TaskStubs

An Instrumentation Plugin for Asynchronous Task Based Runtimes and Tools

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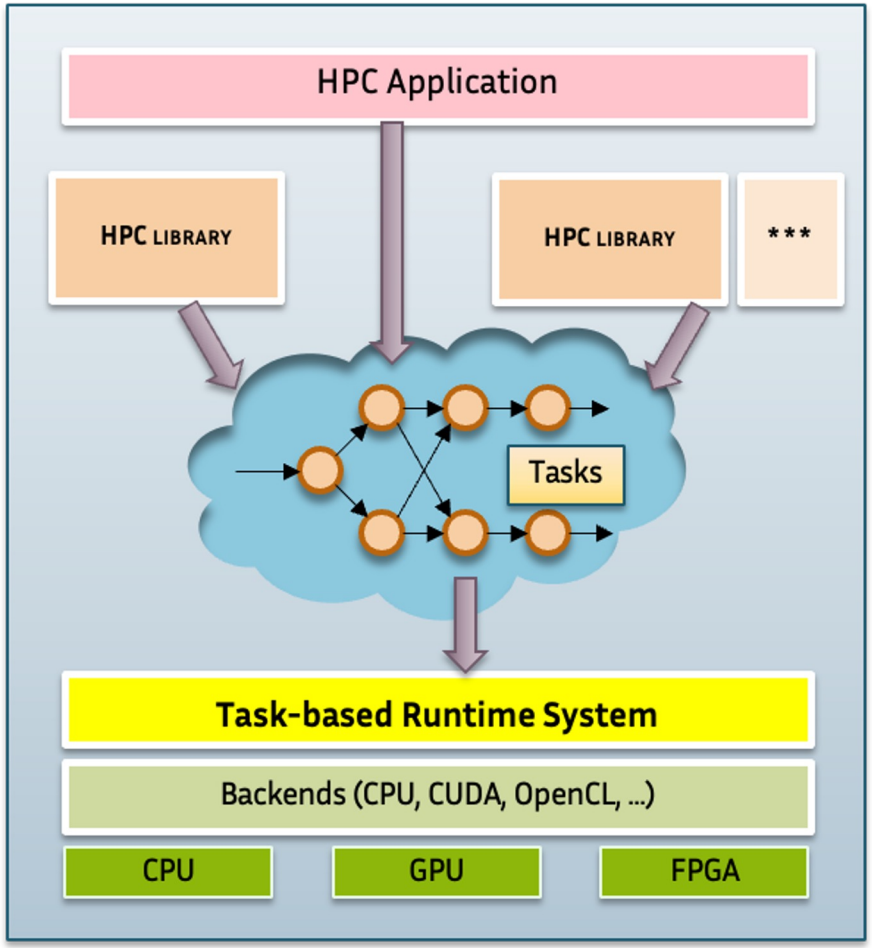
Programming models for HPC

Reducing or eliminating latency in high performance computing

- Asynchronous Tasking Models (ATM)
  - IRIS
  - PaRSEC
  - StarPU
  - …

Task-based runtime systems

- Asynchronous task scheduling
- Asynchronous data transfers
  - Network
  - Accelerators / GPUs
- Complex execution flows, data flows



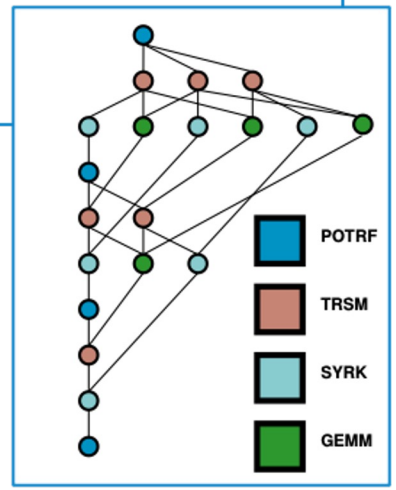
Motivation for an instrumentation plugin

ATM runtimes difficult to analyze for conventional HPC performance tools

- Program call stack vs dependency graph
  - Local execution context does not reflect logical program context
- Function life cycle vs task life cycle
  - Capturing full task life cycle stages
- Flow of execution vs flow of data
  - Data and code take different paths

```
for (j = 0; j < N; j++)
{
    starpu_task_insert( POTRF (RW,A[j][j]) );

    for (i = j+1; i < N; i++)
        starpu_task_insert( TRSM (RW,A[i][j], R,A[j][j]) );

    for (i = j+1; i < N; i++)
    {
        starpu_task_insert( SYRK (RW,A[i][i], R,A[i][j]) );

        for (k = j+1; k < i; k++)
            starpu_task_insert( GEMM (RW,A[i][k], R,A[i][j], R,A[k][j]) );
    }
}

starpu_task_wait_for_all();
```

Flow of task submissions



Dependence graph

Need for dedicated performance tools for ATM runtimes

- Yet, need to prevent **M** *Runtimes* x **N** *Tools* integration complexity

Introducing TaskStubs

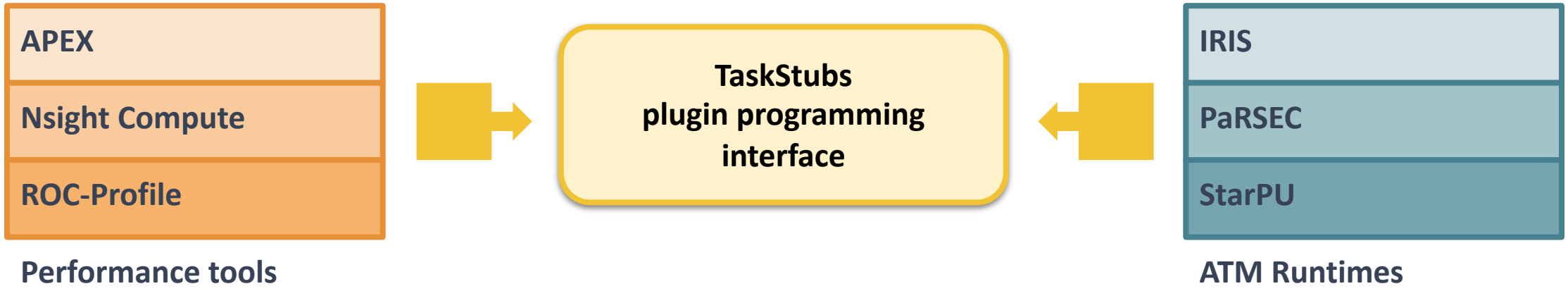
Instrumenting ATMs while preventing MxN integration complexity

- Generic plugin programming interface
- Enable coupling of performance tools and ATM runtimes

Contributions

API and software integration

- TaskStubs plugin programming interface
- Integration within three ATM runtimes
  - IRIS, PaRSEC, StarPU
- Integration with three performance tools
  - APEX, Nvidia Nsight ComputeTM, AMD ROC-Profiler



Requirements

Asynchronous tasking models measurements

- No assumptions about timer nesting
  - No perfectly nested timer stack
- No assumptions about immutable task / OS thread mapping
  - Yields
  - Asynchronous operations
- No one-to-one relationship between a parent timer and a child timer
  - Multiple children for one parent
  - Multiple parents for one child

- Ability to connect tasks after they are created
  - Full task / data dependency graph may not necessarily be known at task creation time

TaskStubs API Design

Timer object

- Performance state of a task
- Maintained with ATM's task object
  - Matches task lifetime
  - No timer stack needed
- 64-bit unsigned integer id assigned by perf. Tool
  - Memory address
  - Reference
  - GUID
- Callbacks

TaskStubs API Design

Other objects

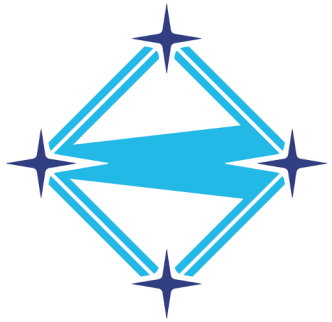
- Counters
  - Measure discrete values at points in time

- Event markers
  - Mark occurrences of specific events at points in time

TaskStubs-enabled ATM runtime systems

- **IRIS**
  - ORNL
  - https://iris-programming.github.io
- **PaRSEC**
  - ICL / UTK (+Inria)
  - https://icl.utk.edu/parsec/
- **StarPU**
  - Inria
  - https://starpu.gitlabpages.inria.fr

IRIS



PaRSEC

StarPU

Performance Tool Support

- **APEX**
  - Autonomic Performance Environment for eXascale
  - https://github.com/UO-OACISS/apex

- **NVTX**
  - NVIDIA Tools Extension Library
  - https://github.com/NVIDIA/NVTX

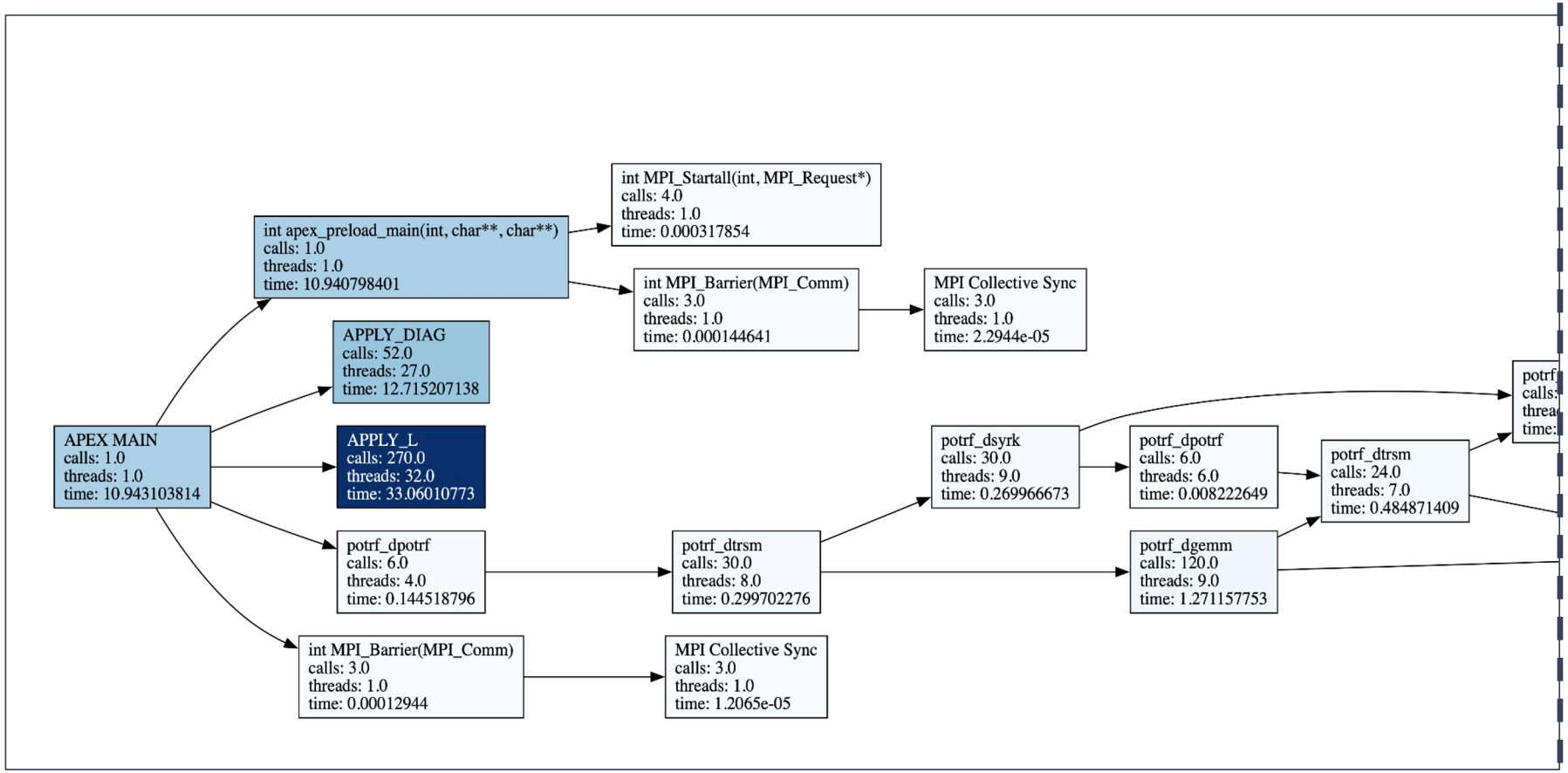
- **ROC-TX**
  - AMD ROCmTM application code instrumentation API

TaskStubs API Mappings

TaskStubs call	APEX	NVTX	ROCTX
initialize	apex::initialize	nvtxDomainCreateA	n/a
finalize	apex::finalize	nvtxDomainDestroy	n/a
timer_create	apex::new_task	nvtxDomainMarkEx	roctxMarkA
add_parents	timer->add_parents	n/a	n/a
add_children	timer->add_children	n/a	n/a
timer_schedule	apex::schedule	nvtxDomainMarkEx	roctxMarkA
timer_start	apex::start	nvtxDomainRangeStartEx	roctxRangeStartA
timer_yield	apex::yield	nvtxDomainRangeStopEx	roctxRangeStop
timer_resume	apex::resume	nvtxDomainRangeStartEx	roctxRangeStartA
timer_stop	apex::stop	nvtxDomainRangeStopEx	roctxRangeStop
timer_destroy	apex::destroy	nvtxDomainMarkEx	roctxMarkA
data_xfer_start	apex_task	nvtxDomainRangeStartEx	roctxRangeStartA
data_xfer_stop	apex_task	nvtxDomainStop	roctxRangeStop
command_start	apex timer start	nvtxDomainStartEx	roctxRangeStartA
command_stop	apex timer stop	nvtxDomainStop	roctxRangeStop
sample value	apex::sample_value	nvtxDomainMarkEx	n/a
mark_event	n/a	nvtxDomainMarkEx	roctxMarkA

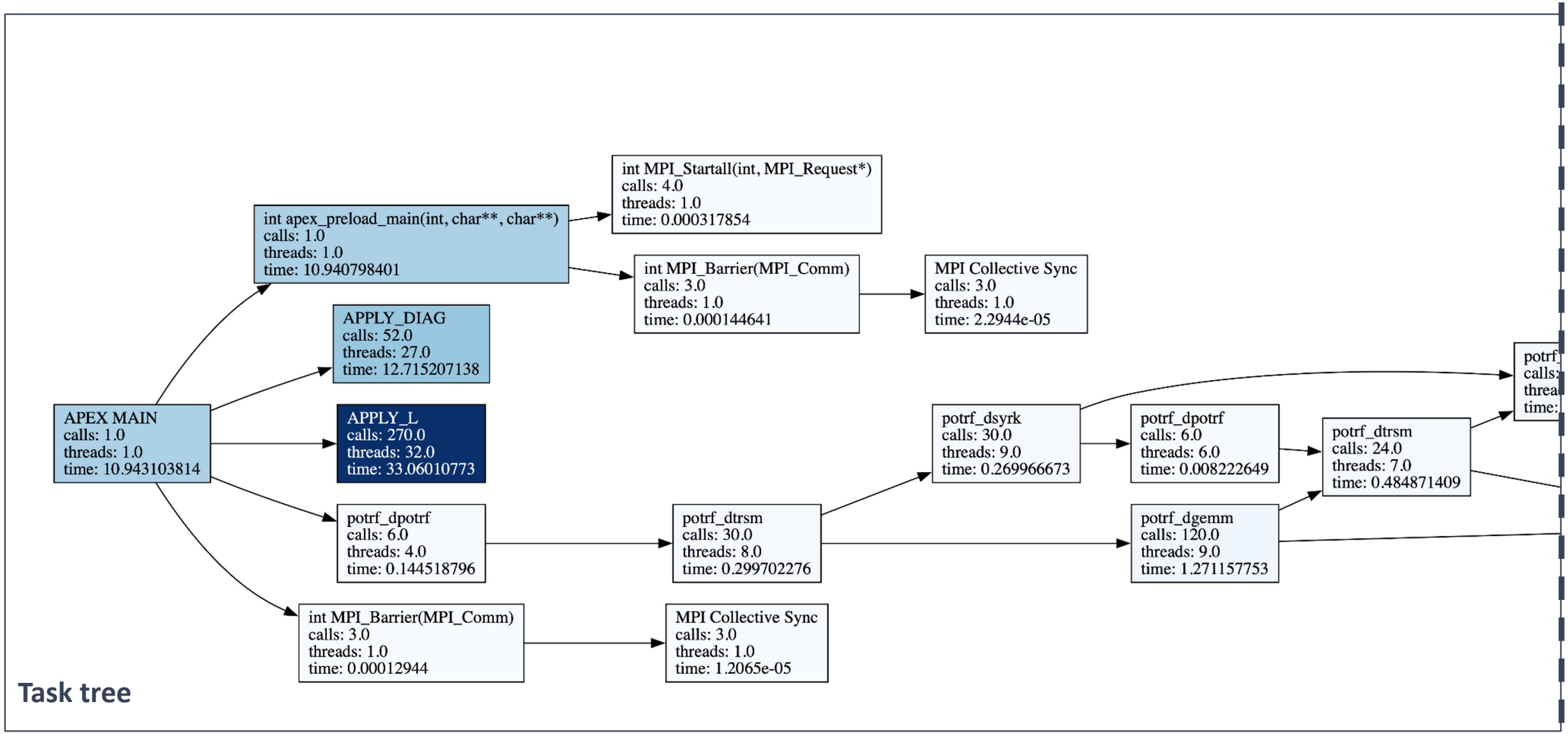
Experiments – PaRSEC / TaskStubs / APEX

Library dplasma: APEX task tree from testing_dpotrf()



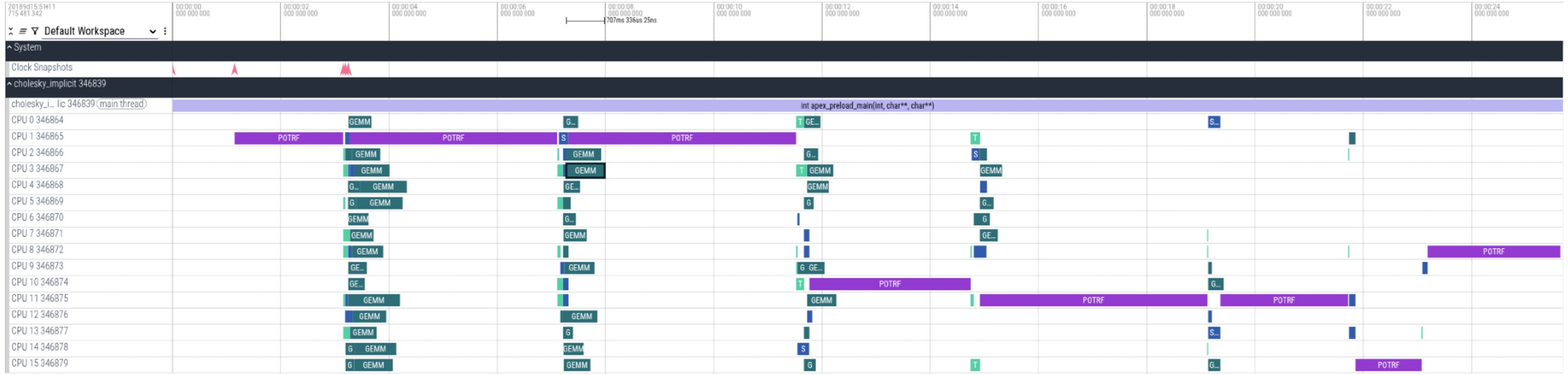
Task Tree

Experiments – PaRSEC / TaskStubs / APEX



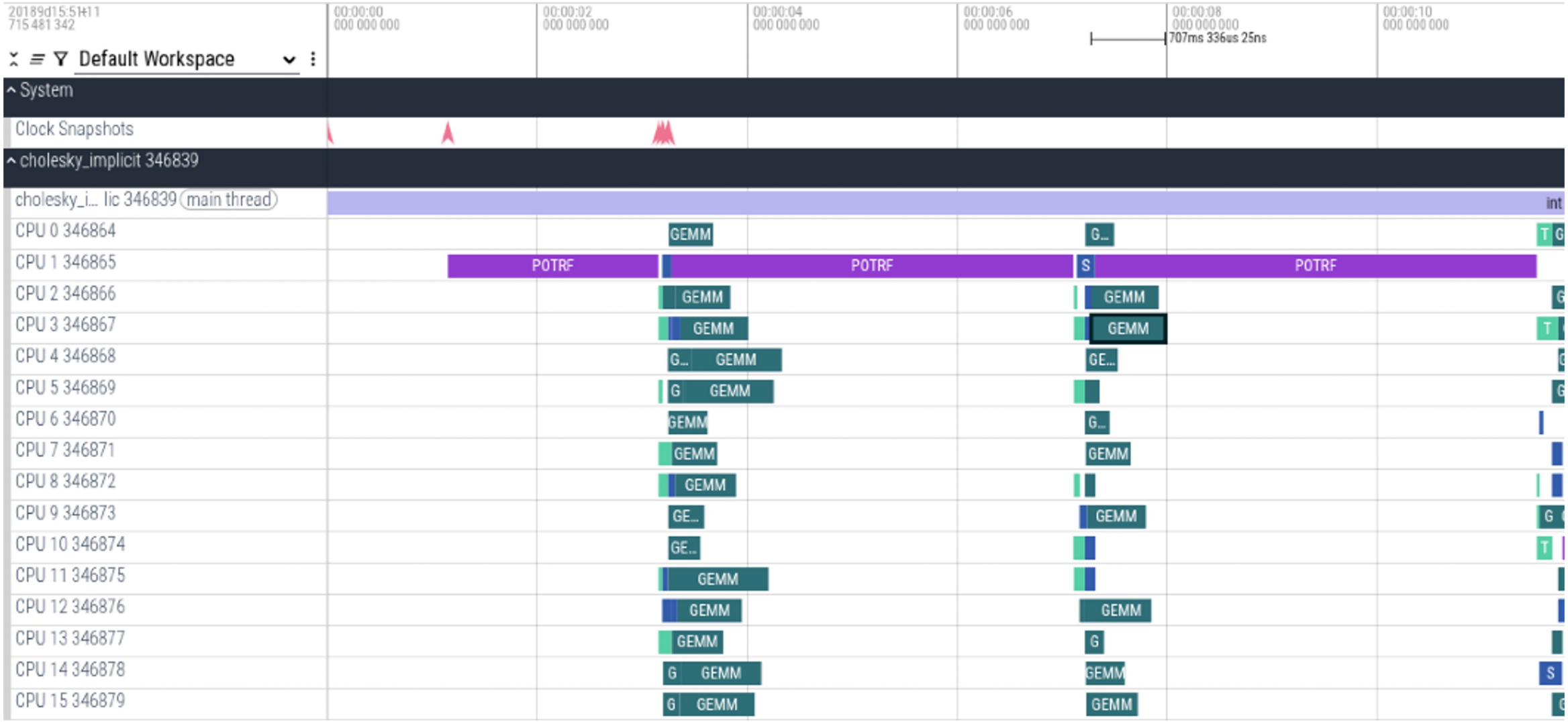
Experiments – StarPU / TaskStubs / APEX

Cholesky decomposition



Task trace visualization with Perfetto

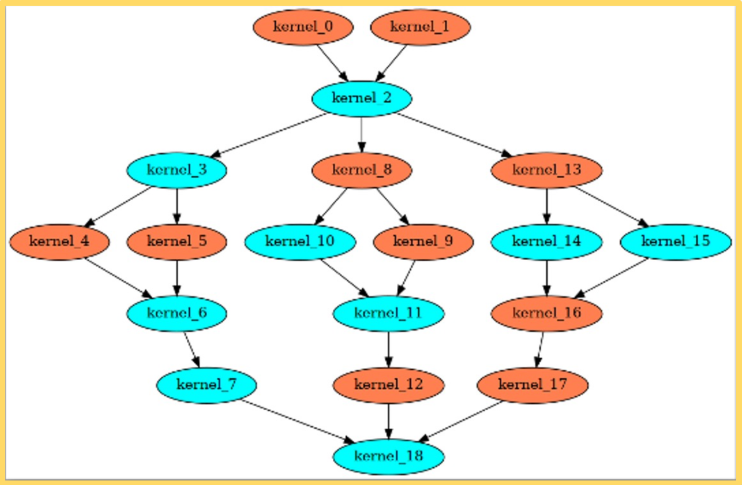
Experiments – StarPU / TaskStubs / APEX



Task trace visualization with Perfetto

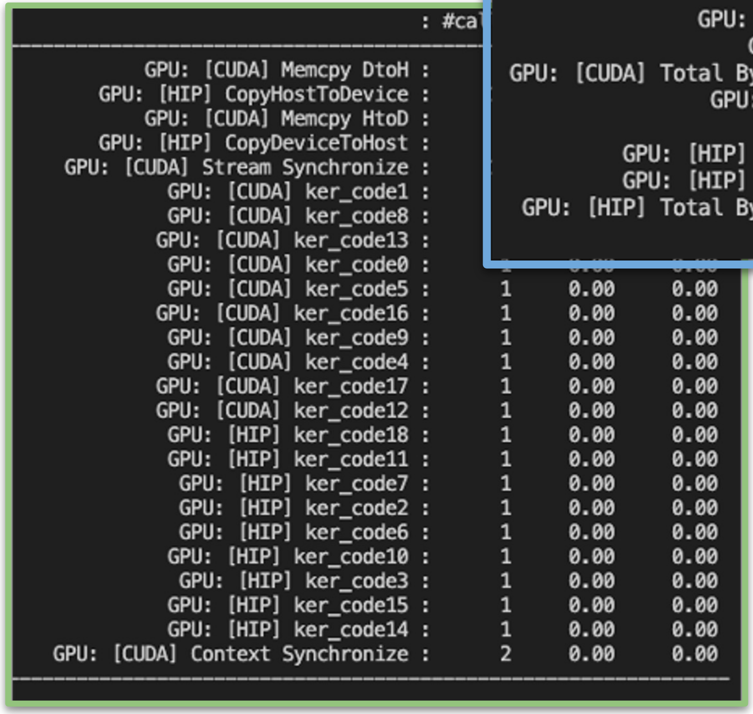
Experiments – IRIS / TaskStubs / APEX

Heterogeneous profiling



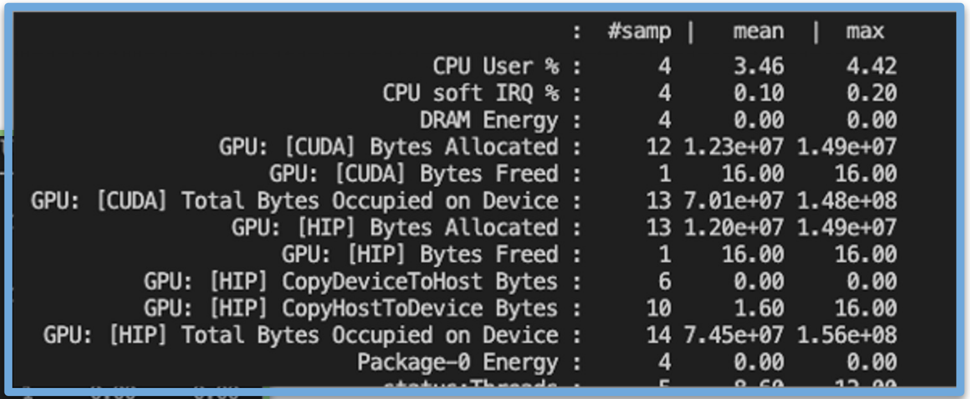
- IRIS DAG execution on NVIDIA and AMD GPUs
- Profiling with APEX

Brown: NVidia GPU
Cyan: AMD GPU



```
                                    : #ca
---------------------------------------------------------------
            GPU: [CUDA] Memcpy DtoH :
         GPU: [HIP] CopyHostToDevice :
            GPU: [CUDA] Memcpy HtoD :
         GPU: [HIP] CopyDeviceToHost :
      GPU: [CUDA] Stream Synchronize :
            GPU: [CUDA] ker_code1 :
            GPU: [CUDA] ker_code8 :
           GPU: [CUDA] ker_code13 :
            GPU: [CUDA] ker_code0 :
            GPU: [CUDA] ker_code5 :      1    0.00    0.00
           GPU: [CUDA] ker_code16 :      1    0.00    0.00
            GPU: [CUDA] ker_code9 :      1    0.00    0.00
            GPU: [CUDA] ker_code4 :      1    0.00    0.00
           GPU: [CUDA] ker_code17 :      1    0.00    0.00
           GPU: [CUDA] ker_code12 :      1    0.00    0.00
            GPU: [HIP] ker_code18 :      1    0.00    0.00
            GPU: [HIP] ker_code11 :      1    0.00    0.00
             GPU: [HIP] ker_code7 :      1    0.00    0.00
             GPU: [HIP] ker_code2 :      1    0.00    0.00
             GPU: [HIP] ker_code6 :      1    0.00    0.00
            GPU: [HIP] ker_code10 :      1    0.00    0.00
             GPU: [HIP] ker_code3 :      1    0.00    0.00
            GPU: [HIP] ker_code15 :      1    0.00    0.00
            GPU: [HIP] ker_code14 :      1    0.00    0.00
     GPU: [CUDA] Context Synchronize :      2    0.00    0.00
---------------------------------------------------------------
```

Combined Kernel execution
and data transfer reports

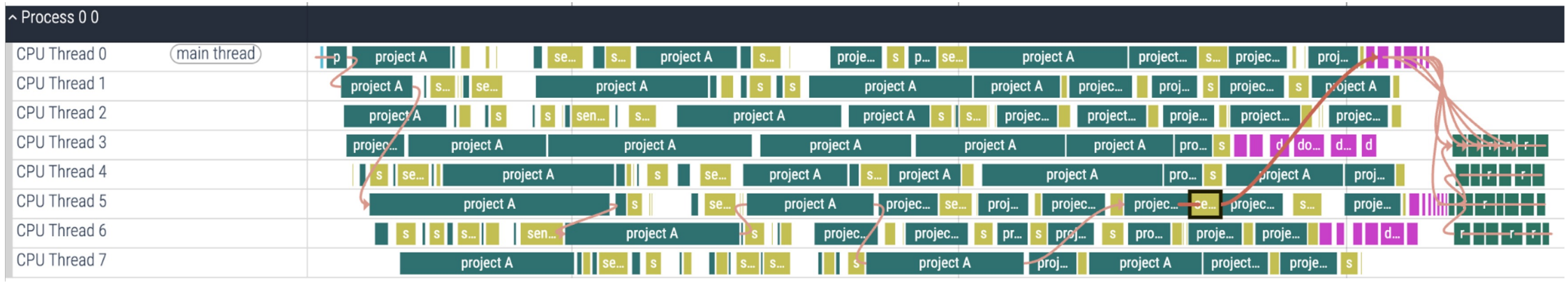


```
                                              : #samp |    mean  |   max
                                  CPU User % :     4      3.46      4.42
                              CPU soft IRQ % :     4      0.10      0.20
                                 DRAM Energy :     4      0.00      0.00
                 GPU: [CUDA] Bytes Allocated :    12  1.23e+07  1.49e+07
                      GPU: [CUDA] Bytes Freed :     1     16.00     16.00
 GPU: [CUDA] Total Bytes Occupied on Device :    13  7.01e+07  1.48e+08
                  GPU: [HIP] Bytes Allocated :    13  1.20e+07  1.49e+07
                       GPU: [HIP] Bytes Freed :     1     16.00     16.00
           GPU: [HIP] CopyDeviceToHost Bytes :     6      0.00      0.00
           GPU: [HIP] CopyHostToDevice Bytes :    10      1.60     16.00
  GPU: [HIP] Total Bytes Occupied on Device :    14  7.45e+07  1.56e+08
                            Package-0 Energy :     4      0.00      0.00
```

Performance and energy metrics collection from
CUDA and HIP Runtimes

Experiments – PaRSEC / TaskStubs / APEX

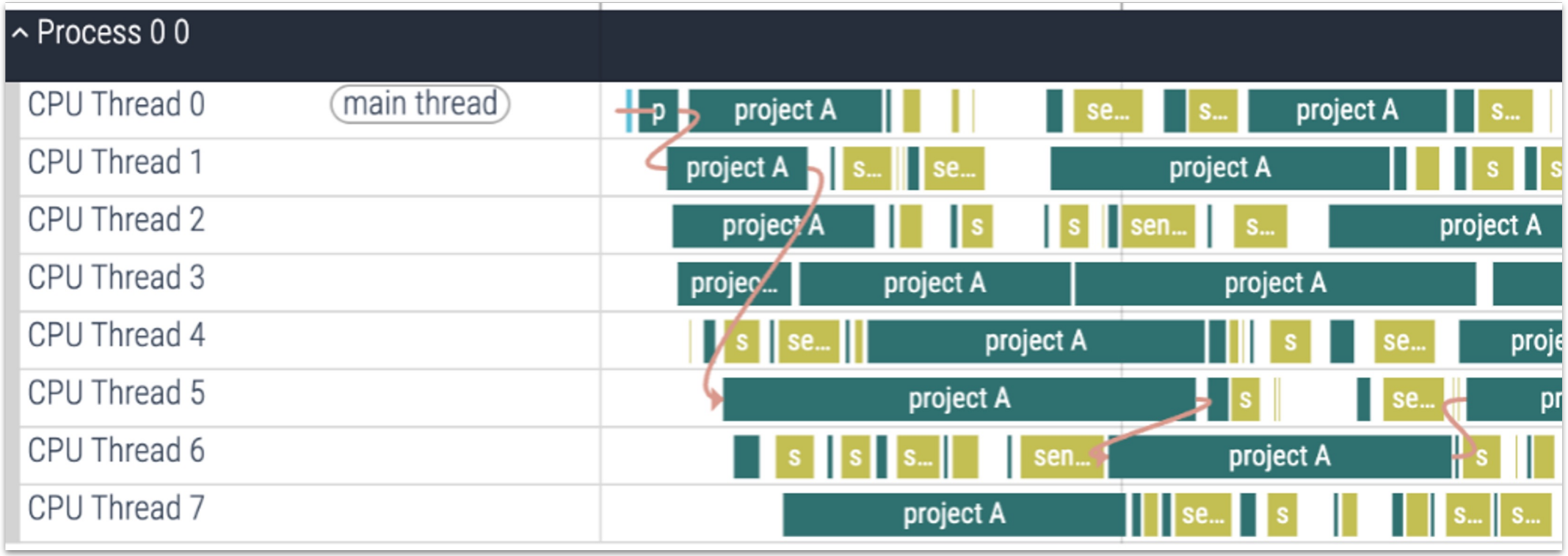
Data flow tracking: Multi-resolution analysis with PaRSEC



Task trace and flow of data visualization with Perfetto

Experiments – PaRSEC / TaskStubs / APEX

Data flow tracking: Multi-resolution analysis with PaRSEC



Task trace and flow of data visualization with Perfetto

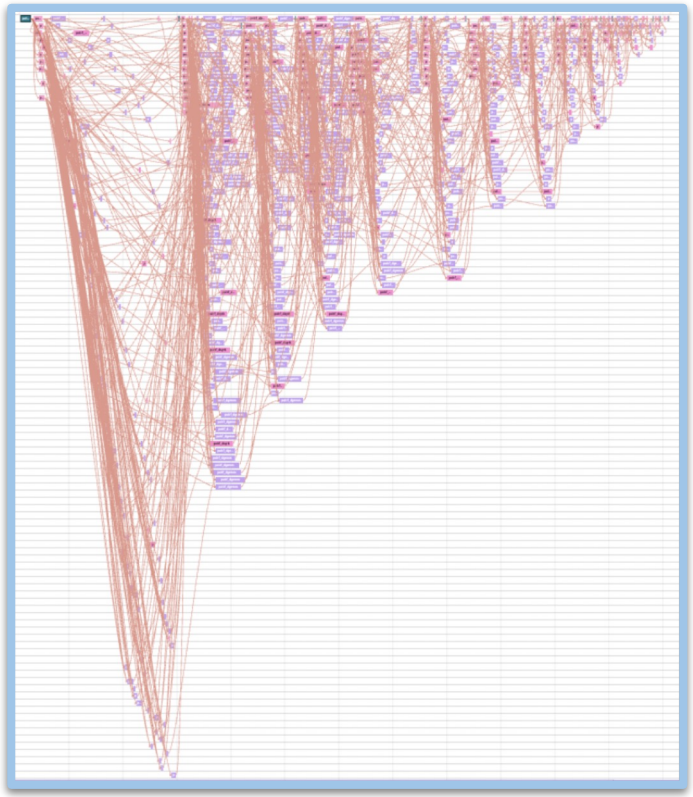
Experiments – PaRSEC / TaskStubs / APEX

Active tasks concurrency view

- One active task per resource line (instead of OS thread)
- Line reused when task destroyed, for next created task

APEX alternative view to classical Gantt chart traces

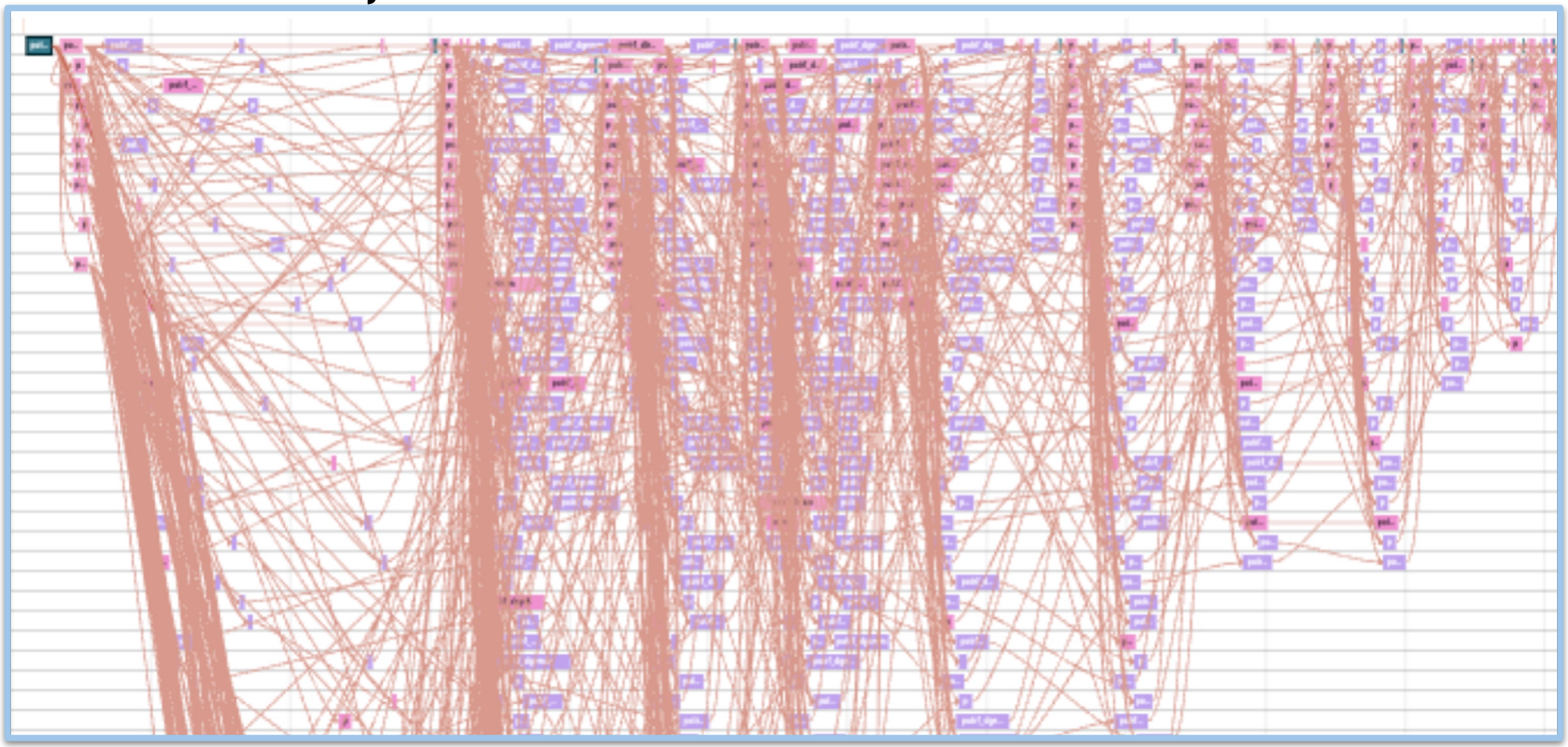
- Focus on critical path



Active tasks concurrency visualization with Perfetto

Experiments – PaRSEC / TaskStubs / APEX

Active tasks concurrency view



Active tasks concurrency visualization with Perfetto

Conclusion

TaskStubs plugin API

- Concise ATM runtime instrumentation plugin API
- Integrated in several task-based runtime systems
  - PaRSEC, StarPU, IRIS
- Support for a variety of performance tools
  - APEX, NVIDIA NVTX, AMD ROCTX

- **Open source**
  - https://github.com/UO-OACISS/taskstubs
  - BSD license