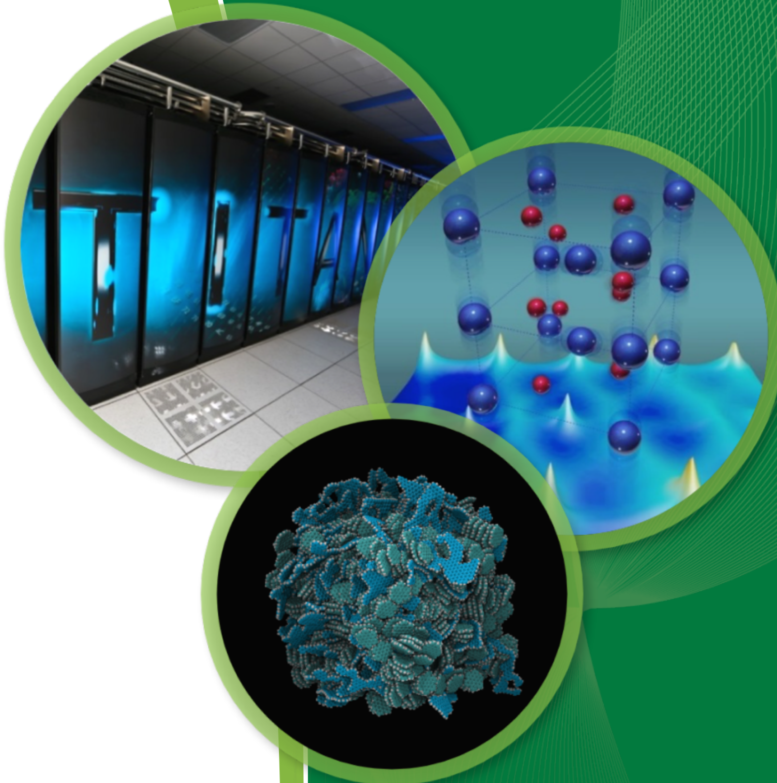
An in-depth evaluation of GCC's OpenACC implementation on Cray systems



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Overview

- OpenACC implementations
- GCC's OpenACC implementation
- Known Limitations
- An Example
- Evaluating GCC's OpenACC
- Conclusions
- Future Work

OpenACC implementations

- Relatively new directive-based specification
  - Current release is v2.5
- Several implementations already support OpenACC:
  - PGI, Cray Compiler Environment, and Pathscale
- Support different targets:
  - PGI can offload to both GPUs and multicore targets
  - CCE can offload to GPUs (craype-accel-nvidia*), host (craype-accel-host)
  - Pathscale can offload to GPUs and host
- Recently, GCC started an effort to add support for OpenACC
- Partial support for OpenACC is already available in GCC 6.3
- This work explores the functionality and performance of GCC's OpenACC implementation

GCC's OpenACC implementation

- Mentor Graphics is developing and maintaining the OpenACC implementation in GCC's gomp-4_0-branch development branch
- GCC is widely used, open source, that supports a subset of CilkPlus, OpenACC 2.0a, and OpenMP 4.5 programming models
- GCC's support for for OpenACC was built on top of its existing support for OpenMP
  - Extensive modifications were required to implement OpenACC efficiently on GPUs
  - GCC does not currently offload OpenMP to GPUs, only to Intel MIC targets

GCC's OpenACC Known Limitations

- Only supports NVIDIA GPUs
  - Single CPU thread is used if executed on multicore hosts
- No support for nested parallelism, `device_type`, and `bind` clauses
- Dynamic arrays in OpenACC data constructs limitations:
  - Pointer-to-arrays not supported
  - Target host not supported
- Loop private variables stored in local memory, rather than shared
- `private` and `firstprivate` clauses do not support subarrays
- Unable to detect parallelism inside `acc kernels` regions
  - Fallbacks to single thread execution

Evolution of GCC's OpenACC implementation

GCC 5
- Highly experimental
- Vector parallelism

GCC 6
- Gang, worker, vector parallelism
- Preliminary support for OpenACC routines

GCC 6.3 (upstream)

GCC 6.3 (gomp4)
- Additional OpenACC functionality
- Enhanced performance for NVIDIA GPUs

GCC 7
- Focuses on performance
- Refines support for OpenACC 2.0a routines
- Adds support for the declare directive

GCC 8
- Includes full support for OpenACC 2.5

An Example: Matrix Multiplication

Porting Matrix Multiplication: Parallel

```
#pragma acc parallel
for (i = 0; i < n; i++)
{
  for (j = 0; j < n; j++)
  {
    int t = 0;

    for (k = 0; k < n; k++)
      t += at(i, k, a) * at(k, j, b);

    at(i, j, c) = t;
  }
}
```

Porting Matrix Multiplication: Parallel Loop

```
#pragma acc parallel
#pragma acc loop
for (i = 0; i < n; i++)
{
  for (j = 0; j < n; j++)
  {
    int t = 0;

    for (k = 0; k < n; k++)
      t += at(i, k, a) * at(k, j, b);

    at(i, j, c) = t;
  }
}
```

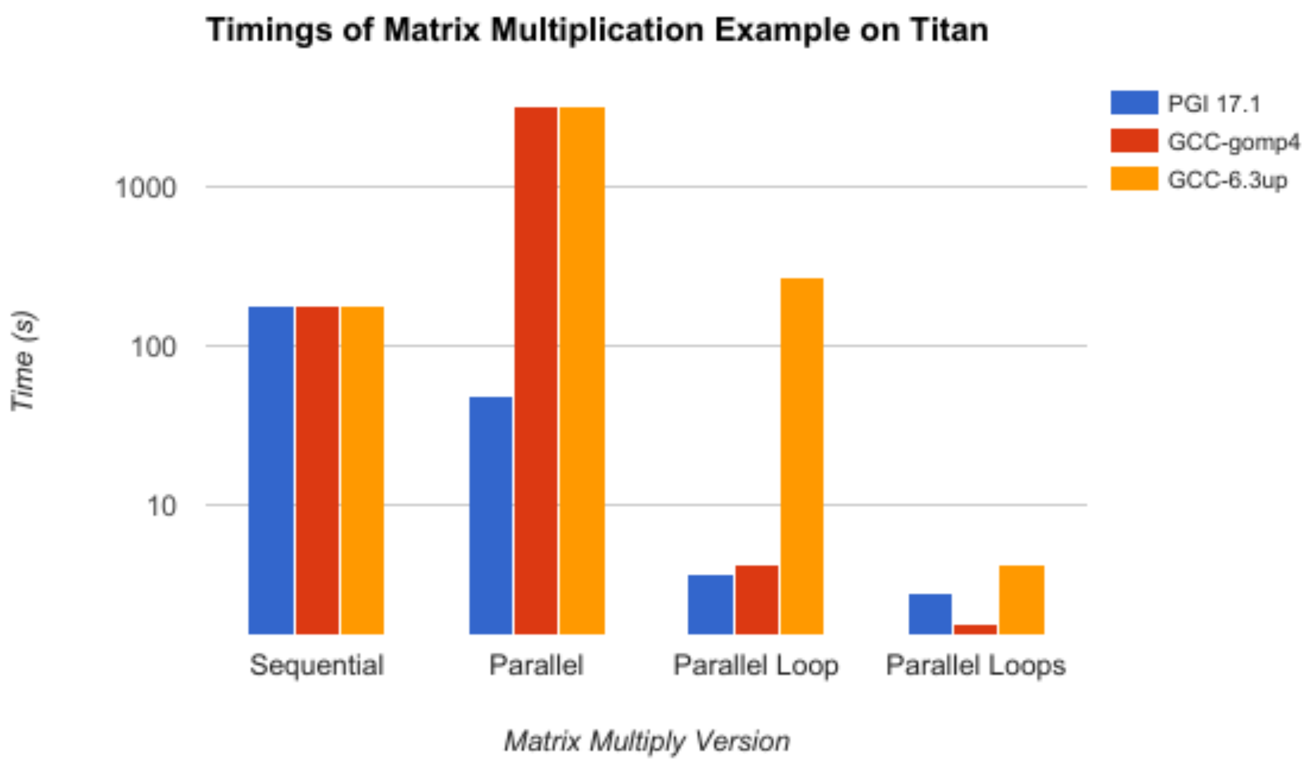
Porting Matrix Multiplication: Parallel Loops + Reductions

```
#pragma acc parallel present (a[0:n*n], \
b[0:n*n], c[0:n*n])
#pragma acc loop
for (i = 0; i < n; i++)
{
  #pragma acc loop
  for (j = 0; j < n; j++)
  {
    int t = 0;

    #pragma acc loop reduction (+:t)
    for (k = 0; k < n; k++)
      t += at(i, k, a) * at(k, j, b);

    at(i, j, c) = t;
  }
}
```

Porting Matrix Multiplication



Evaluating GCC's OpenACC

Evaluating Compliance: OpenACC V&V

- Used the OpenACC Verification and Validation suite from University of Houston
- Validates implementations to the OpenACC v1.0 specification using microtests
  - New version targeting OpenACC v2.5 is expected to be available later this year

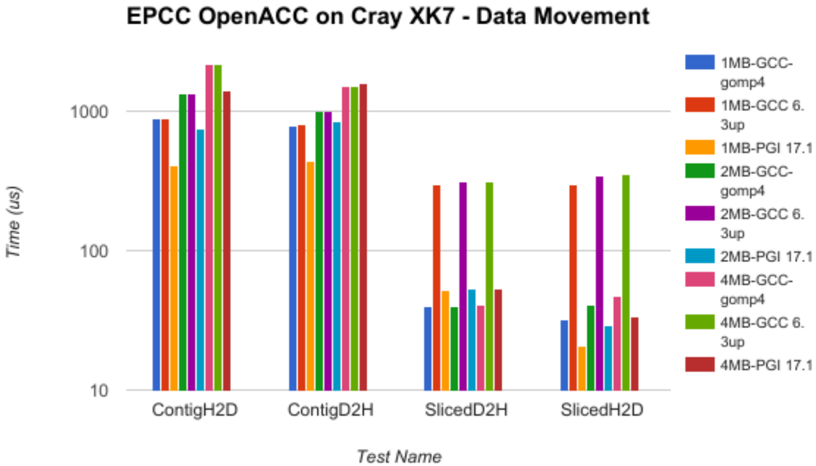
Compiler	Passed	Failed	CE	RE	Total
GCC-gomp4	163	17	56	57	293
PGI 17.1	204	19	20	51	294
CCE 8.5.5	158	27	38	72	295

Measuring OpenACC overheads: EPCC OpenACC benchmark suite

- The EPCC OpenACC benchmark suite was introduced in 2013
  - The suite has not been updated.
- Designed to measure and compare the performance of OpenACC implementations on different architectures
- Contains three levels of tests:
  - Level 0: overheads of certain OpenACC constructs
  - Level 1: performance of computationally intensive linear algebra kernels
  - Level 2: kernels from real-world applications
- A few tests produce compilers and runtime errors
  - Even with mature compilers like PGI

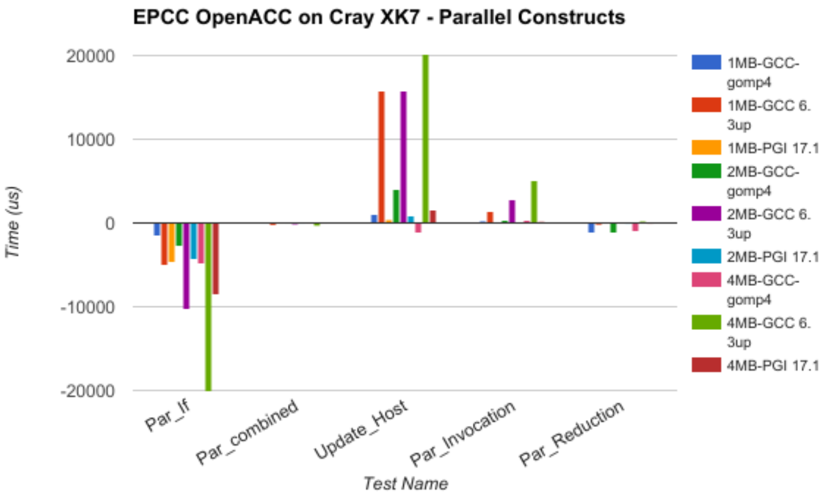
Measuring OpenACC overheads: EPCC OpenACC benchmark suite

Data movement



GCC-gomp4 fastest GPU -> CPU
PGI fastest CPU -> GPU

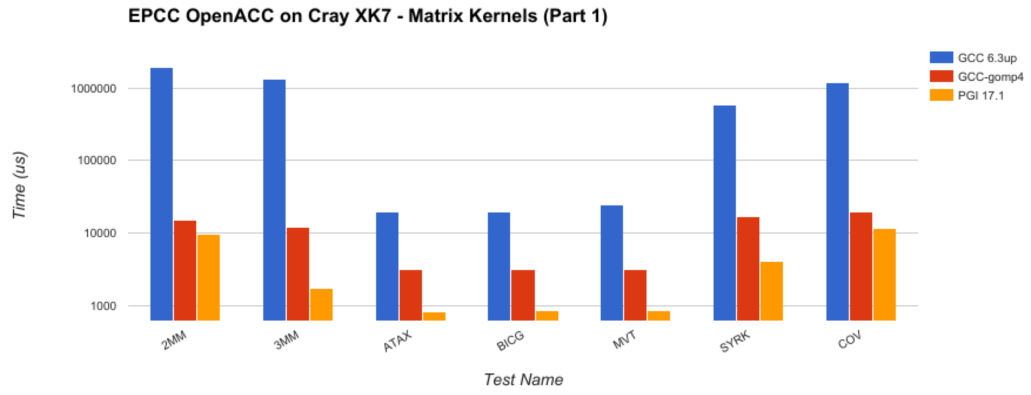
Parallel constructs

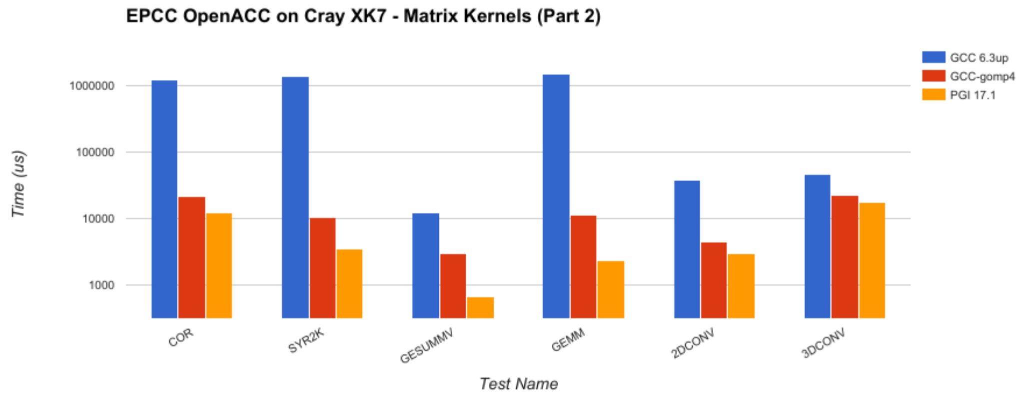


Parallel Reduction much slower
with GCC
(varies by type of reduction)

Measuring OpenACC overheads: EPCC OpenACC benchmark suite

Linear Algebra Kernels



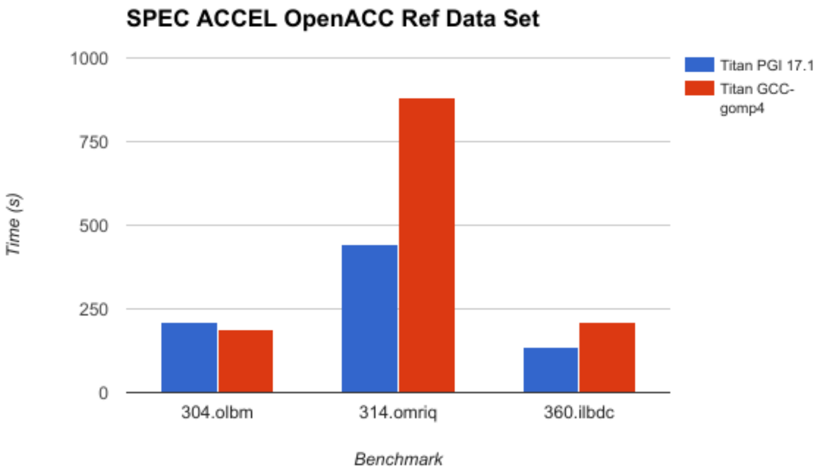


Measuring OpenACC performance: SPEC ACCEL OpenACC

- Developed by SPEC High Performance Group to measure performance for compute intensive parallel applications on accelerators
- Released in September 2015
- Contains two benchmark sets: OpenCL and OpenACC
- OpenACC set contains 15 application kernels: 7 C kernels, 6 Fortran, 2 combined.
- Three data sets: test, train, ref. Only ref is used to compare performance across architectures
- Only three benchmarks that use acc parallel could be used
  - The rest use `acc kernels` and run on a single thread

Measuring OpenACC performance: SPEC ACCEL OpenACC

Measured Estimates



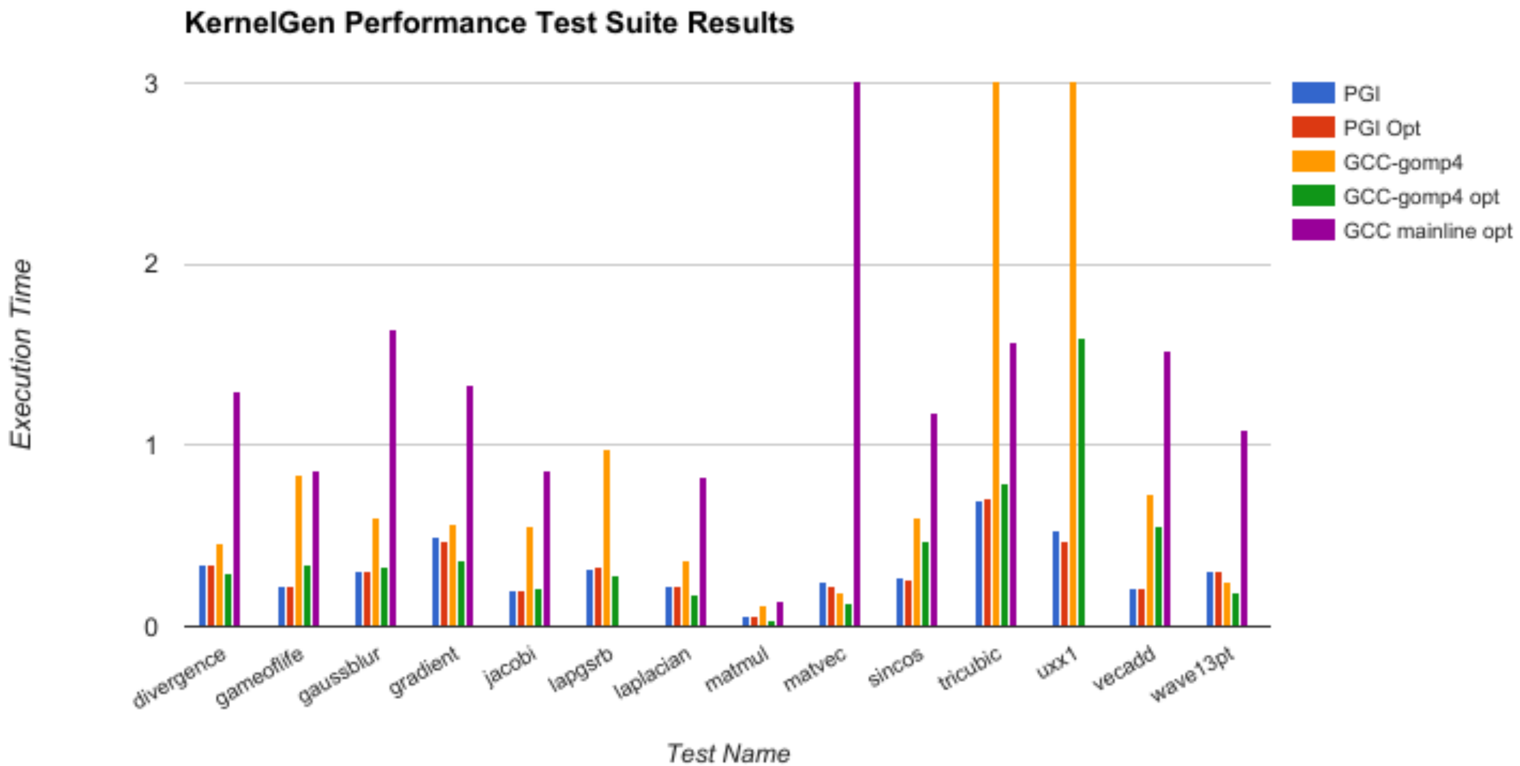
Performance Difference

Benchmark	Perf. Diff
304.olbm	11.48%
314.omriq	-100.00%
360.ilbdc	-51.21%

Measuring OpenACC performance: KernelGen

- Set of OpenACC codes developed as part of the KernelGen project
- Evaluates the ability of compilers to exploit “easy” parallelism
- Consists of single precision numerical algorithms in 2D and 3D grids
- 10 tests use C, 3 use Fortran
  - Tests were modified to update OpenACC syntax to latest specification
  - Also modified tests to use `acc parallel` where `acc kernels` were used
- Tests executed with and without optimization flags

Measuring OpenACC performance: KernelGen



Conclusions

- GCC's OpenACC implementation is now available with partial support for OpenACC v2.0a
  - Mentor Graphics public GCC branch gomp-4_0-branch has the latest updates
- GCC-gomp4 can in some cases outperform more mature implementations.
  - As was the case with the SPEC ACCEL 304.olbm benchmark
  - Overall, GCC is ~47% slower than PGI for SPEC ACCEL measured estimates
- Known limitations of the implementation reduce the number of tests available for the evaluation

Conclusions (cont'd)

- For portability, OpenACC implementations should support many targets
  - e.g., PGI achieves good performance on both GPU-based and manycore-based systems
  - To compare performance, support for additional architectures is needed in GCC's OpenACC implementation
- An open source implementation is useful to expand the adoption of OpenACC
- Many of the benchmarks available have not been recently updated
  - Community involvement could improve and encourage updates to benchmarks

Future Work

- Evaluation should be repeated when GCC 7 is released
  - And again with GCC 8
- Work on validation benchmarks for OpenACC 2.5 is on-going
- A larger study including more implementations should be conducted once GCC's OpenACC implementation is more mature
  - Should include newer hardware as well as additional compilers
- Experiments using a Cray XC40 KNL system were conducted using PGI.
  - Need GCC to also support multicore architectures to fully evaluate and compare implementations

Thank you!

Questions?

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