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Welcome to the RADIUSS AWS Tutorial Series!

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Date	Time (Pacific)	Project
August 3, 2023	9:00a.m.–11:00a.m.	Build, link, and test large-scale applications with **BLT**
August 8–9 2023	8:00a.m.–11:30a.m. both days	Learn to install your software quickly with **Spack**
August 10, 2023	9:00a.m.–11:00a.m.	Use **MFEM** for scalable finite element discretization application development
August 14, 2023	9:00a.m.–12:00p.m.	Integrate performance profiling capabilities into your applications with **Caliper** Analyze hierarchical performance data with **Hatchet** Optimize application performance on supercomputers with **Thicket**
August 17, 2023	9:00a.m.–11:00a.m.	Use **RAJA** to run and port codes quickly across NVIDIA, AMD, and Intel GPUs Discover, provision, and manage HPC memory with **Umpire**
August 22, 2023	9:00a.m.–11:00a.m.	Visualize and analyze your simulations in situ with **Ascent**
August 24, 2023	9:00a.m.–11:00a.m.	Leverage robust, flexible software components for scientific applications with **Axom**
August 29, 2023	9:00a.m.–11:00a.m.	Analyze runs of your code with **WEAVE**
August 31, 2023	9:00a.m.–11:00a.m.	Learn to run thousands of jobs in a workflow with **Flux**

Caliper: A Performance Profiling Library

2023 RADIUSS Tutorial Series

August 14, 2023

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Lawrence Livermore National Laboratory

Caliper: A Performance Profiling Library

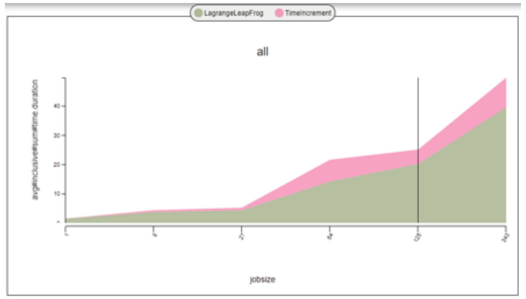
- Integrates a performance profiler into your program
  - Profiling is always available
  - Simplifies performance profiling for application end users
- Common instrumentation interface
  - Provides program context information for other tools
- Designed for HPC
  - MPI, OpenMP, CUDA, HIP, Kokkos support; call-stack sampling; hardware counters; memory profiling

Caliper Use Cases

- Lightweight always-on profiling
  - Performance summary report for each run
- Performance debugging
- Performance introspection
- Comparison studies across runs
  - Performance regression testing
  - Configuration and scaling studies
- Automated workflows

Performance reports

Path	Min time/rank	Max time/rank	Avg time/rank	Time %
main	0.000119	0.000119	0.000119	7.079120
mainloop	0.000067	0.000067	0.000067	3.985723
foo	0.000646	0.000646	0.000646	38.429506
init	0.000017	0.000017	0.000017	1.011303



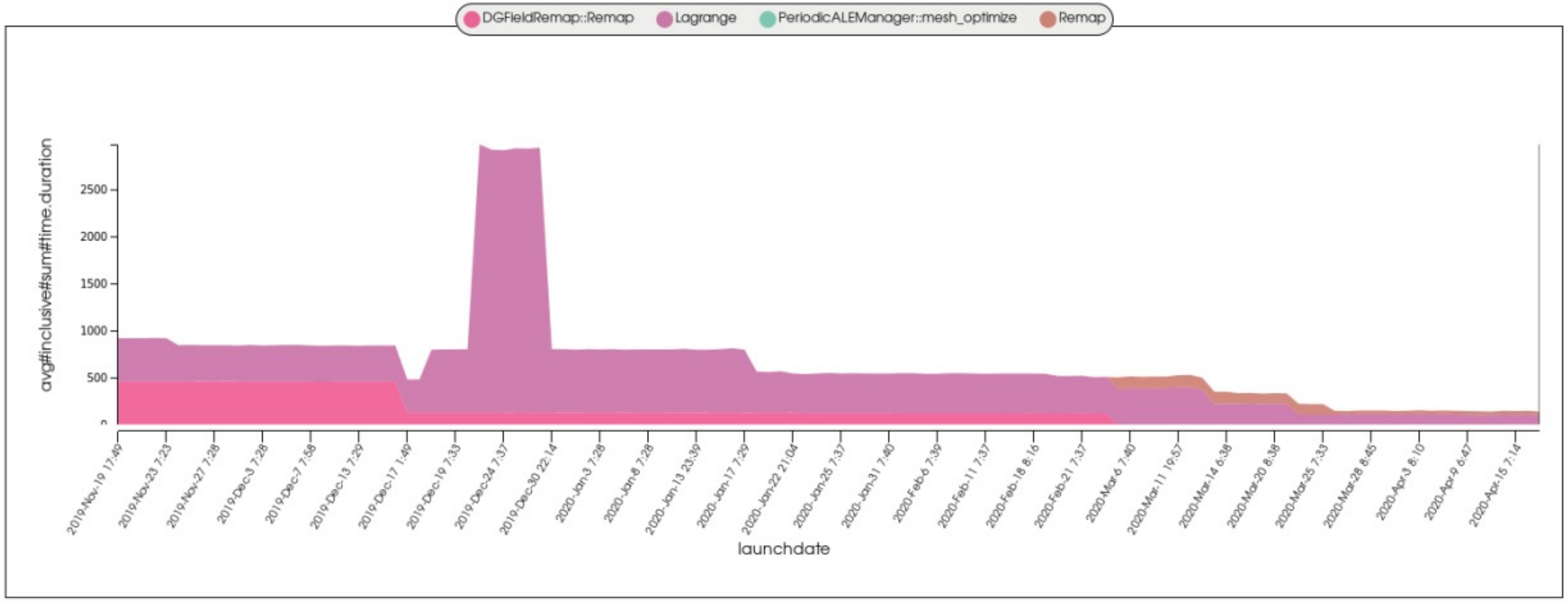
Comparing runs

```
0.000 foo
├─ 5.000 bar
|  ├─ 5.000 baz
|  └─ 10.000 grault
├─ 0.000 qux
|  └─ 5.000 quux
|     └─ 10.000 corge
|        ├─ 5.000 bar
|        |  ├─ 5.000 baz
|        |  └─ 10.000 grault
|        ├─ 10.000 grault
|        └─ 15.000 garply
└─ 0.000 waldo
```

Debugging

Building Automated Performance Analysis Workflows

Enabling performance analysis as a routine activity
for HPC software development

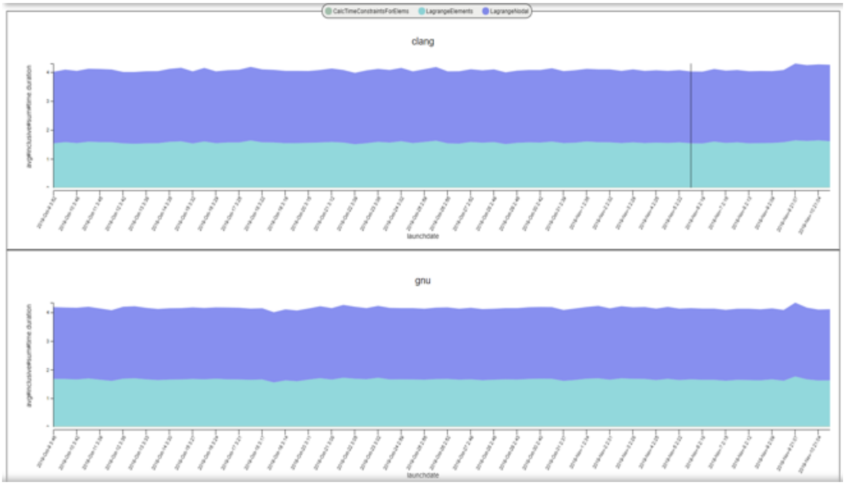


Nightly test performance of a large physics code over 5 months

Performance Analysis with Caliper, SPOT, Hatchet, and Thicket

"spot" config

Pre-populated Jupyter notebooks



SPOT and Thicket:
Analysis of
large collections of runs

```
#include <caliper/cali.h>

void LagrangeElements(Domain& domain,
Index_t numElem)
{
   CALI_CXX_MARK_FUNCTION;
// ...
```

Caliper:
Instrumentation and Profiling

hatchet-region-profile,
hatchet-sample-profile

```
0.000 foo
├─ 5.000 bar
|  ├─ 5.000 baz
|  └─ 10.000 grault
├─ 0.000 qux
|  └─ 5.000 quux
|     └─ 10.000 corge
|        ├─ 5.000 bar
|        |  ├─ 5.000 baz
|        |  └─ 10.000 grault
|        ├─ 10.000 grault
|        └─ 15.000 garply
└─ 0.000 waldo
```

Hatchet:
Call graph analysis in Python

Materials, Contact & Links

- Tutorial materials: https://github.com/daboehme/caliper-tutorial

```
$ git clone --recursive https://github.com/daboehme/caliper-tutorial.git
$ . setup-env.sh
```

- GitHub repository: https://github.com/LLNL/Caliper
- Documentation: https://llnl.github.io/Caliper
- GitHub Discussions: https://github.com/LLNL/Caliper/discussions

- Contact: David Boehme (boehme3@llnl.gov)

Using Caliper

Using Caliper: Workflow

```
cali::ConfigManager mgr;
mgr.add(opts.caliperConfig.c_str());
mgr.start();
// ...
mgr.flush();
```

ConfigManager API

```
Path          Min time/rank Max time/rank
main               0.000119      0.000119
  mainloop         0.000067      0.000067
    foo            0.000646      0.000646
  init             0.000017      0.000017
```

Human-readable reports

```
#include <caliper/cali.h>

void LagrangeElements(Domain& domain,
Index_t numElem)
{
   CALI_CXX_MARK_FUNCTION;
// ...
```

Source-code annotation API

```
0.000 foo
├─ 5.000 bar
│  ├─ 5.000 baz
│  └─ 10.000 grault
├─ 0.000 qux
│  └─ 5.000 quux
│     └─ 10.000 corge
│        ├─ 5.000 bar
│        │  ├─ 5.000 baz
│        │  └─ 10.000 grault
│        ├─ 10.000 grault
│        └─ 15.000 garply
└─ 0.000 waldo
```

```
$ CALI_CONFIG=runtime-report ./app
```

Environment variables

Profile/trace data processing
(e.g., Hatchet or Thicket)

Code Instrumentation

Runtime Configuration

Data Analysis

Region Profiling: Marking Code Regions

C/C++

```
#include <caliper/cali.h>

void main() {
  CALI_MARK_BEGIN(”init”);

  do_init();

  CALI_MARK_END(”init”);
}
```

Fortran

```
USE caliper_mod


CALL cali_begin_region(‘init’)

CALL do_init()

CALL cali_end_region(‘init’)
```

- Use annotation macros (C/C++) or functions to mark and name code regions

Region Profiling: Best Practices

- Be selective: Instrument high-level program subdivisions (kernels, phases, ...)
- Be clear: Choose meaningful names
- Start small: Add instrumentation incrementally

```
RAJA::ReduceSum<RAJA::omp_reduce, double> ompdot(0.0);

CALI_MARK_BEGIN(”dotproduct”);

RAJA::forall<RAJA::omp_parallel_for_exec>(RAJA::RangeSegment(0, N), [=] (int i) {
  ompdot += a[i] * b[i];
});
dot = ompdot.get();

CALI_MARK_END(”dotproduct”);
```

Caliper annotations give meaningful names to high-level program constructs

Region Profiling: Printing a Runtime Report

```
$ cd Caliper/build
$ make cxx-example
$ CALI_CONFIG=runtime-report ./examples/apps/cxx-example
```

```
Path         Min time/rank Max time/rank Avg time/rank Time %
main              0.000119      0.000119      0.000119  7.079120
  mainloop        0.000067      0.000067      0.000067  3.985723
    foo           0.000646      0.000646      0.000646 38.429506
  init            0.000017      0.000017      0.000017  1.011303
```

- Set the CALI_CONFIG environment variable to access Caliper's built-in profiling configurations
- "runtime-report" measures, aggregates, and prints time in annotated code regions

List of Caliper's Built-in Profiling Recipes

Config name	Description
runtime-report	Print a time profile for annotated regions
loop-report	Print summary and time-series information for loops
mpi-report	Print time spent in MPI functions
sample-report	Print time spent in regions using call-path sampling
event-trace	Record a trace of region enter/exit events in .cali format
hatchet-region-profile	Record a region time profile for processing with hatchet or cali-query
hatchet-sample-profile	Record a sampling profile for processing with hatchet or cali-query
spot	Record a time profile for the SPOT web visualization framework or Thicket

Use `cali-query --help=configs` to list all built-in configs and their options

Built-In Profiling Recipes: Configuration String Syntax

Config name specifies the kind of performance measurement

Parameters enable additional features, metrics, or output options

```
$ CALI_CONFIG="runtime-report(mem.highwatermark,output=stdout)" ./examples/apps/cxx-example
```

```
Path         Min time/rank Max time/rank Avg time/rank    Time % Allocated MB
main              0.000179      0.000179      0.000179 2.054637      0.000047
  mainloop        0.000082      0.000082      0.000082 0.941230      0.000016
    foo           0.000778      0.000778      0.000778 8.930211      0.000016
  init            0.000020      0.000020      0.000020 0.229568      0.000000
```

- Most Caliper measurement recipes have optional parameters to enable additional features or configure output settings

Sample Profiling

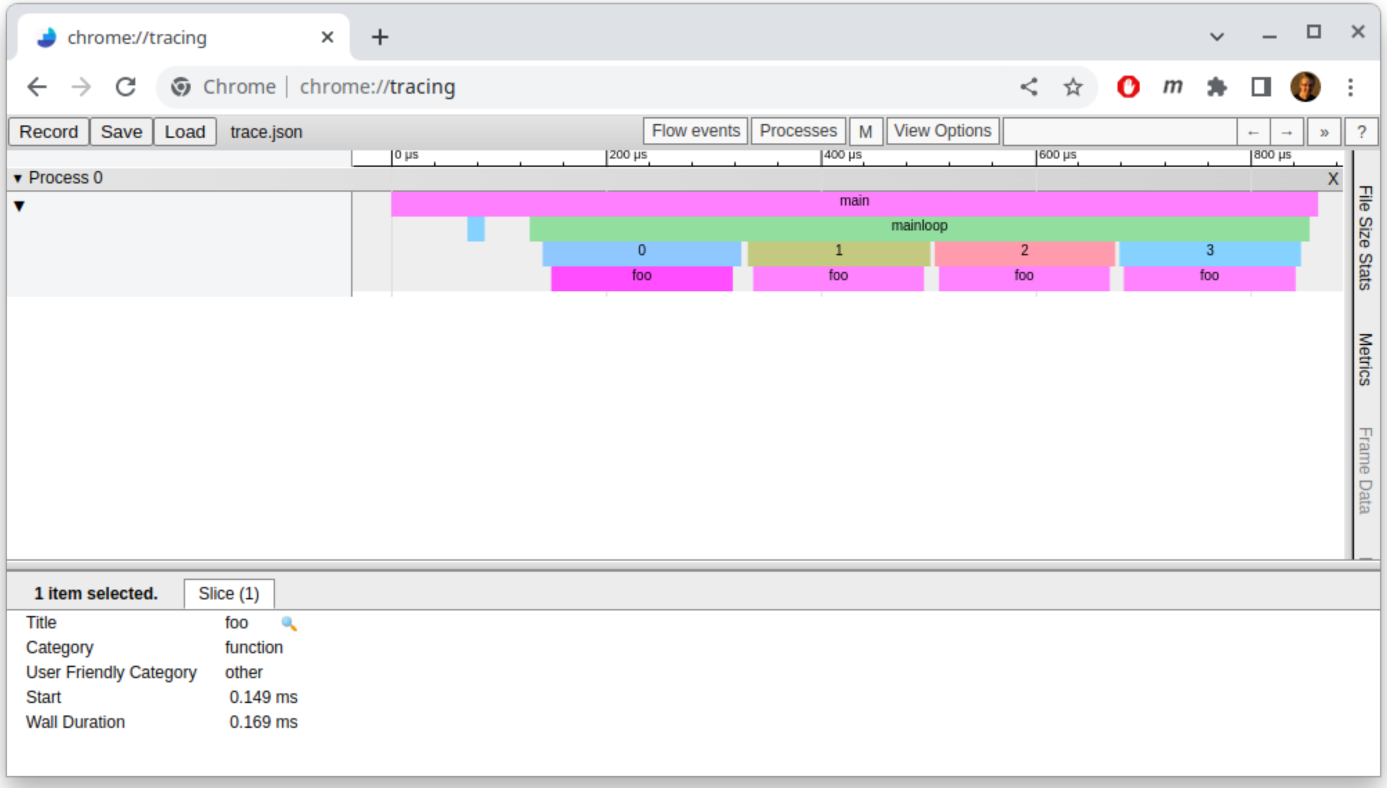
```
$ CALI_CONFIG=sample-report ./lulesh2.0
```

```
Path    Min time/rank Max time/rank Avg time/rank Total time   Time % Function
main
 |-          0.005000      0.005000      0.005000   0.035000 0.059691 Domain::AllocateElemPersistent
 |-          0.005000      0.005000      0.005000   0.035000 0.059691 Domain::SetupThreadSupportStru
 |-          0.005000      0.005000      0.005000   0.005000 0.008527 sysmalloc
 |-          0.005000      0.005000      0.005000   0.005000 0.008527 Domain::BuildMesh(int, int, in
lulesh.cycle
   TimeIncrement
    |-       0.075000      0.740000      0.355000   2.840000 4.843523 gomp_barrier_wait_end
    |-       0.005000      0.060000      0.027857   0.195000 0.332566 psm2_mq_ipeek2
    |-       0.005000      0.005000      0.005000   0.015000 0.025582 psm_no_lock
    |-       0.005000      0.060000      0.023571   0.165000 0.281402 psm_progress_wait
    |-       0.015000      0.030000      0.022143   0.155000 0.264347 mv2_shm_bcast
    |-       0.005000      0.025000      0.013750   0.055000 0.093801 amsh_poll
    |-       0.005000      0.010000      0.007500   0.030000 0.051164 psmi_poll_internal
...
```

The *sample-report* recipe samples source functions or file+line locations.

Event Tracing and Timeline Visualization

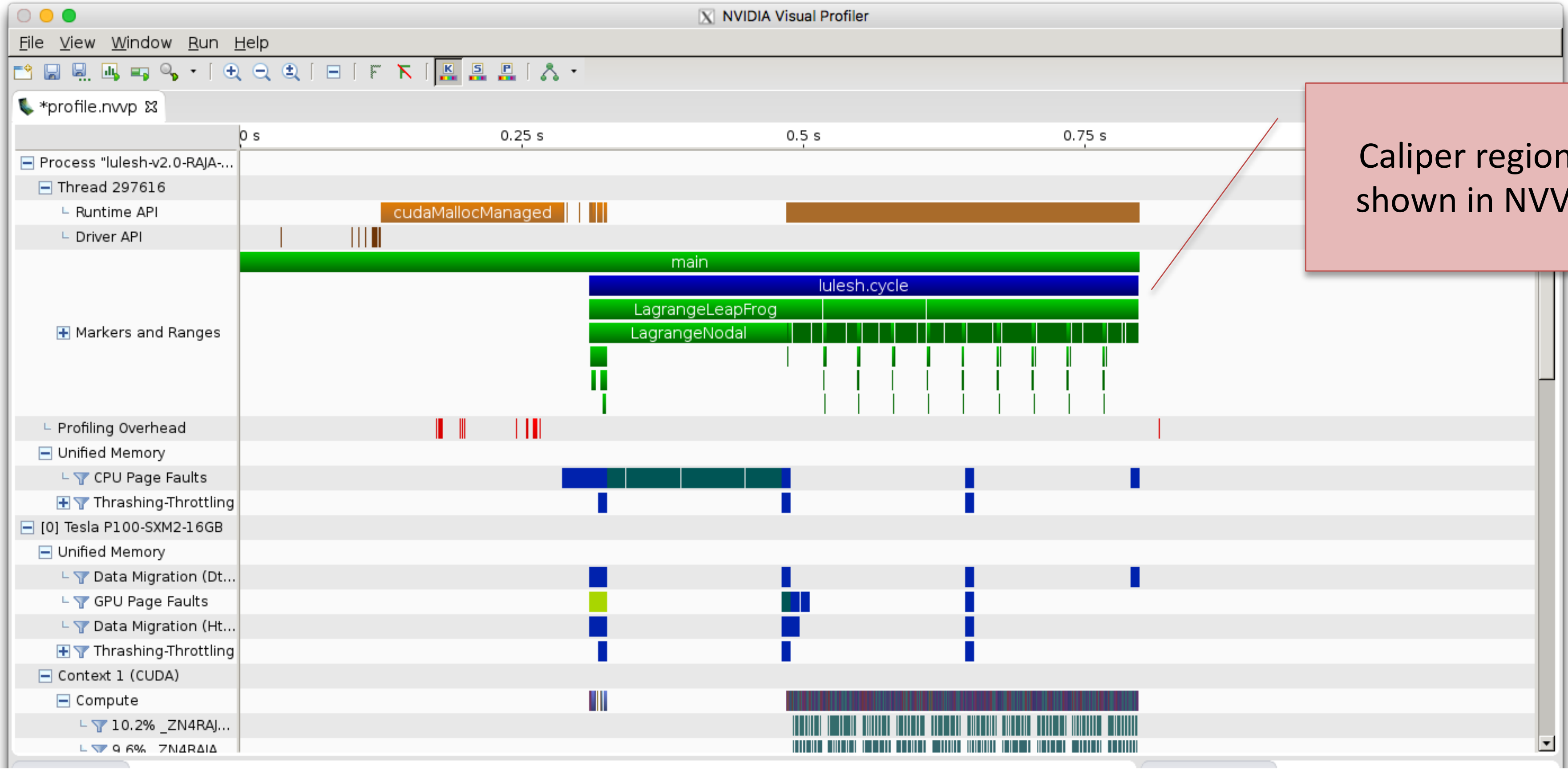
```
$ CALI_CONFIG=event-trace,output=trace.cali ./lulesh2.0
$ cali2traceevent.py trace.cali trace.json
```



Caliper event traces can be visualized in Chrome trace browser or Perfetto

Forwarding Annotations to Third-Party Tools

```
$ CALI_CONFIG=nvtx nvprof <nvprof-opts> ./app
```



Caliper regions shown in NVVP

The nvtx config forwards annotations to NVidia's NVTX API

Call Graph Analysis with the Hatchet Python Library

- Caliper records data for hatchet with `hatchet-region-profile` or `hatchet-sample-profile`

```
$ CALI_CONFIG=hatchet-sample-profile srun -n 8 ./lulesh2.0
```

Hatchet allows manipulation, computation, comparison, and visualization of call graph data

```
>>> gf = hat.GraphFrame.from_caliper_json('/Users/boehme3/Documents/Data/lulesh_8x4_callpath-sample-profile.json')
>>> gf.subgraph_sum(['time'])
>>> gf = gf.filter(lambda x: x['name'] != '__restore_rt')
>>> gf = gf.filter(lambda x: x['name'].find('_omp_fn') == -1).squash()
>>> print(gf.tree())

    __          __       __         __
   / /_  ____ _/ /______/ /_  ___  / /_
  / __ \/ __ `/ __/ ___/ __ \/ _ \/ __/
 / / / / /_/ / /_/ /__/ / / /  __/ /_
/_/ /_/\__,_/\__/\___/_/ /_/\___/\__/  v1.3.0

5.850 __clone
└─ 5.850 start_thread
   └─ 5.850 gomp_thread_start
      ├─ 0.070 CalcElemVolume(dou...t*, double const*)
      ├─ 0.005 UNKNOWN 4
      ├─ 0.075 cbrt
      │  ├─ 0.000 frexp
      │  └─ 0.020 ldexp
      │     └─ 0.010 scalbn
      ├─ 0.005 gomp_barrier_wait
      ├─ 2.545 gomp_barrier_wait_end
      ├─ 0.605 gomp_team_barrier_wait_end
```

Control Profiling Programmatically: The ConfigManager API

```
#include <caliper/cali.h>
#include <caliper/cali-manager.h>

int main(int argc, char* argv[])
{
  cali::ConfigManager mgr;
  mgr.add(argv[1]);
  if (mgr.error())
    std::cerr << mgr.error_msg() << "\n";

  mgr.start();
  // ...
  mgr.flush();
}
```

- Use ConfigManager to access Caliper's built-in profiling configurations

```
$ ./app runtime-report
```

- Now we can use command-line arguments or other program inputs to enable profiling

Manual Configuration Allows Custom Analyses

```
cali-query -q "select alloc.label#cupti.fault.addr as Pool,
  cupti.uvm.kind as UVM\ Event,
  scale(cupti.uvm.bytes,1e-6) as MB,
  scale(cupti.activity.duration,1e-9) as Time
group by
  prop:nested,alloc.label#cupti.fault.addr,cupti.uvm.kind
where cupti.uvm.kind format tree” trace.cali
```

caliper.config

```
CALI_SERVICES_ENABLE=alloc,cupti,cuptitrace,mpi,trace,recorder
CALI_ALLOC_RESOLVE_ADDRESSES=true
CALI_CUPTI_CALLBACK_DOMAINS=sync
CALI_CUPTITRACE_ACTIVITIES=uvm
CALI_CUPTITRACE_CORRELATE_CONTEXT=false
CALI_CUPTITRACE_FLUSH_ON_SNAPSHOT=true
```

```
Path
main
  solve
    TIME_STEPPING
      enforceBC
        CURVI in EnforceBC
          CurviCartIC
            CurviCartIC::PART 3  Pool          UVM Event       MB          Time
              curvilinear4sgwind UM_pool       pagefaults.gpu              2.806946
              curvilinear4sgwind UM_pool       HtoD            7862.747136 0.232238
              curvilinear4sgwind UM_pool_temps pagefaults.gpu              0.130167
              curvilinear4sgwind UM_pool       DtoH            9986.441216 0.378583
              curvilinear4sgwind UM_pool       pagefaults.cpu
```

- Mapping CPU/GPU unified memory transfer events to Umpire memory pools in SW4

Ensemble Performance Data Collection for Thicket

```
#include <caliper/cali.h>

void LagrangeElements(Domain& domain,
Index_t numElem)
{
   CALI_CXX_MARK_FUNCTION;
// ...
```

Region instrumentation

```
adiak::clustername();
adiak::jobsize();

adiak::value("iterations", opts.its);
adiak::value("problem_size", opts.nx);
adiak::value("num_regions", opts.numReg);
```

Metadata collection [Adiak]

```
cali::ConfigManager mgr;
mgr.add(opts.caliperConfig.c_str());
mgr.start();
// ...
mgr.flush();
```

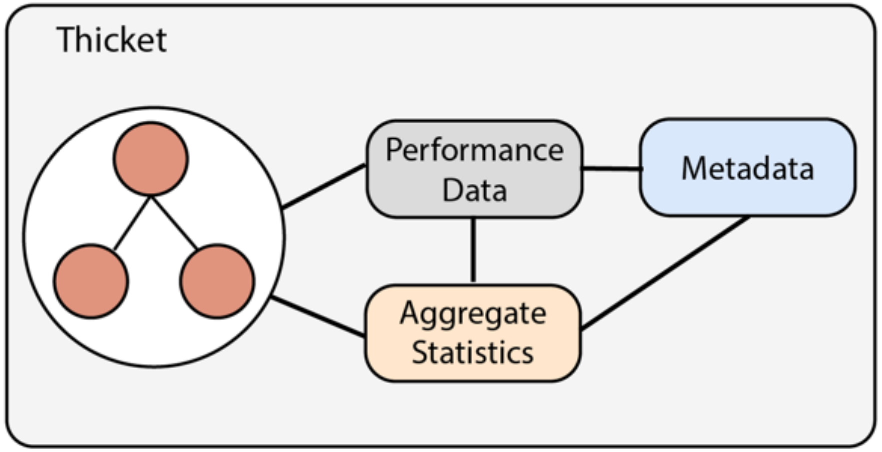
Caliper configuration

```
$ ./app -P spot
```

Run program with the “spot” profiling config

Profile data (.cali)

Experiment directory



Thicket analysis framework

Recording Program Metadata with the Adiak Library

TeaLeaf_CUDA example [C++]

```
#include <adiak.hpp>

adiak::user();
adiak::launchdate();
adiak::jobsize();

adiak::value("end_step", readInt(input, "end_step"));
adiak::value(”halo_depth", readInt(input, ”halo_depth"));

if (tl_use_ppcg) {
  adiak::value(“solver”, “PPCG”);
// [...]
```

Use built-in Adiak functions to collect common metadata

Use key:value functions to collect program-specific data

- Use the Adiak C/C++ library to record program metadata
  - Environment info (user, launchdate, system name, ...)
  - Program configuration (input problem description, problem size, ...)

- Enables performance comparisons across runs. Required for SPOT and Thicket.

Adiak: Built-in Functions for Common Metadata

```
adiak_user();                /* user name */
adiak_uid();                 /* user id */
adiak_launchdate();          /* program start time (UNIX timestamp) */
adiak_executable();          /* executable name */
adiak_executablepath();      /* full executable file path */
adiak_cmdline();             /* command line parameters */
adiak_hostname();            /* current host name */
adiak_clustername();         /* cluster name */

adiak_job_size();            /* MPI job size */
adiak_hostlist();            /* all host names in this MPI job */

adiak_walltime();            /* wall-clock job runtime */
adiak_cputime();             /* job cpu runtime */
adiak_systime();             /* job sys runtime */
```

- Adiak comes with built-in functions to collect common environment metadata

Adiak: Recording Custom Key-Value Data in C++

C++

```
#include <adiak.hpp>

vector<int> ints { 1, 2, 3, 4 };
adiak::value("myvec", ints);

adiak::value("myint", 42);
adiak::value("mydouble", 3.14);
adiak::value("mystring", "hi");

adiak::value("mypath", adiak::path("/dev/null"));
adiak::value("compiler", adiak::version("gcc@8.3.0"));
```

- Adiak supports many basic and structured data types
  - Strings, integers, floating point, lists, tuples, sets, ...
- `adiak::value()` records key:value pairs with overloads for many data types

Adiak: Recording Custom Key-Value Data in C

C

```
#include <adiak.h>

int ints[] = { 1, 2, 3, 4 };
adiak_namevalue(“myvec”,    adiak_general, NULL, “[%d]”, ints, 4);

adiak_namevalue(“myint”,    adiak_general, NULL, “%d”, 42);
adiak_namevalue(“mydouble”, adiak_general, NULL, “%f”, 3.14);
adiak_namevalue(“mystring”, adiak_general, NULL, “%s”, “hi”);

adiak_namevalue(“mypath”,   adiak_general, NULL, “%p”, “/dev/null”);
adiak_namevalue(“compiler”, adiak_general, NULL, “%v”, “gcc@8.3.0”);
```

- In C, `adiak_namevalue()` uses printf()-style descriptors to determine data types

Live Demo

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ECP

EXASCALE COMPUTING PROJECT

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