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

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Outline

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  - SPEC ACCEL
  - 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
Benchmarks & Mini-applications
Benchmarks & Mini-Apps

- **SPEC ACCEL** *(Standard Performance Evaluation Corporation Accelerator suite)*
  - Collection of computationally intensive parallel applications in C and Fortran
  - Includes OpenACC, OpenMP target offload, and OpenCL versions

- **GenASiS** *(General Astrophysics Simulation System)*
  - 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](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
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

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<th>PGI 20.1</th>
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**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/](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)

Timings for XL 7-threads CPU and GCC 10.1.0 OpenMP offload on are scaled down by 25X to fit this plot.
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

- 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) stories of application problems and better compilers

3. GridMini SU(3)@SOLLVE Hackaton (recently)          [graphs and quotes by: Meifeng Lin (BNL)]

Day 1. “The performance of Benchmark_su3 is poor (~100 GB/s vs. 680 GB/s in CUDA on V100).”

Day 2. Tropical Storm Isaias hit the East Coast

Day 3. - talking about the performance problems with the compiler vendor
- trying out if a known performance problem was hit
- turns out "fopenmp cuda mode improves the performance of GridMini’s Benchmark_su3 significantly!

Day 4. - Profiling the code, here with nvprof:
“Culprit for poor performance at small memory footprints: 30% time spent on cuMemAlloc/cuMemFree”
- report the problem to the compiler vendor

“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?