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 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

```c
#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;
    }
}
```
#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

```c
#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

Timings of Matrix Multiplication Example on Titan

- PGI 17.1
- GCC-gomp4
- GCC-6.3up

Time (s)

Sequential  Parallel  Parallel Loop  Parallel Loops

Matrix Multiply Version
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

<table>
<thead>
<tr>
<th>Compiler</th>
<th>Passed</th>
<th>Failed</th>
<th>CE</th>
<th>RE</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCC-gomp4</td>
<td>163</td>
<td>17</td>
<td>56</td>
<td>57</td>
<td>293</td>
</tr>
<tr>
<td>PGI 17.1</td>
<td>204</td>
<td>19</td>
<td>20</td>
<td>51</td>
<td>294</td>
</tr>
<tr>
<td>CCE 8.5.5</td>
<td>158</td>
<td>27</td>
<td>38</td>
<td>72</td>
<td>295</td>
</tr>
</tbody>
</table>
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

Parallel constructs

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

Parallel Reduction much slower with GCC
 (varies by type of reduction)
Measuring OpenACC overheads: EPCC OpenACC benchmark suite

Linear Algebra Kernels

EPCC OpenACC on Cray XK7 - Matrix Kernels (Part 1)

EPCC OpenACC on Cray XK7 - Matrix Kernels (Part 2)
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

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Perf. Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>304.olbm</td>
<td>11.48%</td>
</tr>
<tr>
<td>314.omriq</td>
<td>-100.00%</td>
</tr>
<tr>
<td>360.ilbdc</td>
<td>-51.21%</td>
</tr>
</tbody>
</table>
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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