A Study of Cross-Platform, Cross-Compiler Performance and Portability

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  - GenASiS
  - su3
- How to get more efficient compilers?
  - Three (short) stories of application problems and better compilers
- Conclusions

Motivation

- Past works have focused primarily on the performance and portability of codes across differing hardware architectures
- Performance portability is also required between compilers on the same architecture
- Explore performance portability using widely available benchmarks and mini-apps
- Provide feedback to vendors on issues identified

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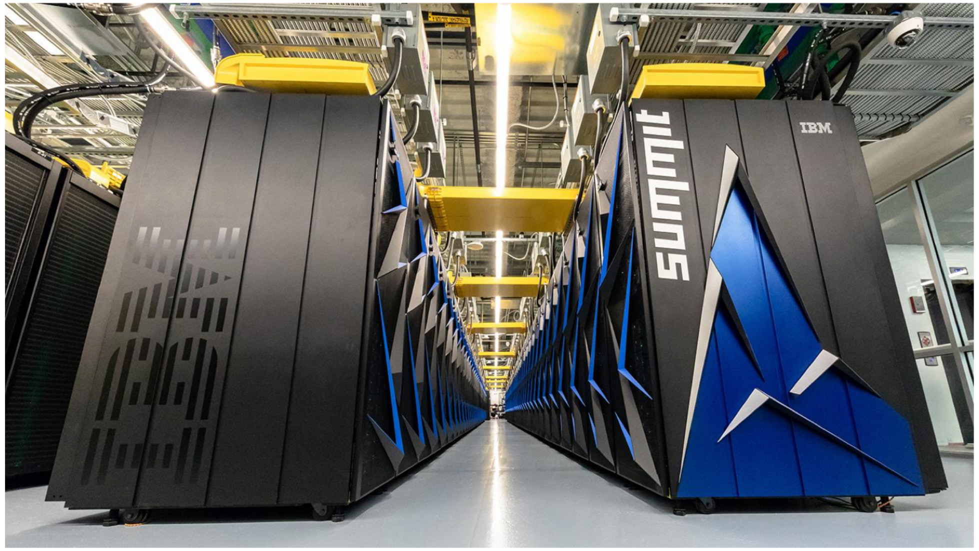
Benchmarks & Mini-applications

Benchmarks & Mini-Apps

- SPEC ACCEL (**S**tandard **P**erformance **E**valuation **C**orporation **Accel**erator suite)
  - Collection of computationally intensive parallel applications in C and Fortran
  - Includes OpenACC, OpenMP target offload, and OpenCL versions
- GenASiS (**Gen**eral **A**strophysics **Si**mulation **S**ystem)
  - A simulation system (a collection of solvers, manifolds, physics) for astrophysics simulation
  - A subdivision, `GenASiS Basics`, contains simplified proxy-applications
- su3
  - mini-application extracted from MILC (Lattice QCD code)
  - matrix-matrix multiply with complex numbers

Experimental Setup: SPEC ACCEL

- SPEC ACCEL (https://www.spec.org/accel)
  - Three benchmark sets: OpenCL, OpenACC, and OpenMP
    - Here we focus on OpenACC and OpenMP sets
    - ACC: contains OpenACC ports
    - OMP: contains OpenMP ports
  - Consists of 15 benchmarks in a wide range of domains: thermodynamics, molecular dynamics, image processing, and more!
    - 7 in C; 6 in Fortran; 2 use C & Fortran
- Target system: Summit
  - ACC experiments:
    - PGI 20.1, GCC 9.2.0
  - OMP experiments:
    - XL 16.1.1 PTF8, GCC 9.2.0, LLVM 11.0.0-rc1 (C-only)
  - Single node jobs offloading to a single NVIDIA V100 GPU



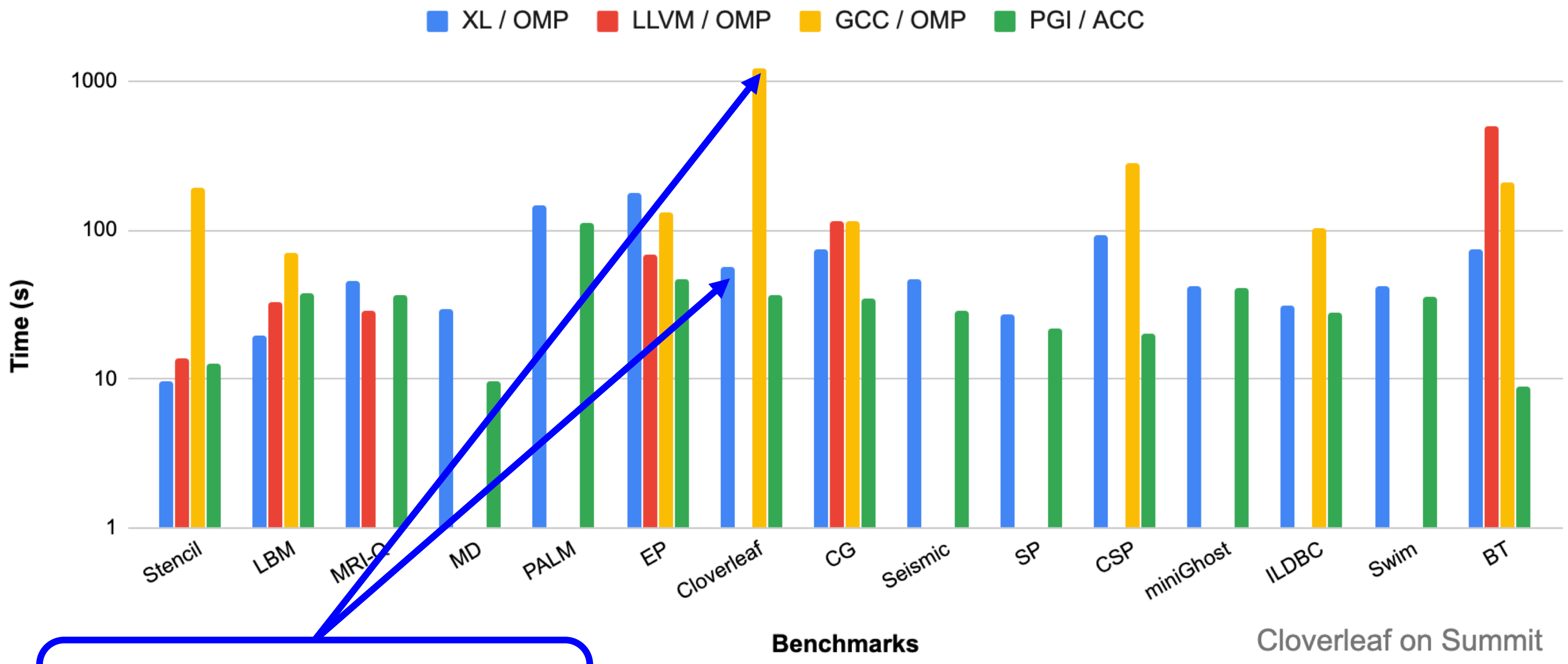
Summit supercomputer (Source: ORNL)

Results: SPEC ACCEL

- XL compiler and PGI compiler can compile all benchmarks
  - Improvement over previous XL versions
- GCC support can compile 11 OpenACC and all OpenMP benchmarks
  - 7 OpenMP and 2 OpenACC benchmarks encounter runtime errors
- All but one of the C benchmarks compile and run successfully with LLVM
  - CSP encounters a compiler error

	XL 16.1.1 PTF8	PGI 20.1	GCC 9.2.0		LLVM 11.0.0rc1
Benchmark	OMP	ACC	OMP	ACC	OMP
Stencil	✓	✓	✓	✓	✓
LBM	✓	✓	✓	✓	✓
MRI-Q	✓	✓	!	✗	✓
MD	✓	✓	!	!	
PALM	✓	✓	!	✗	
EP	✓	✓	✓	✗	✓
Cloverleaf	✓	✓	✓	✗	
CG	✓	✓	✓	✓	✓
Seismic	✓	✓	!	✓	
SP	✓	✓	!	!	
CSP	✓	✓	✓	✓	✗
miniGhost	✓	✓	!	✓	
ILDBC	✓	✓	✓	✓	
Swim	✓	✓	!	✓	
BT	✓	✓	✓	✓	✓

Results: SPEC ACCEL

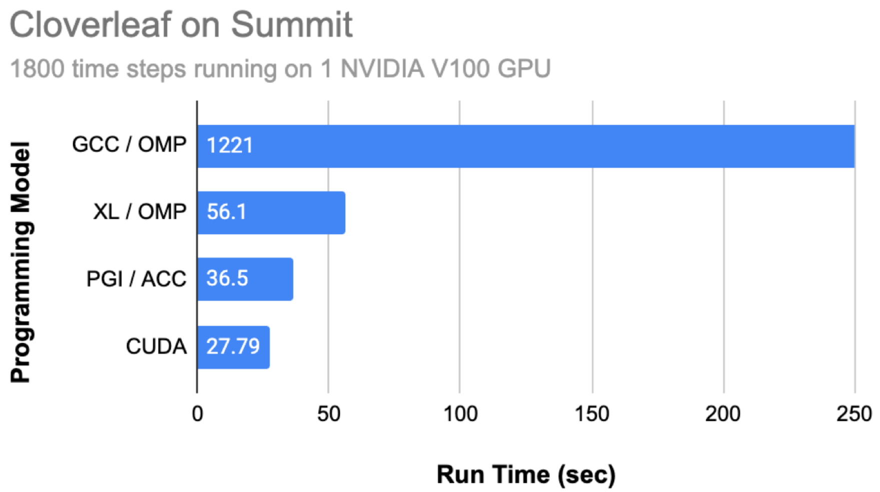


Cloverleaf OpenACC / PGI:

- **~33x faster than OpenMP / GCC**
- **~1.5x faster than OpenMP / XL**

Cloverleaf CUDA:

- **~43x and ~2x faster than OpenMP with GCC and XL, respectively**
- **~1.3x faster than PGI OpenACC**



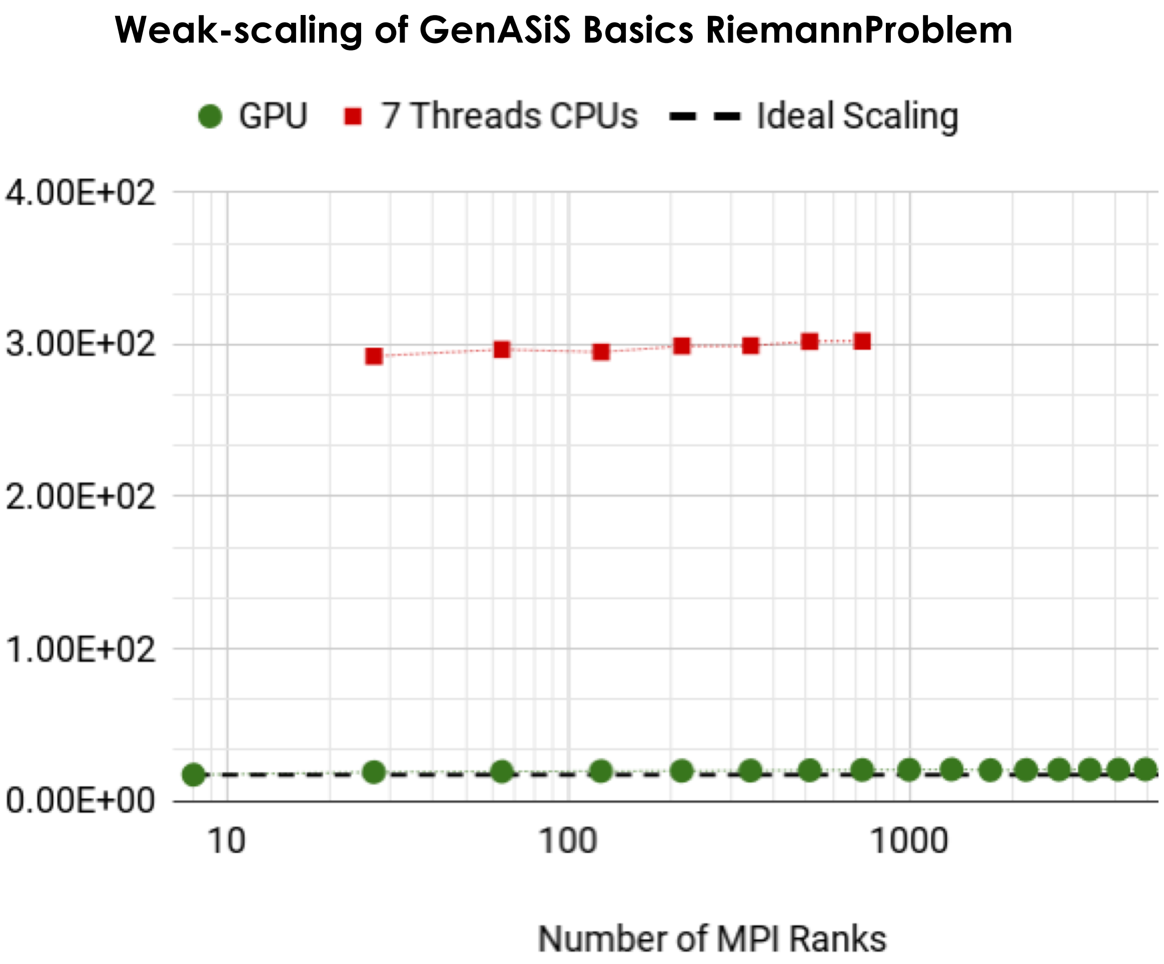
Cloverleaf CUDA: https://uk-mac.github.io/

Lessons Learned: SPEC ACCEL

- More OpenMP implementations can now successfully compile the SPEC ACCEL suite
- Can achieve good performance with OpenMP without significant changes to the code
  - More work is needed to match optimized CUDA versions for some of the benchmarks
- GCC offloading has improved but performance gaps remain
- Need to work with implementation providers to report issues
  - Iterative improvements resulted from collaboration with XL team
  - Submitting issues for GCC

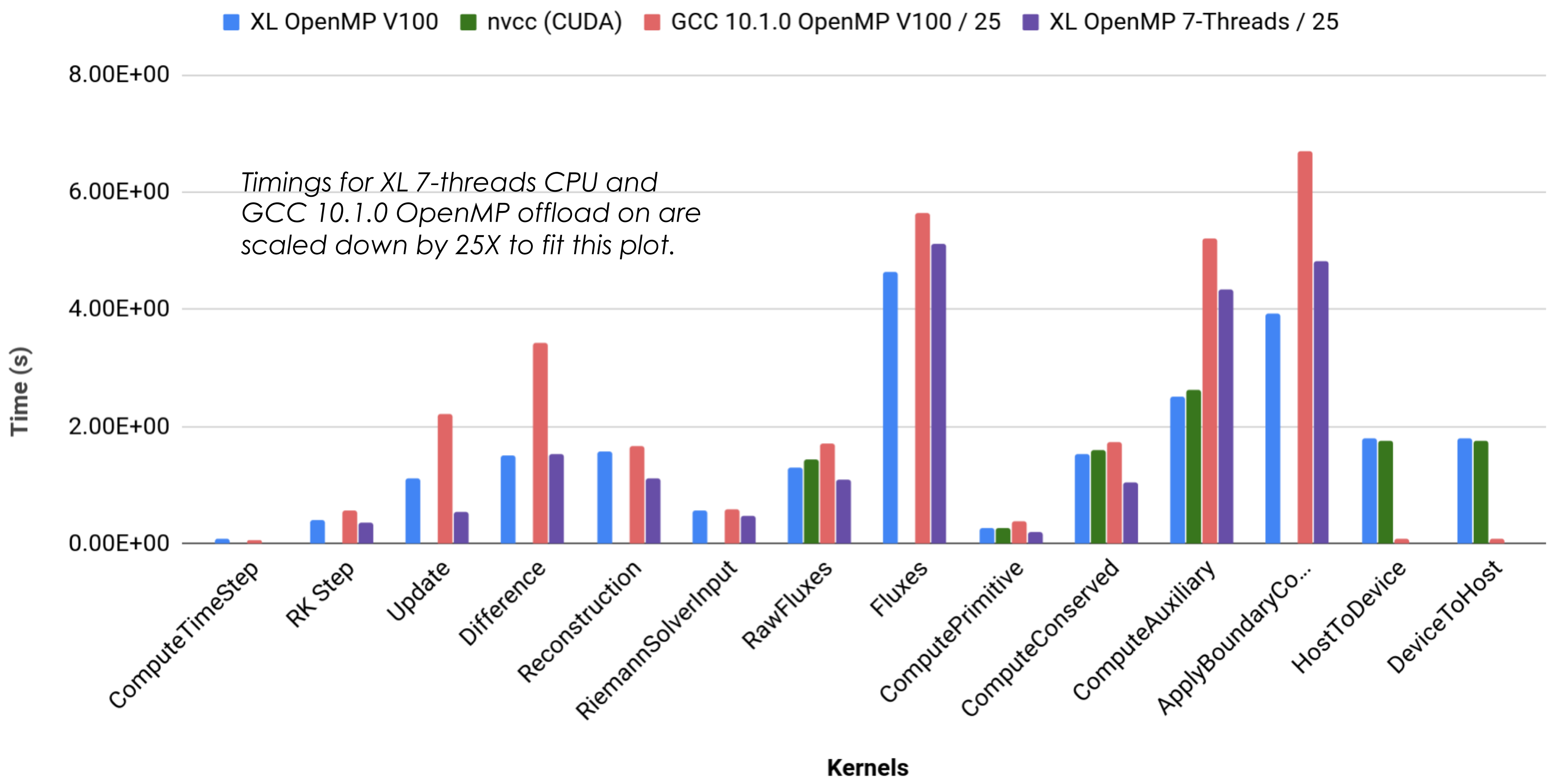
Experimental Setup: GenASiS

- GenASiS
  - Target system: Summit, Frontier (future)
  - Programming model:
    - OpenMP (CPU + target offload)
    - CUDA / HIP library routines, to supplement missing functionality in OpenMP 4.5
    - CUDA / HIP kernels (experimental only)
  - Compilers:
    - XL Fortran 16.1.1 PTF 8, nvcc / hipcc, GCC
- 1 GPU + n CPU threads per MPI task
  - "proportional resource tests" comparisons on Summit:
    7 CPU threads + 1 GPU per MPI task:
    `jsrun -r6 -c7 -g1 -a1 -bpacked:7`



Results: GenASiS Basics RiemannProblem

Kernel timings for 50 cycles, 3D - 256^3 cells per GPU (**lower is better/faster**)



Lesson Learned from GenASiS

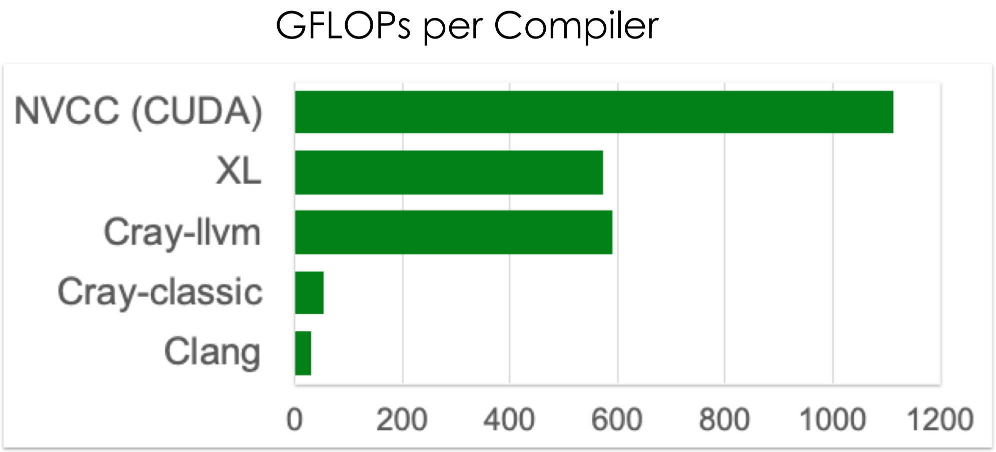
- Explicit memory management and control of data movement is essential for performance
  - persistent memory allocation on the device
  - explicitly map data location on GPU → avoid (implicit) allocation and transfer

- **Performance parity** between OpenMP offload and CUDA is **achievable**
  - OpenMP is more portable
  - OpenMP has benefits of being more “natural” to the application
  - compilers need to do a good job of optimization
  - no need to rewrite kernels, simpler to port from multi-threading to GPU offload
  - can continue to exploit base language feature (Fortran)

Experimental Setup: su3

- su3 mini-app
  - Target system: Cori GPU Nodes, Summit
  - Programming model: OpenMP, CUDA
  - Compilers:
    - Clang 11 [Cori]
    - CCE 9.0.0 (Classic) [Cori]
    - CCE 10.0.0 (LLVM) [Cori]
    - NVCC 10.2.89 [Cori, CUDA]
    - XL 16.0.0-5 [Summit]
  - Mini-app: matrix-matrix multiply with complex numbers, proxy for MILC

Results: su3 mini-app




```
#pragma omp target teams distribute
for(int i = 0; i < total_sites; ++i) {
    #pragma omp parallel for collapse(3)
    // for loops...
```

```
#pragma omp target teams {
    #pragma omp parallel {
        // compute istart, iend...
        for (int i = istart; i < iend; ++i) {
            #pragma omp for collapse(3)
            // for loops...
```

- Excess DRAM transactions responsible for Clang slowdown
- Cray-classic slowdown associated with small grid size, low utilization
  - Can get **4.6x speedup** by increasing num_teams
- Unnecessary memory flushes in Clang caused by splitting directives, interleaving code
- Restructuring directives gives an **18x speedup** with Clang

Lessons Learned: su3 mini-app

- Tuning is necessary for best performance across compilers
    - Particularly of launch parameters: compiler defaults can be quite poor
- Splitting constructs can impair performance
    - Avoid interleaving code between teams and parallel directives
- Some implementations are more robust than others
- Guide tuning and changes with profiling

How to get Efficient Compilers?

Three (short) stories of application problems and better compilers

How To Get Efficient Compilers? --- Talk to the compiler people ...

Three (short) stories of application problems and better compilers

1. HPGMG

Application people: "One performance limiter I see with LLVM/Clang is a huge amount of time spent in cuMemAlloc and cuMemFree calls.**"**

Compiler People (as I recall it): Thanks for reporting this, we'll look into it!

Compiler People (as I recall it): Can you try this version?

Application people: "I now only see 1 cuMemAlloc [...] The net effect is that this particular version of HPGMG runs 2.4x faster"

How To Get Efficient Compilers? --- Talk to the compiler people ...

Three (short) stories of application problems and better compilers

2. (Mini)QMCPack

- Observe a problem and file a bug:

  Bug 46450 - More registers are used when multiple target regions are compiled together

(paraphrased)

- **Compiler people:** How to reproduce the problem?
- **Application people:** Here is a reproducer!
- **Compiler people:** I see, it's a weird implementation detail, can you try this version please?
- **Application people:** It works for me, there are still issues but this solves my problem for now.

How To Get Efficient Compilers? --- Talk to the compiler people...

Three (short) st

3. GridMini SU(3 ifeng Lin (BNL)]

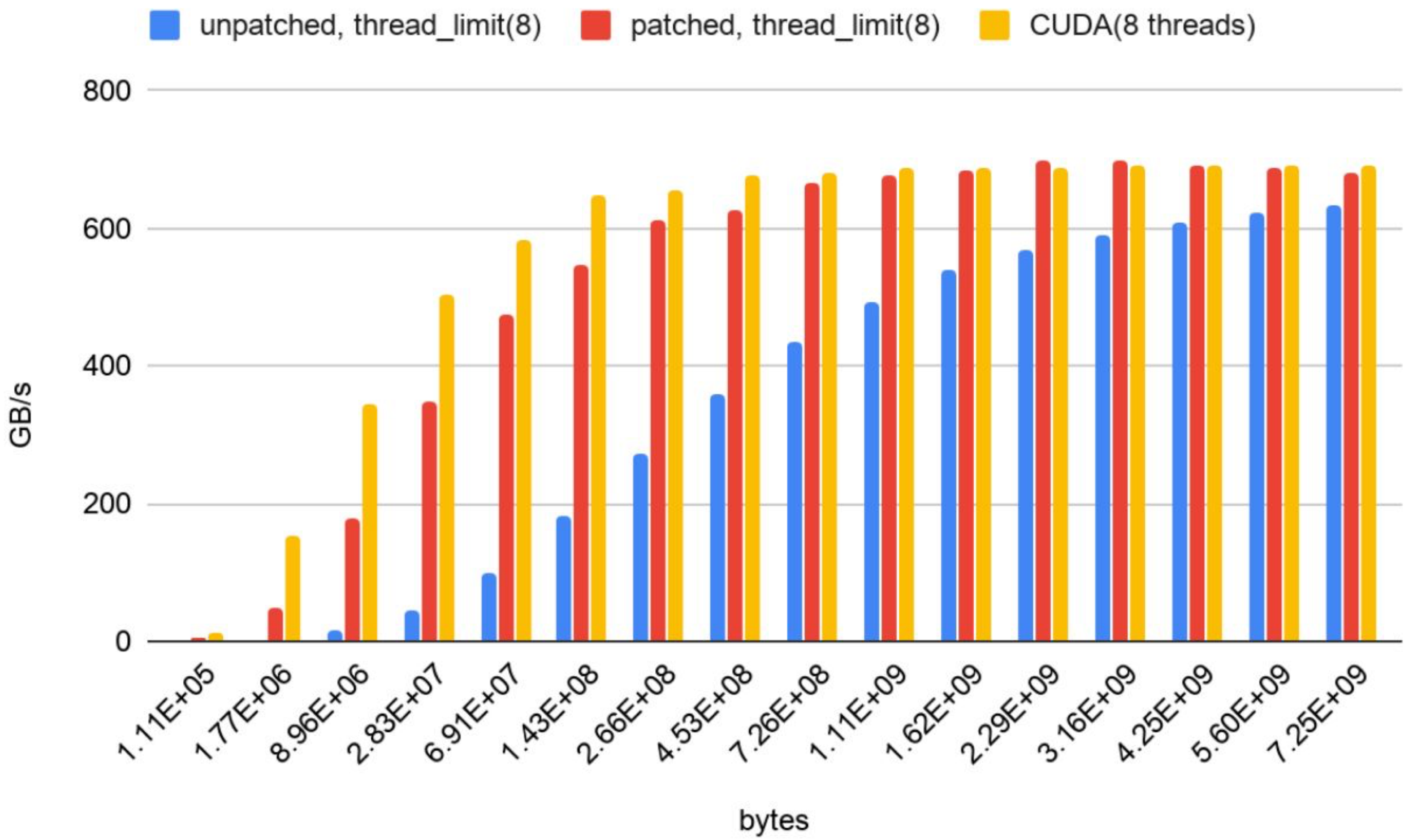
Day 1. "The p A on V100)."

Day 2. Tropica

Day 3. - talking
- trying
- turns c ficantly!"

Day 4. - Profi

"Culprit for poor perf
- repoi



"Application/Compiler Team communication is key!"

Conclusions

- Performance portability is often required not just between architectures but also between compilers on the same architecture
- As seen with GenASiS and SU(3)xSU(3), it is not necessary to sacrifice performance for portability
  - OpenMP kernels can achieve performance parity with their CUDA version
- As seen with su3, significant speedups can be attained by tuning parameters and rearranging OpenMP directives
- Talk to compiler vendors about observations, issues, problems, and ideas!
  - More implementations that perform well on various architectures benefit everyone!

Thank you! Questions?