Enabling Profiling and Analysis Tools for Aurora

Rashawn L. Knapp
Intel, Software and Service Group (SSG)
Technical Computing, Analyzers, and Runtimes
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rashawn.l.knapp@intel.com
Goals

- Enable open source profiling and analysis tools for HPC to run well on Intel’s newest and upcoming high-end server platforms.

- Collaboration of Oak Ridge, Argonne and Livermore National Laboratories (CORAL)
  - Intel with partner Cray to deliver two supercomputers to Argonne: Theta in 2016 (8.5 PF) and Aurora in 2018 (180 PF)
    - Knights Landing (KNL) for Theta and beyond for Aurora

- Current work on Xeon Haswell - EP through 2015

- Develop relationships with institutions and tool owners
  - Contribute patches to ensure tool coverage, quality, and performance on Intel platforms
    - Do this on Haswell and repeat on KNL (2016) and again on early Aurora servers

- Demonstrate a path for all tools on the new platforms via Intel and GNU compilers
  - Why Intel Compilers?
    - Expectation is that these will produce the highest quality code for the Xeon Phi based nodes (especially when first released)
    - We will explore vectorization opportunities for optimization wherever possible.
<table>
<thead>
<tr>
<th>Tool/Version</th>
<th>Description</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyninst 8.2.1</td>
<td>dynamic binary instrumentation tool</td>
<td>GNU and Intel compilations, Test suite completed, Minor change to CMake configuration</td>
</tr>
<tr>
<td>PAPI 5.4.1</td>
<td>interface to sample CPU and off-core performance events</td>
<td>GNU and Intel compilations, Test suite completed, Patch accepted for off-core events</td>
</tr>
<tr>
<td>TAU 2.24.1</td>
<td>profiling and tracing tool for parallel applications, supporting both MPI and OpenMP</td>
<td>Intel Compilation with Intel MPI and Intel C/C++/Fortran compilers, many suite examples tested</td>
</tr>
<tr>
<td>Score-P 1.3</td>
<td>Provides a common interface for high-level tools</td>
<td>2015/16</td>
</tr>
<tr>
<td>Open</td>
<td>Speedshop 2.1</td>
<td>Dynamic Instrumentation tool for Linux: profiling, event tracing for MPI and OpenMP programs. Incorporates Dyninst and PAPI</td>
</tr>
<tr>
<td>HPCToolKit 5.3.x r4793</td>
<td>Lightweight sampling measurement tool for HPC; supports PAPI</td>
<td>GNU and Intel compilations with Intel MPI, tests with PAPI and Intel MPI</td>
</tr>
<tr>
<td>Darshan 5.3.2-r4532</td>
<td>IO monitoring tool</td>
<td>2015/16</td>
</tr>
<tr>
<td>Valgrind 3.10.1</td>
<td>framework for constructing dynamic analysis tools; includes suite of tools including a debugger, and error detection for memory and pthreads.</td>
<td>2015/16</td>
</tr>
<tr>
<td>memcheck</td>
<td>Detects memory errors: stack, heap, memory leaks, and MPI distributed memory. For C and C++.</td>
<td>2015/16</td>
</tr>
<tr>
<td>helgrind</td>
<td>Pthreads error detection: synchronization, incorrect use of pthreads API, potential deadlocks, data races. C, C++, Fortran</td>
<td>2015/16</td>
</tr>
</tbody>
</table>
# Dyninst 8.2.1 Overview

## Compilers

<table>
<thead>
<tr>
<th>Compiler</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>GCC 5.1</td>
<td>Completed</td>
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<tr>
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</table>

## MPI

<table>
<thead>
<tr>
<th>MPI</th>
<th>Status</th>
</tr>
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<tbody>
<tr>
<td>Intel 5.1.038</td>
<td>Completed</td>
</tr>
<tr>
<td>MPICH 3.1.4</td>
<td>TBD</td>
</tr>
</tbody>
</table>

## Validation

**Test Suite**

```
./runTests -gcc -g++
```

363 tests, 353 PASSED, 10 SKIPPED, 0 CRASHED

```
./runTests -icpc -icc
```

329 tests, 319 PASSED, 10 SKIPPED, 0 CRASHED

**Examples in DyninstAPI Appendix A**

GCC and Intel Ports

## Contributions

- CMake Configuration Change to enable Intel compilers
Dyninst 8.2.1 Results

Intel 15.0.3 Test results (./runTests -icpc -icc):

In total 329 tests ran, 0 CRASHED, 10 SKIPPED, 319 PASSED, and 0 FAILED:

22 test2_11          icc  none 64  create  NA   dynamic nonPIC  SKIPPED
100 test2_11         icpc none 64  create  NA   dynamic nonPIC  SKIPPED
194 test1_35         icc  none 64  create  NA   dynamic nonPIC  SKIPPED
195 test1_35         icc  none 64  rewriter NA   dynamic nonPIC  SKIPPED
196 test1_35         icpc none 64  create  NA   dynamic nonPIC  SKIPPED
197 test1_35         icpc none 64  rewriter NA   dynamic nonPIC  SKIPPED
310 test_ser_anno    icc  none 64  disk   NA    dynamic nonPIC  SKIPPED
311 test_symtab_ser_funcs icpc none 64  disk   NA    dynamic nonPIC  SKIPPED
320 test_ser_anno    icpc none 64  disk   NA    dynamic nonPIC  SKIPPED
321 test_symtab_ser_funcs icpc none 64  disk   NA    dynamic nonPIC  SKIPPED

GCC 5.1.0 Test Results (./runTests -gcc -g++):

In total 363 tests ran, 0 CRASHED, 10 SKIPPED, 353 PASSED, and 0 FAILED:

22 test2_11          g++  none 64  create  NA   dynamic nonPIC  SKIPPED
100 test2_11         gcc none 64  create  NA   dynamic nonPIC  SKIPPED
194 test1_35         g++  none 64  create  NA   dynamic nonPIC  SKIPPED
195 test1_35         g++  none 64  rewriter NA   dynamic nonPIC  SKIPPED
196 test1_35         gcc none 64  create  NA   dynamic nonPIC  SKIPPED
197 test1_35         gcc none 64  rewriter NA   dynamic nonPIC  SKIPPED
344 test_ser_anno    g++  none 64  disk   NA    dynamic nonPIC  SKIPPED
345 test_symtab_ser_funcs g++ none 64  disk   NA    dynamic nonPIC  SKIPPED
354 test_ser_anno    gcc none 64  disk   NA    dynamic nonPIC  SKIPPED
355 test_symtab_ser_funcs gcc none 64  disk   NA    dynamic nonPIC  SKIPPED
# PAPI 5.4.2 Overview

## Compilers

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## MPI (N/A)

## Validation

<table>
<thead>
<tr>
<th>Test Set</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>ctests</td>
<td>104 tests: 96 PASSED (5 w/warning), 1 FAILED, 6 SKIPPED, 1 does not exist</td>
</tr>
<tr>
<td>perf_event</td>
<td>3 tests: 3 PASSED</td>
</tr>
<tr>
<td>perf_event_uncore</td>
<td>4 tests: 3 PASSED, 1 SKIPPED</td>
</tr>
<tr>
<td>native events (papi_native_avail)</td>
<td>814 base events yields total combination of 11,843 events (2080 added successfully)</td>
</tr>
</tbody>
</table>

## Contributions

- Patch accepted for off-core tests on Haswell-EP
PAPI 5.4.2 Results

### ctests

<table>
<thead>
<tr>
<th>Total</th>
<th>Passed</th>
<th>Failed</th>
<th>Skipped</th>
<th>Event does not exist</th>
</tr>
</thead>
<tbody>
<tr>
<td>104</td>
<td>96</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Failed Test:
- zero.c - Flops validation error

Skipped:
- Dat-range.c - Itanium2 only
- calibrate.c – event does not exist
- earprofile.c - Not implemented
- p4_lst_ins.c - Pentium 4 only
- zero_shmem.c - openSHMEM
- zero_smp.c - architecture not included

Event does not exist:
- hlrates - flips, flops, failure

### perf_event

<table>
<thead>
<tr>
<th>Total</th>
<th>Passed</th>
<th>Failed</th>
<th>Skipped</th>
<th>Event does not exist</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Passed Tests: perf_event_offcore_response.c, perf_event_system_wide.c, perf_event_user_kernel.c

### native events

- 814 events
- 11,843 events with all possible combinations
  - 2,080 PASS by modifying unit mask value (1-10 tested).
  - 9763 combinations did not pass
    - Some may be important

### perf_event_uncore (4 tests)

<table>
<thead>
<tr>
<th>Total</th>
<th>Passed (3)</th>
<th>Skipped (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>perf_event_uncore, perf_event_uncore_multiple, perf_event_uncore_cbox</td>
<td>perf_event_amd_northbridge.c</td>
</tr>
</tbody>
</table>
# TAU 2.24.1 Overview

<table>
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<thead>
<tr>
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<tbody>
<tr>
<td>Suite Examples</td>
<td>MPI and examples incorporating PAPI and Dyninst</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contributions</th>
<th></th>
</tr>
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<tr>
<td>- none</td>
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</tbody>
</table>
TAU 2.24.1 Results - Examples

- taucompiler (c, f90, c++, mpic++)
  - tau_cc.sh -tau_makefile=$TAU_MAKEFILE -tau_options=-optCompInst -o ring ring.c
    - mpirun -n 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX ring
  - tau_cxx.sh -tau_makefile=$TAU_MAKEFILE -tau_options=-optCompInst klargest.cpp -o klargest
    - $ ./klargest 100 98
  - tau_f90.sh -tau_makefile=$TAU_MAKEFILE -tau_options=-optCompInst ring.f90 -o ring
    - mpirun -n 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX ring
  - tau_cxx.sh -tau_makefile=$TAU_MAKEFILE -tau_options=-optCompInst -o ring ring.cpp
    - mpirun -n 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX ring
  - paraprof

- taututorial (computePi)*
  - tau_cxx.sh -tau_makefile=$TAU_MAKEFILE -tau_options=-optCompInst computePi.cpp -o computePi
    - mpirun -n 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX computePi

- NPB2.3 (lu.W.4, sp.W.4)
  - mpirun -n 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX [lu.W.4|sp.W.4]

- Dyninst
  - tau_run -T pdt klargest 2500 23

- papi
  - setenv TAU_METRICS TIME:PAPI_TOT_CYC
  - ./simple
# HPCToolKit Overview

<table>
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<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compute Pi (cpi) example</td>
<td>4 nodes, 1 proc/node, PAPI_TOT_CYC and L2_TCM</td>
</tr>
<tr>
<td>HPL</td>
<td>4 nodes, 1 proc/node, PAPI_TOT_CYC and L2_TCM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contributions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- none</td>
<td></td>
</tr>
</tbody>
</table>
HPCToolKit Results - CPI

CPI
mpiicc -g -O3 cpi.c -o cpi -lm
hpcstruct ./cpi

mpirun -np 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX
    hpcrun -t --event PAPI_TOT_CYC@10000 --event WALLCLOCK@100000 --event PAPI_L2_TCM@10000
./cpi
hpcprof -S cpi.hpcstruct -l ./"*" hpctoolkit-cpi-measurements
hpctraceviewer hpctoolkit-mmult-database
hpcviewer hpctoolkit-mmult-database
### HPCToolKit Results - HPL

#### HPL

```bash
mpirun -np 4 -perhost 1 -env I_MPI_FABRICS tcp -hostfile <pathTo>/machines.LINUX
hpcrun -t --event PAPI_TOT_CYC@10000 --event WALLCLOCK@100000 --event PAPI_L2_TCM@10000
./xhpl_intel64
hpcprof -S cpi.hpcstruct -I ./"* hpctoolkit-cpi-measurements
hpctraceviewer hpctoolkit-mmult-database
hpcviewer hpctoolkit-mmult-database
```

<table>
<thead>
<tr>
<th>T/V</th>
<th>N</th>
<th>NB</th>
<th>P</th>
<th>Q</th>
<th>Time</th>
<th>Gflops</th>
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<tbody>
<tr>
<td>With Instrumentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WR01C2R4</td>
<td>1000</td>
<td>168</td>
<td>1</td>
<td>4</td>
<td>1.14</td>
<td>5.88332e-01</td>
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<tr>
<td>WR01C2R4</td>
<td>2000</td>
<td>168</td>
<td>1</td>
<td>4</td>
<td>0.72</td>
<td>7.38429e+00</td>
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<tr>
<td>Without Instrumentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WR01C2R4</td>
<td>1000</td>
<td>168</td>
<td>1</td>
<td>4</td>
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<tr>
<td>WR01C2R4</td>
<td>2000</td>
<td>168</td>
<td>1</td>
<td>4</td>
<td>0.55</td>
<td>9.79022e+00</td>
</tr>
</tbody>
</table>
Summary, Challenges, and Next Steps

- **Summary**
  - We have started and have a plan to ensure that these tools run well on the CORAL machines
  - We have conducted coverage studies up to this point; still need to conduct quality and performance studies
  - We welcome collaboration with the tool groups
    - We will contribute patches as necessary
  - We started with the building block components of high level tools (e.g., Dyninst and PAPI), and we are now incorporating these into the higher level tools (OpenSpeedShop, Score-P).

- **Challenges**
  - We are working on small clusters at this time, but will need to transition to larger clusters to complete the performance studies

- **Other open-source tools to consider for this contract?**
  - STAT, MRNet

- **New Technologies**
  - Omni-Path network, NUMA technologies
Acknowledgments

All of the tool groups have been very responsive and helpful.

I want to thank Bill Williams from Dyninst who answered all of my questions regarding building, testing, and using.

Many thanks to the supportive PAPI team in guiding us through upgrading and testing.

And without my colleague, Preeti Suman, we would not have progressed to where we are.
References

Coral

New Technologies
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Notice revision #20110804
Backup PAPI 5.4.2

- Kernel upgrade from version 3.10 to 4.0.5, to enable uncore and offcore support on HSW
- Successfully installed PAPI-5.4.2 with GCC 5.1.0 and Intel Compilers
- Successfully added and tested uncore and offcore events to PAPI component tests
- Successfully added and tested imc uncore event support on HSW EP
- Reason for failed tests: disabled floating point counters
- 814 native events enabled on HSW
  - 11843 events extracted from all possible combination of native events and respective unit masks
  - 1848 events were successfully added and 232 events were successfully added after changing the unit mask value, ranging from 1 to 10.
  - 9,763 events that have not been added with the changes to the unit mask value. This returns two evenly distributed error messages: “invalid argument” and “Event does not exist”.
Configure:

```
./configure -c++=icpc -cc=icc -fortran=intel \
-pdt=<pathToPDT-3.20-IntelBuild> \
-papi=<pathToPAPI-5.4.2-IntelBuild> \
-PAPIWALLCLOCK -PAPIVIRTUAL -mpi \
-mpiinc=<pathToIntelMPI-5.1.0.38-IntelBuild>/compilers_and_libraries_2016/linux/mpi/intel64/include \
-mpilib=<pathToIntelMPI-5.1.0.38-IntelBuild>/compilers_and_libraries_2016/linux/mpi/intel64/lib \
-tag=IntelMPI5.1-IntelC15.3.187-PAPI5.4.2-Dyninst8.2.1-profiling \
-nocomm -COMPENSATE -PROFILEHEADROOM -PROFILEMEMORY -pthread \
-dyninst=<pathToDyninst-8.2.1-IntelBuild> -CPUTIME -LINUXTIMERS -iowrapper \
-prefix=<pathToTAU-2.24.1-IntelBuild> -bfd=download -unwind=download -pdtcompdir=intel \
-dwarflib=/nfs/fx/proj/coralhpctools/builds/libdwarf/intel/lib64<pathTo-libdwarf-20150507-IntelBuild>
```
HPCToolKit - Calling Contexts View for cpi Backup
HPCToolKit - Depth View for cpi Backup
HPCToolKit - Histogram for cpi Backup
HPCToolKit - Flat View for xhpl_intel64 Backup
HPCToolKit - Depth View for xhpl_intel64 Backup
HPCToolKit - Histogram for xhpl_intel64 Backup