The Case for a Common Instrumentation Interface for HPC Codes

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Instrumentation Reality (everyone does it)

Runtime behavior of production runs is a black box without it

- Explicit, *targeted* instrumentation allows for
  - Low overhead, always-active notifications about runtime behavior
- Exposing internal timer data is helpful for
  - Light-weight profiling (report-on-exit)
  - Interactive bottleneck analysis (by users/sites)
  - Monitoring for regressions due to toolchain/source changes
  - Dynamic tuning in runtimes / system tools
- Many/most/all applications already have some instrumentation - but mostly one-off implementations
- A common, agreed-on interface could benefit everybody

Several potential examples

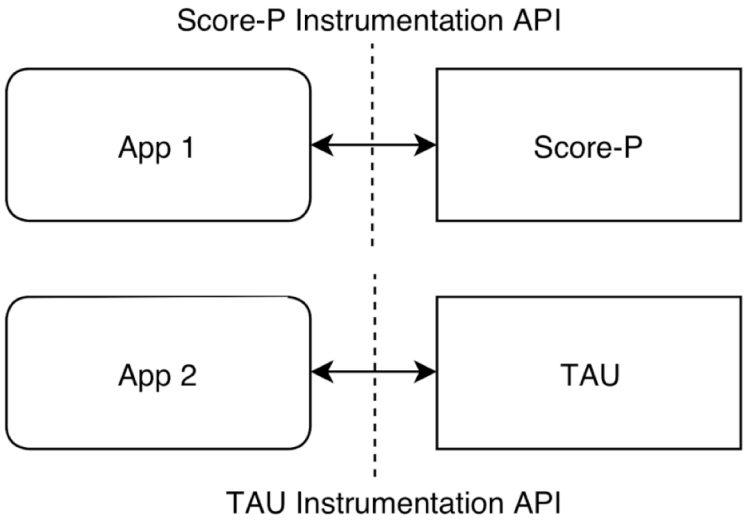
- Caliper
- TiMemory
- PerfStubs
- GOTCHA
- TAU
- Score-P
- -finstrument-functions
- Others...

Targeted instrumentation:

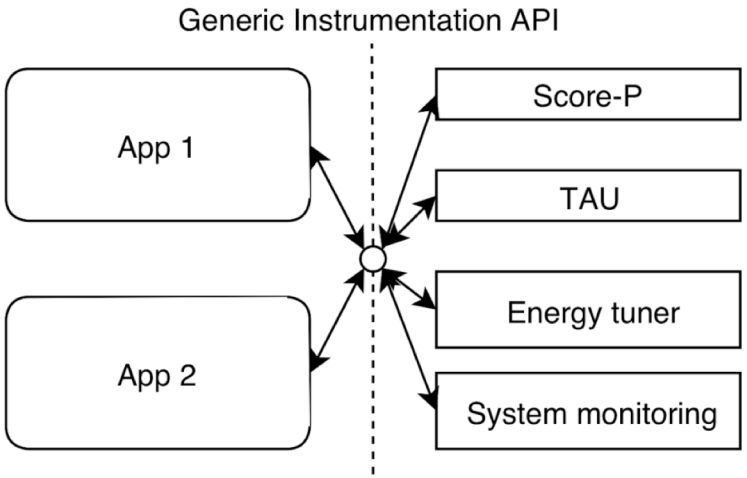
- Granularity control
- Explicit interpretation
- Reproducibility
- Robustness

But adding a tool to a build can be...frustrating

Always-On Instrumentation Interfaces



(a) only enabled during profiling experiments



(b) adaptive, always-on instrumentation interface

Caliper

- Performance Analysis Toolbox in a Library
  - Instrumentation API
  - Measurement config API
- Supports lightweight always-on profiling and detailed performance debugging
- Configuration at runtime via API or environment

https://github.com/LLNL/Caliper

```
int main(int argc, char* argv[])
{
    cali::ConfigManager mgr;
    mgr.add("runtime-report");
    mgr.start();

    CALI_MARK_FUNCTION_BEGIN;

    CALI_CXX_MARK_LOOP_BEGIN(mainloop, "main loop");
    for (int i = 0; i < count; ++i) {
        CALI_CXX_MARK_LOOP_ITERATION(mainloop, i);
        t += foo(i);
    }
    CALI_CXX_MARK_LOOP_END(mainloop);

    CALI_MARK_FUNCTION_END;
    mgr.flush();
}
```

TiMemory

- Arbitrarily-composable, type-safe C++ API
  - C and Python bindings
- Users can write their own fully integratable measurement or analysis tools
  - Can store data of any type and reprocess data to any other type
- Select tools at compile-time or run-time
- Single handler for multiple tools

```
auto_tuple<real_clock, cpu_roofline<double>>;
```

- No nesting restrictions
  - Start/stop in any order w/o artifacts
  - Geant4 attaches timers to particle objects
- Template interface simplifies GOTCHA generation to a single LOC
  - Extracts return type and args
  - Mangler for non-templated C++ functions
  - Inspect incoming arguments before function call and result before returning

```
TIMEMORY_C_GOTCHA(tool, idx, MPI_Allreduce);
```

https://github.com/NERSC/timemory

TiMemory

Sample Components

- wall_clock
- cpu_clock
- peak_rss
- gperf_cpu_profiler
- caliper
- nvtx_marker
- cupti_activity
- cupti_counters
- cpu_roofline<Types…>
  - e.g. cpu_roofline<double>
- gpu_roofline<Types…>
  - e.g. gpu_roofline<half2, float>

Sample Bundles

- type A = component_tuple<wall_clock, peak_rss>;
- type B = component_list<caliper, nvtx_marker>;
- type C = component_list<B, gpu_roofline<float>>;
- type D = auto_hybrid<A, C>;
- D obj;
  - obj.mark_begin(cudaStream_t);
  - obj.get<wall_clock>();
    - Get reference to individual tool
  - storage<wall_clock>::instance()->get();
    - Get entire call-stack

TiMemory instrumentation examples

```
// LIBRARY (C, C++)
#define INSTRUMENT_CREATE   uint64_t id;
#define INSTRUMENT_START    timemory_begin_record(__FUNCTION__, &id);
#define INSTRUMENT_STOP     timemory_end_record(id);
```

```
// AUTO_TIMER (C)
#define INSTRUMENT_START    void* timer = TIMEMORY_AUTO_TIMER("");
#define INSTRUMENT_STOP     FREE_TIMEMORY_AUTO_TIMER(timer);
```

```
// AUTO_TIMER (C++)
#define INSTRUMENT_START    TIMEMORY_AUTO_TIMER("");
```

```
# import
from timemory.util import auto_timer

# decorator for function
@auto_timer("")

# context-manager
with auto_timer("nested", mode="blank"):
```

PerfStubs

- Thin, stubbed-out, “adapter” interface for instrumentation
- The library *doesn’t do any measurement*
- Uses dlsym() or weak/strong symbol replacement to discover timer library implementation symbols
  - If found, sets function pointers to perform measurement
- Could be implemented as *observer* pattern but currently only allows 1 tool to implement the API
- Used with Alpine/Ascent, PETSc, PapyrusKV, proxy/demo applications, will use with ADIOS2
- C/C++ and Fortran macros

https://github.com/khuck/perfstubs

PerfStubs Example

```
1 #define PERFSTUBS_TIMER_START_FUNC(_timer) \
2     static void * _timer = NULL; \
3     if (_timer == NULL) \
4         _timer = psTimerCreate(psMakeTimerName(__FILE__, __func__, __LINE__)); \
5     psTimerStart(_timer);
6
7 #define PERFSTUBS_TIMER_STOP_FUNC(_timer) \
8     psTimerStop(_timer);
9
10 void myfunc(void) {
11     /* Will generate something like: "myfunc [{filename.c} {123,0}]" */
12     PERFSTUBS_START_FUNC(timer);
13     ...
14     PERFSTUBS_STOP_FUNC(timer);
15 }
```

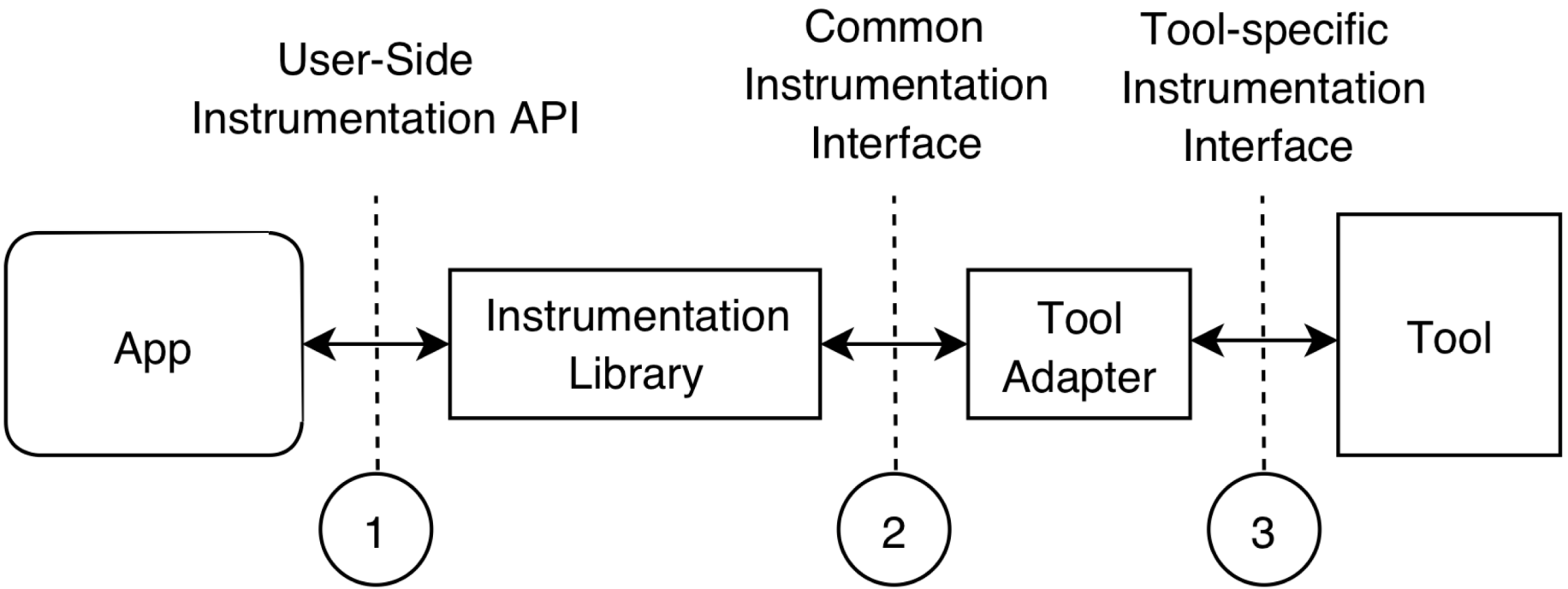
Potential use cases for common API:

- Performance regression testing / CI
- On-site application / library support
- Refactoring efforts
- 1st step in performance diagnosis
- Application/system monitoring
- Phase announcement (not detection) for energy saving strategies
- Feedback/control systems (assumes reconfigurable app)
- Startup tool discovery, instantiation
- Dynamic instantiation?

An Instrumentation Adapter Interface

- Should provide notification about
  - region enter/exit events
  - custom execution contexts / metrics (simulated years per day)
  - Metadata?
- Versioning / query for support of optional capabilities
  - enables extensibility / adaptation to custom use-cases
- Selective disabling of instrumentation points
  - enables methods for overhead control
- Multiplexing to multiple tools
- Back-channels from tool to application
  - enables feedback / setting application tuning parameters

An Instrumentation Adapter Interface



Instrumentation Evaluation Benchmark

- https://github.com/NERSC/instrumentation-benchmark
  - Suite of benchmark problems
    - Matrix multiplication in C and C++
    - Fibonacci calculation in C++
  - Generic specification of an instrumentation API
    - E.g. INSTRUMENT_CREATE(...)
    - Generates Python bindings for each benchmark problem per-API and makes them accessible as submodules
    - Python scripts to loop over all submodules, run benchmarks, generate statistics on overhead, and plot
  - Facilitate development of a front-end API
  - Facilitate research into optimal balance of flexibility and performance

Conclusion

- Need for common, high-level, runtime-available, context-aware application/library instrumentation
- Many applications/libraries already instrument
- Some implementations exist, can we figure out a high-level interface for pulling in useful tools?
- How much abstraction needed? 3 levels? 2?
- Project to evaluate solution(s) for quality, overhead
  - https://github.com/NERSC/instrumentation-benchmark
- Contact us!

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