant cores or the Tofu interface.



CMG – core memory group

http://www.jicfus.jp/jp/wp-content/uploads/2018/11/msato-190109.pdf

Compilers and flags used in our experiments

	Versions	
Compiler Family	**Fugaku**	**Ookami**
ARM	-	20.3
Cray	-	10.0.1
Fujitsu	4.3.0a	-
GCC	8.3.1, 10.2.1	8.3.1, 10.2.1, 11.0.0
LLVM	11.0.0	11.0.0, 12.0.0

Compiler	Flags
Cray	`-homp -hvector3 -hthread3`
GCC	`-mcpu=a64fx` `-Ofast -fopenmp`
LLVM	`-mcpu=a64fx` `-Ofast -fopenmp`
Fujitsu-Traditional	`-Nnoclang -Nlibomp -O3` `-KSVE,fast,openmp,ARMV8_2_A`

Fujitsu-LLVM	`-Nclang -Nlibomp -Ofast`
	`-Kfast,openmp`
	`-mcpu=a64fx+sve`

Experiment breakdown

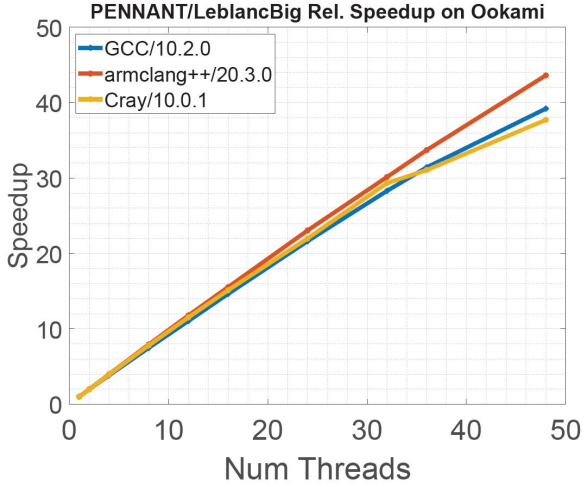
- Relying on intra-node/OpenMP-only communication for experiments
- Threads bound to cores
  - Evenly divided among CMGs
  - Use minimum number of CMGs needed for thread count
- Run application 5 times on each thread value and take arithmetic mean
- Performed for each of the “best-in-class” compilers

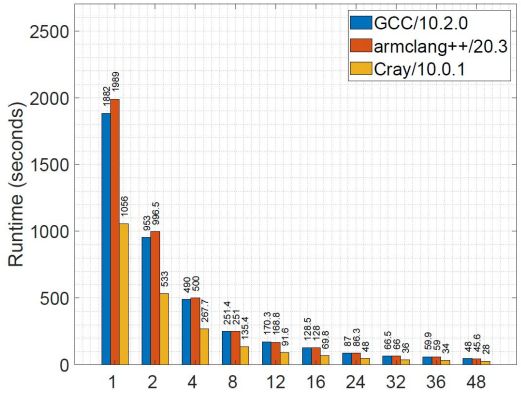
PENNANT

- Mesh physics application developed by LANL
  - Studies performance of unstructured physics
- Hybrid MPI/OpenMP application (static loop scheduling)
- Advanced architecture research dominated by pointer chasing and irregular memory accesses
  - Also features optimizations for SIMD and memory locality
- Our study: Dealing with Sedov and Leblanc meshes: structured, with square zones

PENNANT on Ookami - LeblancBig input

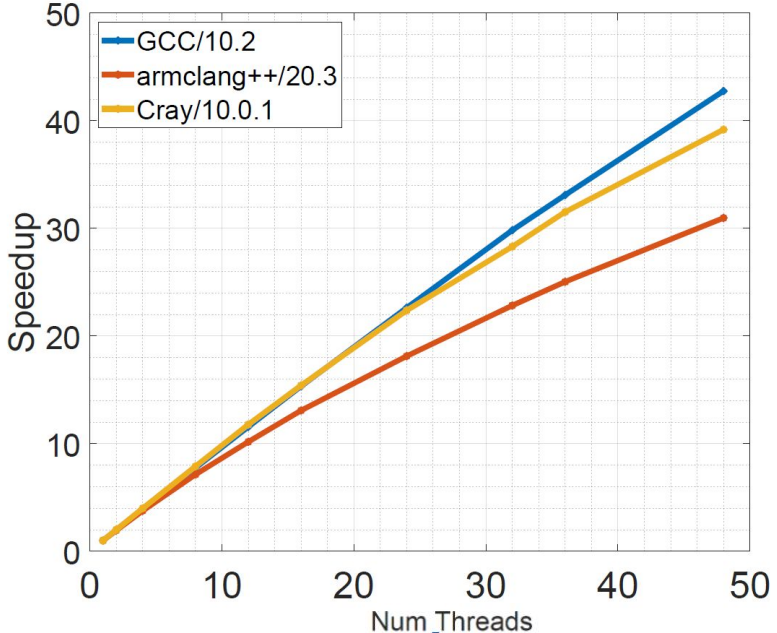
- ARM compiler achieves the most linear speedup here
- Cray compiler: use of SVE maximizes bandwidth use.
  - Leads to lesser speedup at higher thread values
  - Found in analysis of generated assembly code between each compiler

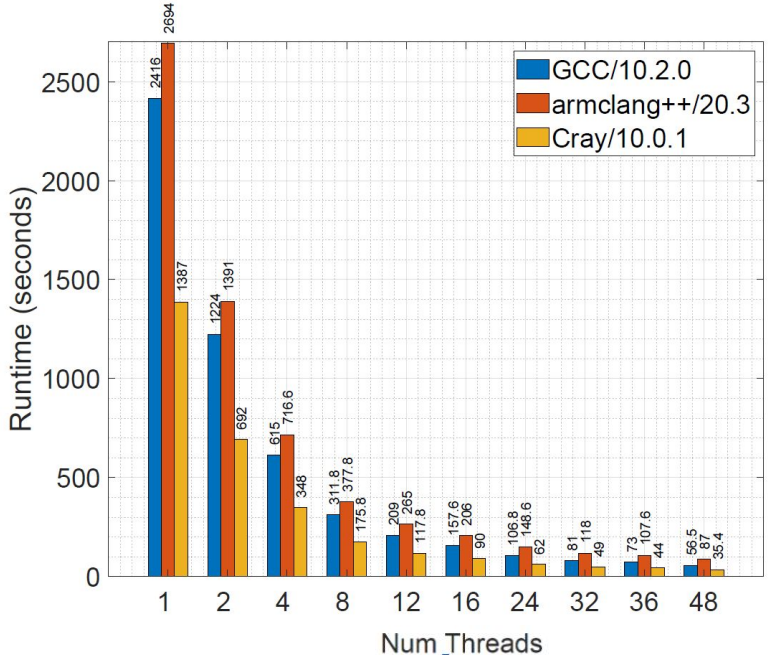




PENNANT on Ookami - SedovBig input

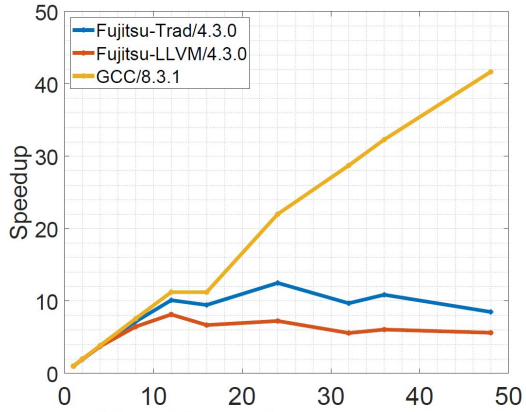
- The “SedovBig” mesh is mildly larger than that of the “LeblancBig” input (540x540 compared to 160x1440)
  - Left chart: Relative Speedup; Right char: Runtime of “best in class” compilers on Ookami as of 01/2021
  - Here armclang has worse speedup as well as performance

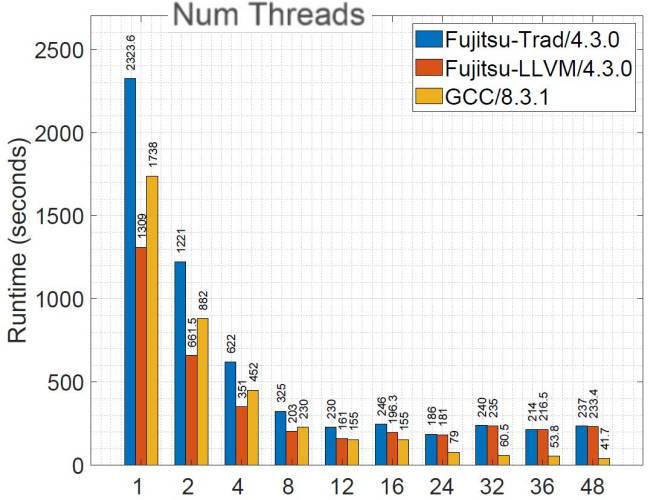




PENNANT on Fugaku - LeblancBig input

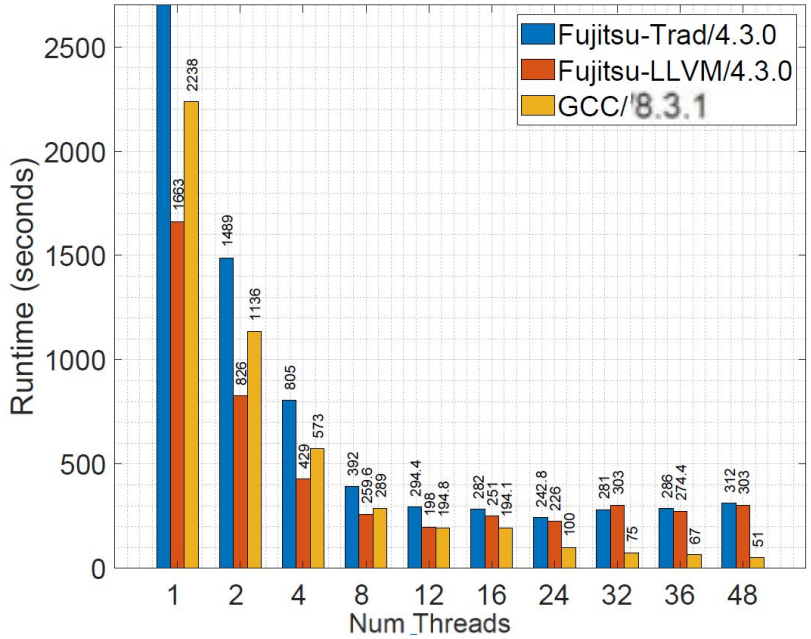
- Fujitsu Compilers: Smaller relative speedup after saturating 2+CMG's.
- GCC: maintains similar performance
  - Deviates greatly from Fujitsu performance as more OpenMP threads requested
- PENNANT is NUMA-aware
- Profiling: traditional Fujitsu backend takes longer, but executes a higher amount of GFLOPS than LLVM backend

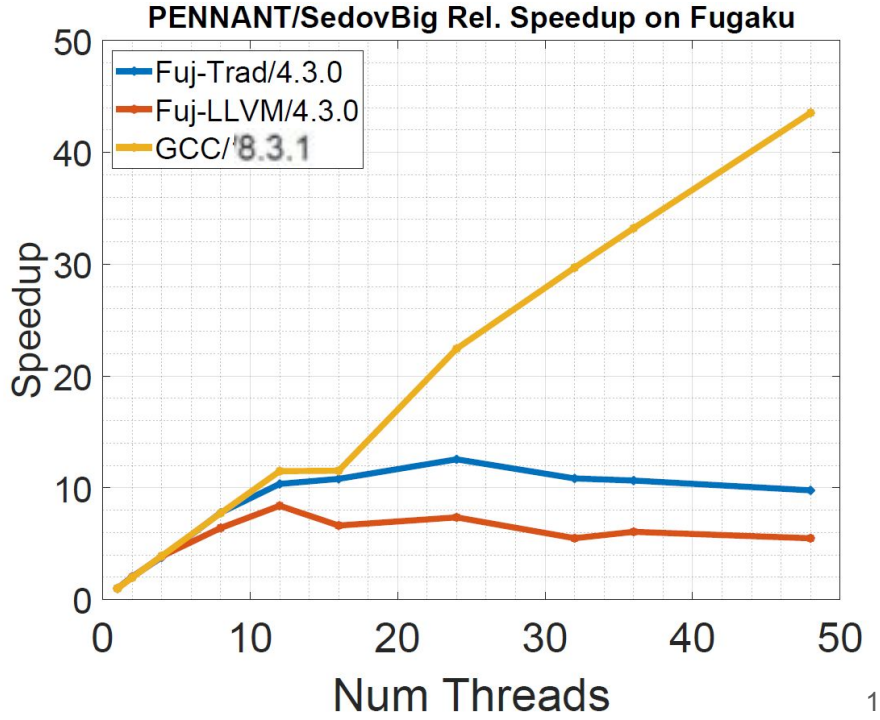




PENNANT on Fugaku - SedovBig input

- Runtime trends are more defined with larger meshes (e.g. SedovBig), though the speedup trends stay consistent.



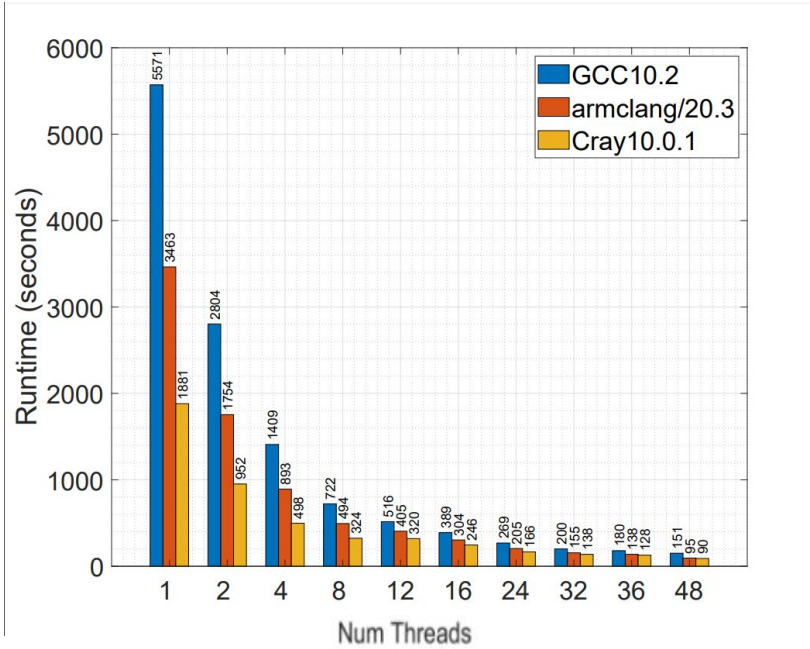


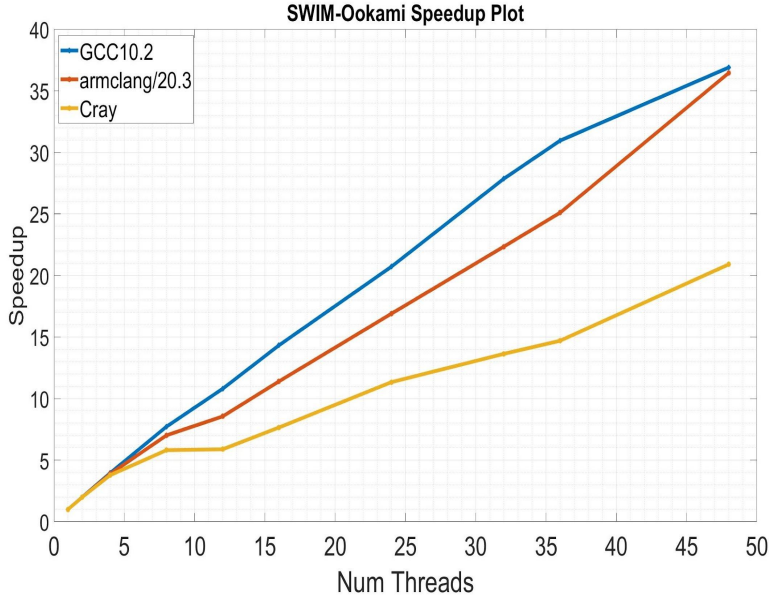
SWIM

- Weather-prediction modeling, solving the shallow-water equations using finite difference methods. Tracks FP speed, bandwidth, and cache characteristics
- OpenMP and Fortran-based benchmark
- Testing with Ookami compilers:
  - armflang (arm compiler/20.3 (based on LLVM 9.0.1))
  - armgfortran (arm compiler/20.3 (it is gcc 9.3.0))
  - Crayftn (10.0.1)
- “Ref” problem size (7701 by 7701 matrix running 3000 iterations)

SWIM on Ookami

- The Cray compiler obtained the lowest speedup but the fastest runtime performance.
- It is generally more efficient on the A64FX processor than the armclang and GCC compilers.
  - Likely due to superior use of SVE





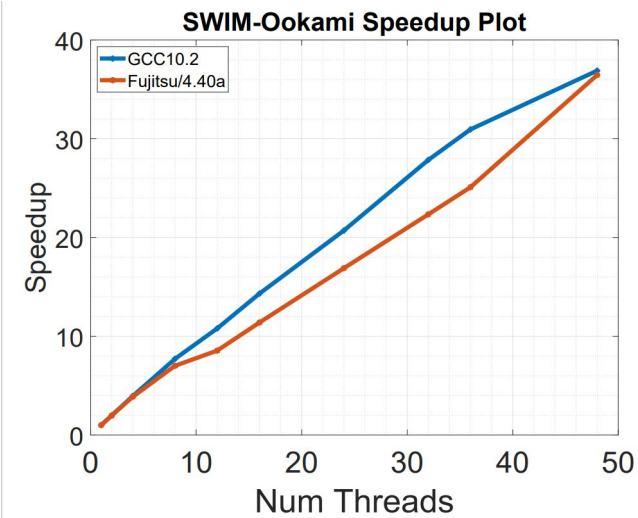
SWIM on Fugaku

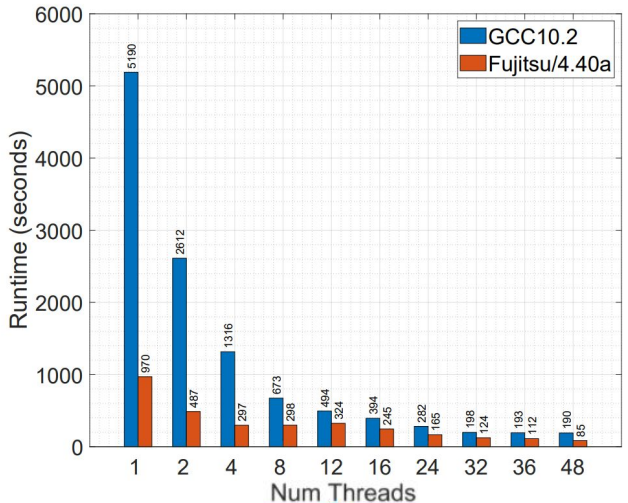
The Fujitsu compiler obtains performance superior to the GNU compiler.

GNU compiler seems to have a greater speed up than the Fujitsu compiler. 36 threads achieve a 32x speed-up over 1 thread. The Fujitsu compiler only obtained 25x speed up with 36 threads over 1 thread. The Fugaku-based runs show a drop in relative speedup starting at 8 OpenMP threads before leveling out at 12 threads. It could be explained by the insufficient optimization of Fujitsu compiler targeting OpenMP applications.

NUMA optimization critical for Fujitsu compiler performance:

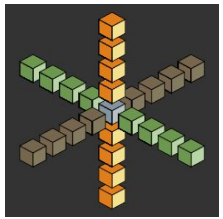
- XOS_MMM_L_PAGING_POLICY=demand:demand:demand for multiple CMGs





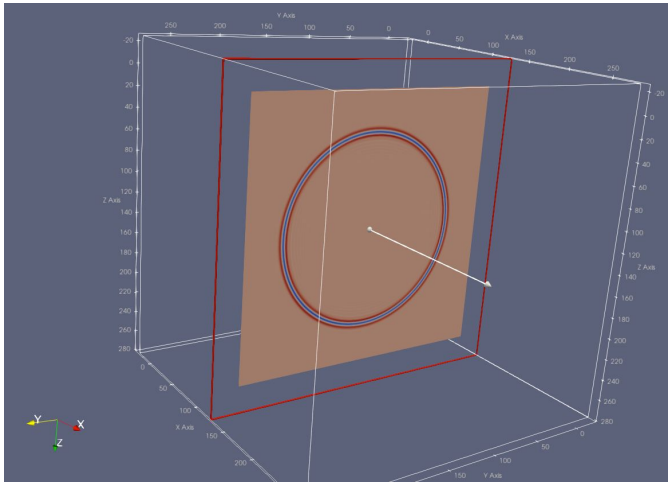
Minimod: Geophysics Exploration

- Wave equation important to many geophysics applications
- One simple solution method is finite difference (FD); involves stencil computation



$$\frac{1}{v_p^2}\frac{\partial^2 p(\mathbf{x},t)}{\partial t^2} - \nabla^2 p(\mathbf{x},t) = f(\mathbf{x},t),$$

- *Minimod*: wave propagation mini-app developed by TotalEnergies
  - Designed to test new and emerging programming models and hardware
  - Contains OpenMP loop-based and task-based implementations

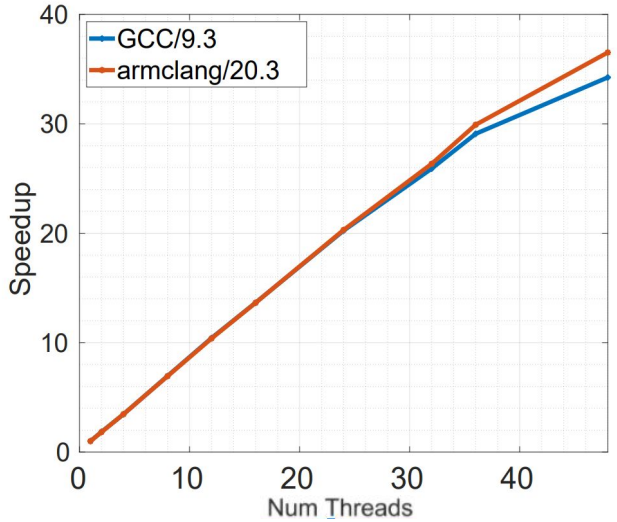


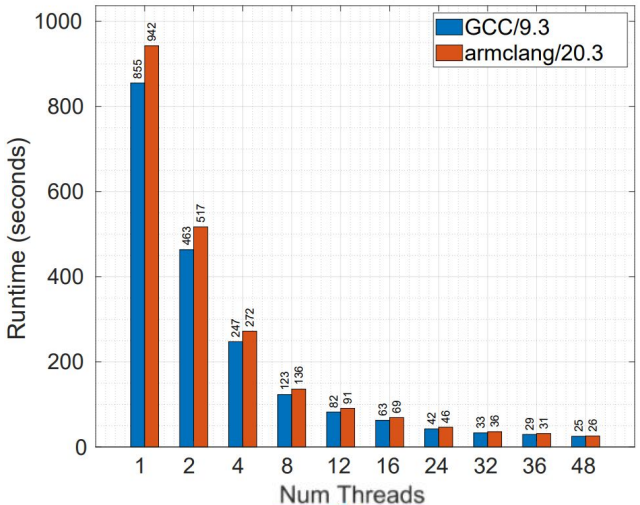
Numerical validation

arXiv:2007.06048 [cs.DC]

Minimod on Ookami - Loop-XY

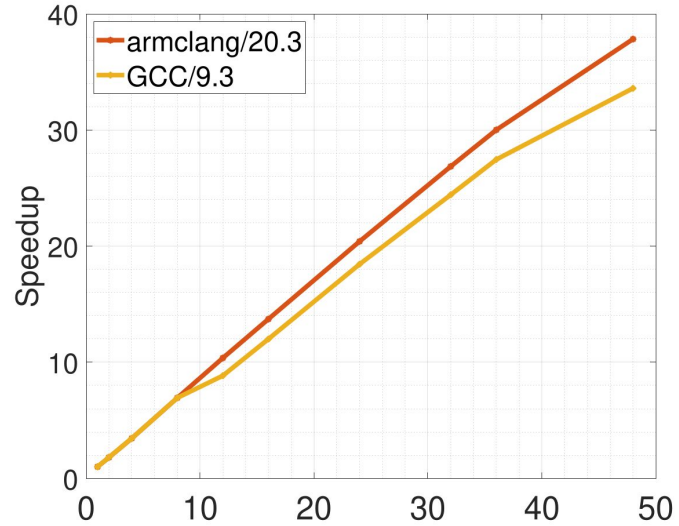
- Speedup of Loop-XY variant is shown.
- The Cray compiler fails to compile this code, resulting in an internal compiler error
- GCC achieves better absolute performance at smaller thread counts than armclang
- At large thread counts, absolute performance is similar between the two compilers; armclang has slightly better speedup

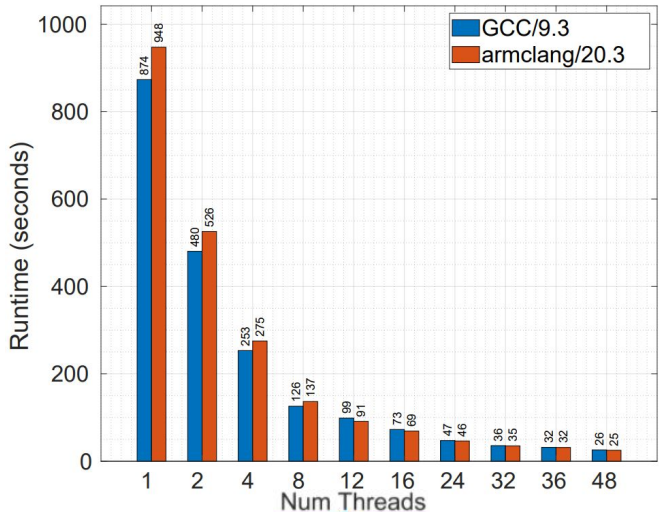




Minimod on Ookami - Tasks-XY

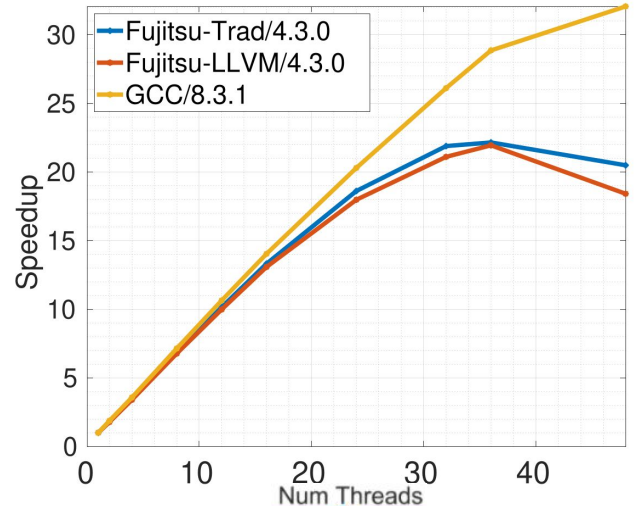
- Speedup of tasks-xy variant is shown.
- Trends are similar to the Loop-XY case.
- Profiling: application (in both configurations) spends almost the entire time in OpenMP regions and is highly memory bound (~80% stalled cycles)
  - Expected behavior for a stencil application

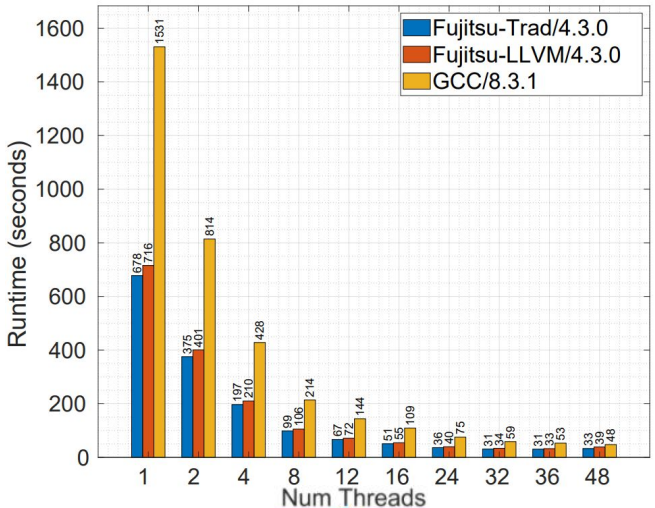




Minimod on Fugaku - Loop-XY

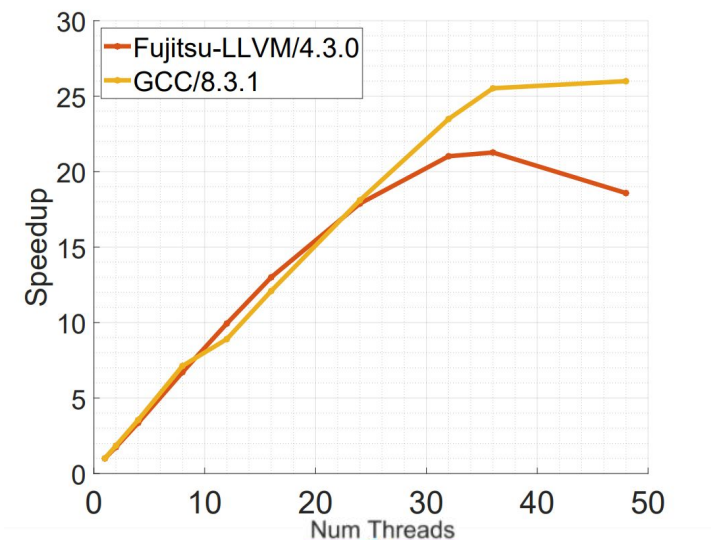
- Speedup of loop-xy variant is shown
- GCC has very poor absolute performance at smaller thread counts, but achieves better scaling
  - Likely due to lack of A64FX/SVE support in GCC 8
- Traditional and LLVM backends have similar performance
- Absolute performance of all compilers is similar at 48 threads

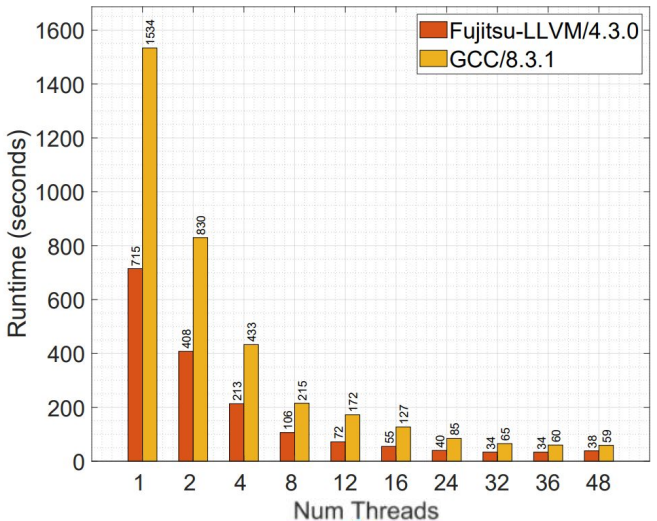




Minimod on Fugaku - Tasks-XY

- Fujitsu compiler (trad mode) fails to run task-based variant due to lack of task dependency support
- Trends for other compilers are similar to the Loop-xy variant





Conclusions and future work

- We evaluated three benchmark applications with different compilers across two A64FX platforms
- In general, Fujitsu and Cray compilers show the best performance on this platform
  - GCC versions used here don't support A64FX/SVE -- the latest GCC has support
  - Scaling issue seen in some Fujitsu compiler experiments
    - Perhaps due to issues with NUMA awareness
  - Cray compiler fails to compile/run some applications (e.g., Minimod)
- Future work
  - On Pennant/SWIM: Analysis of different inputs and mesh types (structured versus unstructured/ zone shapes)
  - On Minimod: Task-based parallelism via OpenMP Tasks, and MPI parallelism
  - Applications featuring other OpenMP directives (data-sharing attributes, SIMD clauses, etc.)

Acknowledgements

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Thank you!

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