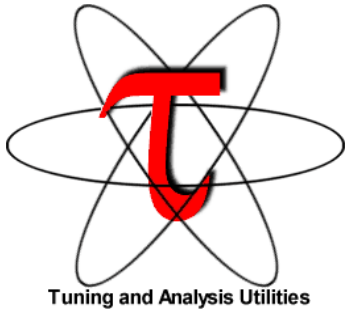
A Community-Driven Portable Profiler at Scale — TAU



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https://tau.uoregon.edu/TAU_ATPESC26.pdf, sameer@uoregon.edu

Using TAU on Aurora@ALCF

```
tar xf /soft/perftools/tau/tar/workshop.tgz
cd workshop; cat README
qsub -I  -l walltime=0:29:00 -lfilesystems=home:flare -A ATPESC2026 -q debug -l select=1 -X
module use /soft/modulefiles
module load tau
module load frameworks

mpiexec -n 4 gpu_tile_compact.sh ./a.out
mpiexec -n 4 gpu_tile_compact.sh tau_exec -l0 -ebs ./a.out

mpiexec -n 4 gpu_tile_compact.sh tau_exec -l0 -ebs python ./foo.py
pprof -a  | more
paraprof --pack foo.ppk
On your desktop: % paraprof foo.ppk
```

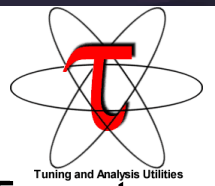
Using TAU on Frontier@OLCF

```
tar xf /sw/frontier/ums/ums002/paratools/tar/workshop.tgz
cd workshop; cat README
salloc -n 4 -A <ACCOUNT> -N 1 -t 0:55:00 -q debug -C nvme --gpus 2
module load ums ums002 tau
srun -n 4 ./a.out
srun -n 4 tau_exec -rocm -ebs ./a.out
srun -n 4 tau_exec -rocm_pc -ebs ./a.out
export TAU_METRICS=ROCM_SQ_WAVES    # see rocprofv3 -L for a complete list of counters
srun -n 4 tau_exec -rocm -ebs ./a.out

pprof -a  | more
paraprof --pack foo.ppk
On your desktop: % paraprof foo.ppk
```

Motivation and Challenges

- With growing hardware complexity, it is getting harder to accurately measure and optimize the performance of our HPC and AI/ML workloads.
- TAU Performance System®:
  - Deliver a scalable, portable, performance evaluation toolkit for HPC and AI/ML workloads.
  - http://tau.uoregon.edu

TAU Performance System®



- Versatile profiling and tracing toolkit that supports:
  - MPI, DPC++/SYCL (Level Zero), OpenCL, and OpenMP (OpenMP Tools Interface for Target Offload)
- Scalable, portable, performance evaluation toolkit for HPC and AI/ML workloads that supports:
  - C++/C/DPC++, Fortran, Python
- Supports PAPI, Likwid for hardware performance counter information
- Instrumentation includes support for Kokkos, MPI, pthread, event-based sampling, GPU runtimes
- A single tool (tau_exec) is used to launch un-instrumented, un-modified binaries
- TAU's paraprof, pprof, perfexplorer for profile analysis; Vampir, Jumpshot, Perfetto.dev for traces
- https://tau.uoregon.edu

UNIVERSITY OF OREGON

ParaTools

Application Performance Engineering using TAU

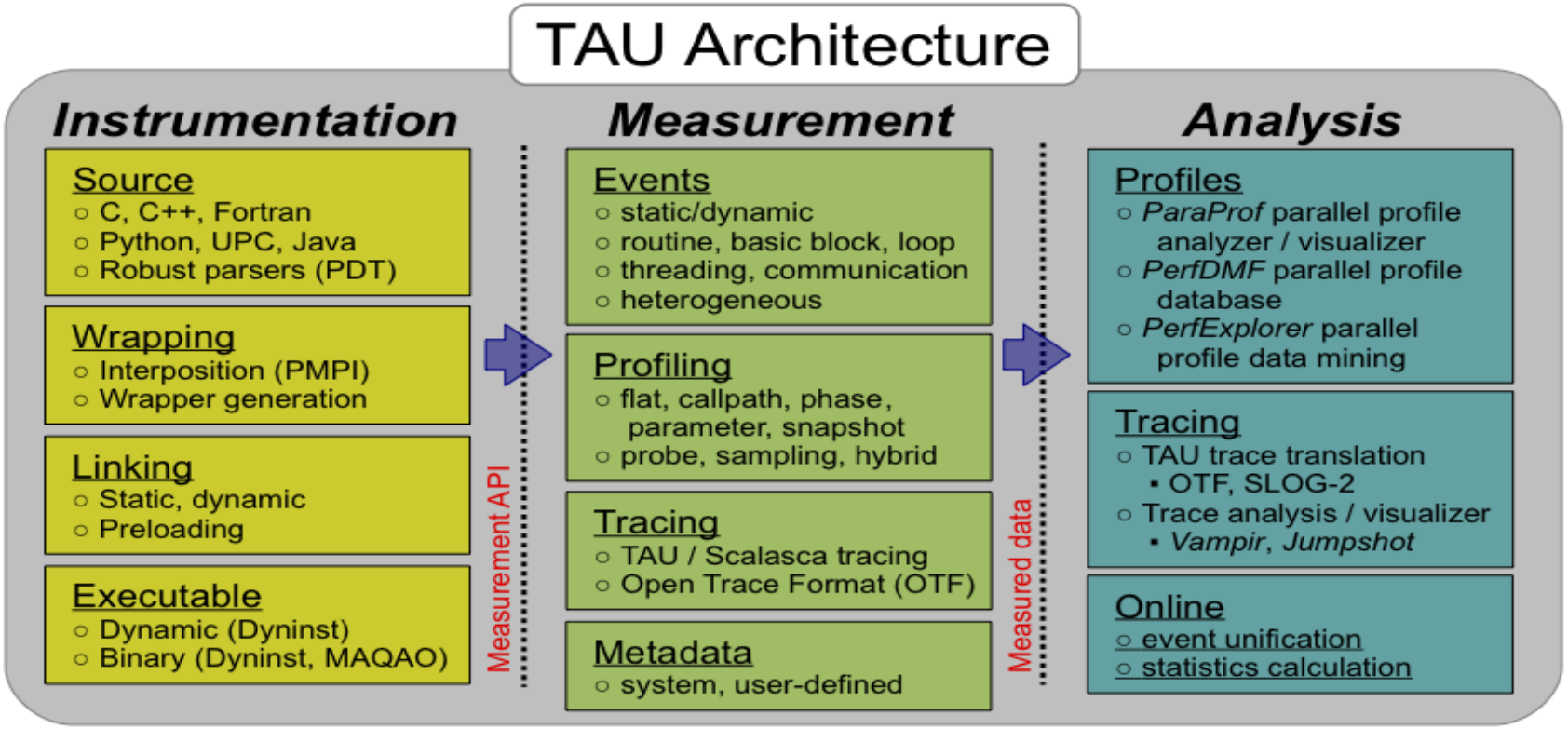
- How much time is spent in each application routine and outer *loops*? Within loops, what is the contribution of each *statement*? What is the time spent in OpenMP loops? In kernels on GPUs and at the level of each statement inside GPU kernels.
- How many instructions are executed in these code regions?
  Floating point, Level 1 and 2 *data cache misses*, hits, branches taken? What is the extent of vectorization for loops? Accessing counters on both CPUs and GPUs.
- How much time did my application spend waiting at a barrier in MPI collective operations?
- What is the memory usage of the code? When and where is memory allocated/de-allocated? Are there any memory leaks? What is the memory footprint of the application? What is the memory high water mark?
- How much energy does the application use in Joules? What is the peak power usage?
- What are the I/O characteristics of the code? What is the peak read and write *bandwidth* of individual calls, total volume?
- How does the application *scale*? What is the efficiency, runtime breakdown of performance across different core counts?

TAU Performance System®

Parallel performance framework and toolkit

- Supports all HPC platforms, compilers, runtime system
- Provides portable instrumentation, measurement, analysis

Tuning and Analysis Utilities



TAU Performance System®

Instrumentation
- Fortran, C++, C, UPC, Java, Python, Chapel, Spark
- Automatic instrumentation

Measurement and analysis support
- MPI (MVAPICH2, Intel MPI), OpenSHMEM, ARMCI, PGAS, DMAPP
- Supports Intel oneAPI compilers
- pthreads, OpenMP, OMPT interface, hybrid, other thread models
- GPU: CUDA, ROCm, oneAPI DPC++/SYCL (Level Zero), OpenACC, Kokkos, RAJA
- Parallel profiling and tracing

Analysis
- Parallel profile analysis (ParaProf), data mining (PerfExplorer)
- Performance database technology (TAUdb)
- 3D profile browser

Instrumentation

Add hooks in the code to perform measurements

Source instrumentation using a preprocessor

- Add timer start/stop calls in a copy of the source code.
- Use Program Database Toolkit (PDT) for parsing source code.
- Requires recompiling the code using TAU shell scripts (tau_cc.sh, tau_f90.sh)
- Selective instrumentation (filter file) can reduce runtime overhead and narrow instrumentation focus.

Compiler-based instrumentation

- Use system compiler to add a special flag to insert hooks at routine entry/exit.
- Requires recompiling using TAU compiler scripts (tau_cc.sh, tau_f90.sh…)

Runtime preloading of TAU's Dynamic Shared Object (DSO)

- No need to recompile code! Use **mpiexec tau_exec ./app** with options.
- It will preload TAU's DSO and intercept MPI calls and generate profile/trace data.

Using TAU's Runtime Preloading Tool: tau_exec

Preload a wrapper that intercepts the runtime system call and substitutes with another

- **MPI**
- **OpenMP**
- **POSIX I/O**
- **Memory allocation/deallocation routines**
- **Wrapper library for an external package**

No modification to the binary executable!

Enable other TAU options (communication matrix, OTF2, event-based sampling)

Configurations of TAU installed on Aurora

```
module use /soft/modulefiles;

module load tau;

module load frameworks

ls $TAU/Makefile*                    # Each configure build of TAU makes one stub Makefile

/soft/perftools/tau/tau-2.35.2/x86_64/lib/

Makefile.tau-level_zero-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics


/soft/perftools/tau/tau-2.35.2/x86_64/lib/

Makefile.tau-level_zero-icpx-papi-ompt-python-pdt-openmp-l0metrics


/soft/perftools/tau/tau-2.35.2/x86_64/lib/

Makefile.tau-level_zero-ittnotify-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics
```

Using TAU for source instrumentation

TAU supports several measurement and thread options

- Phase profiling, profiling with hardware counters, MPI library, Python…
- Each measurement configuration of TAU corresponds to a unique stub makefile and library that is generated when you configure it

To instrument source code automatically using PDT

- Choose an appropriate TAU stub makefile in <arch>/lib:

```
% module use /soft/modulefiles; module load tau
% export TAU_MAKEFILE=/soft/perftools/tau/tau-2.35.2/x86_64/lib/
Makefile.tau-level_zero-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics

% export TAU_OPTIONS='-optVerbose …' (see tau_compiler.sh )
% export PATH=$TAUDIR/x86_64/bin:$PATH
Use tau_f90.sh, tau_cxx.sh, tau_upc.sh, or tau_cc.sh as F90, C++, UPC, or C compilers respectively:
% mpif90 foo.f90       changes to
% tau_f90.sh foo.f90
```

Set runtime environment variables, execute application and analyze performance data:

% pprof (for text based profile display)

% paraprof (for GUI)

Configurations of TAU installed on Polaris

```
module use /soft/modulefiles;

module load tau;

ls $TAU/Makefile*

/soft/perftools/tau/tau-2.35.2/craycnl/lib/Makefile.tau-gnu-mpi-pthread-cupti

/soft/perftools/tau/tau-2.35.2/craycnl/lib/Makefile.tau-gnu-tbb-cupti

/soft/perftools/tau/tau-2.35.2/craycnl/lib/Makefile.tau-nvidia-mpi-pthread-cupti

/soft/perftools/tau/tau-2.35.2/craycnl/lib/Makefile.tau-nvidia-pthread-cupti


srun -n 4 tau_exec -T nvidia-mpi-pthread-cupti -cupti ./a.out
```

TAU's Support for Runtime Systems

- *MPI*
  - PMPI profiling interface
  - MPI_T tools interface using performance and control variables
- *Pthread*
  - Captures time spent in routines per thread of execution
- *OpenMP*
  - OMPT tools interface to track salient OpenMP runtime events
  - Opari source rewriter
  - Preloading wrapper OpenMP runtime library when OMPT is not supported
- *OpenACC*
  - OpenACC instrumentation API
  - Track data transfers between host and device (per-variable)
  - Track time spent in kernels

TAU's Support for Runtime Systems (contd.)

OpenCL
- OpenCL profiling interface
- Track timings of kernels

Intel® OneAPI
- Level Zero
- Track time spent in kernels executing on GPU (-l0), sampling on GPU (-l0_pc), GPU counters
- Track time spent in OneAPI runtime calls

CUDA
- Cuda Profiling Tools Interface (CUPTI)
- Track time spent in kernels executing on GPU (-cupti), sampling on GPU (-cupti_pc), GPU counters
- Track data transfers between host and GPU
- Track access to uniform shared memory between host and GPU

ROCm
- Rocprofiler-SDK instrumentation interfaces
- Track time spent in kernels executing on GPU (-rocm), sampling on GPU (-rocm_pc), GPU counters
- Track data transfers and kernel execution between host and GPU

Kokkos
- Kokkos profiling API
- Push/pop interface for region, kernel execution interface

Python
- Python interpreter instrumentation API

Examples of Multi-Level Instrumentation

- *MPI + OpenMP*
  - MPI_T + PMPI + OMPT may be used to track MPI and OpenMP
- *MPI + pthread*
  - PMPI + pthread interfaces
- *MPI + Intel® oneAPI DPC++/SYCL*
  - PMPI + Level Zero interfaces
- *MPI + ROCprofiler-SDK*
  - PMPI + ROCm ROCprofiler-SDK
- *MPI + CUDA + Python*
  - PMPI + CUPTI + Python instrumentation interfaces
- *Kokkos + OpenMP*
  - Kokkos profiling API + OMPT to transparently track events
- *Kokkos + pthread + MPI*
  - Kokkos + pthread wrapper interposition library + PMPI layer
- *MPI + OpenCL*
  - PMPI + OpenCL profiling interfaces

TAU Execution Command (tau_exec)

Uninstrumented execution

```
% mpirun -np 256  ./a.out
```

Track GPU operations

```
% mpirun -np 256  tau_exec –rocm ./a.out  (-rocm_pc for PC sampling on GPU)
% mpirun -np 256  tau_exec –cupti ./a.out (-cupti_pc for PC sampling on GPU)
% mpirun -np 256  tau_exec –cupti  -um ./a.out  (for Unified Memory) (-cupti_pc for PC sampling on GPU)
% mpirun –np 256  tau_exec –l0      ./a.out   (-l0_pc for PC sampling on GPU)
% mpirun –np 256 tau_exec –opencl ./a.out
% mpirun –np 256 tau_exec –openacc ./a.out
```

Track MPI performance

```
% mpirun -np 256   tau_exec ./a.out
```

Track I/O, and MPI performance (MPI enabled by default)

```
% mpirun -np 256  tau_exec -io  ./a.out
```

Track OpenMP and MPI execution (using OMPT for Intel or LLVM compilers that support OMPT)

```
% export TAU_OMPT_SUPPORT_LEVEL=full;
% mpirun –np 256  tau_exec –T ompt,mpi  -ompt  ./a.out
```

Track memory operations

```
% export TAU_TRACK_MEMORY_LEAKS=1
% mpirun –np 256 tau_exec –memory_debug ./a.out (bounds check)
```

Use event based sampling (compile with –g)

```
% mpirun –np 256 tau_exec –ebs ./a.out
```

Also export TAU_METRICS=TIME,PAPI_L1_DCM… -ebs_resolution=<file | function | line>

export TAU_METRICS=ROCM_|L0|CUPTI_<GPU_metric> for access to GPU counters

TAU Configurations on Aurora

```
% module use /soft/modulefiles; module load tau; ls $TAU/Makefile*
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-icpx-papi-ompt-python-pdt-openmp-l0metrics
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-ittnotify-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics

For an uninstrumented binary:
% mpiexec –n 4 gpu_tile_compact.sh tau_exec –l0 ./a.out
Picks the configuration represented by
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics
To use OpenMP instrumentation:
% export TAU_OMPT_SUPPORT_LEVEL=full
% export OMP_NUM_THREADS=<N>
% mpiexec –n 4 gpu_tile_compact.sh tau_exec –T ompt,mpi –ompt –l0 ./a.out

% pprof –a | more
% paraprof
% paraprof --pack foo.ppk
# Copy it to your local machine and launch: % paraprof foo.ppk
```

Binary instrumentation of libraries: Work in progress

% tau_run a.out –o a.inst

instruments a binary. Other flags –T <tags>, -f <selective instrumentation file>

% tau_run -l /path/to/libhdf5.so.310 –o libhdf5.so.310

instruments a DSO

% tau_exec ./a.out

executes the uninstrumented application with the instrumented shared object.

To use with DyninstAPI 13 on x86_64:

1. Load spack: source spack/share/spack/setup-env.sh
2. Install dyninst: spack install dyninst@13 %gcc@11
3. Configure tau with dyninst:
   3.1 spack find -p dyninst boost tbb elfutils
   3.2 Copy the paths for each package into the configure line

3.3 ./configure -bfd=download -dyninst=<dir> -tbb=<dir> -boost=<dir> -elf=<dir>; <set paths>; make install

Binary instrumentation of libraries: HDF5

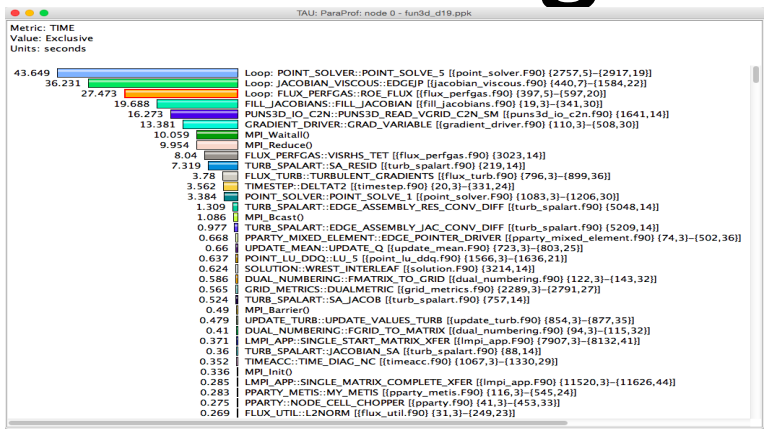
```
$ pprof
Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0       0.272           68           1           1     68245 .TAU application
 99.6           1           67           1          26     67973 taupreload_main
 65.8       0.008           44           6           1      7484 H5open
 65.8           6           44           2          14     22448 H5_init_library
 36.0           4           24           1          12     24563 H5VL_init_phase2
 27.8           1           18           1         319     18943 H5T_init
 19.8       0.193           13         179         179        76 H5T__register_int
 19.5       0.302           13         179         310        74 H5T__register
 19.0           4           12         155        2555        84 H5T__path_find_real
 13.0           2            8           1          79      8857 H5P_init_phase1
 12.7       0.663            8           2          51      4349 H5F_open
 11.2       0.348            7           1           6      7610 H5Fcreate
 10.5       0.386            7           1           6      7138 H5F__create_api_common
  9.8       0.406            6           1           2      6707 H5VL_file_create
  9.2       0.005            6           1           1      6299 H5VL__native_file_create
  7.1           1            4         488         976        10 H5T_copy
  6.5           1            4           1         363      4452 H5E_init
  5.6       0.013            3           4          12       956 H5I_dec_app_ref
  5.6       0.013            3           2          10      1896 H5Fclose
  5.5       0.009            3           2           4      1878 H5F__close_cb
  5.5        0.01            3           2           6      1868 H5VL_file_close
  5.4       0.013            3           2           4      1852 H5VL__native_file_close
  5.4       0.019            3           4           8       924 H5F_try_close.localalias
```

Tags in tau_exec and other tools

```
% cd $TAU; ls Makefile.*
Makefile.tau-icpx-papi-mpi-pdt
% srun -n 4 ./matrix
% tau_exec -T icpx,mpi,pdt ./a.out

Chooses Makefile.tau-icpx-mpi,pdt and associated libraries.

% tau_exec -T serial,pdt ./a.out
Chooses Makefile.tau-pdt or the shortest Makefile name without
-mpi.

-T <list_of_tags> is used in several TAU tools:
      ▪ tau_run
      ▪ tau_python
      ▪ tau_julia
      ▪ tau_exec
      ▪ tau_gen_wrapper
```

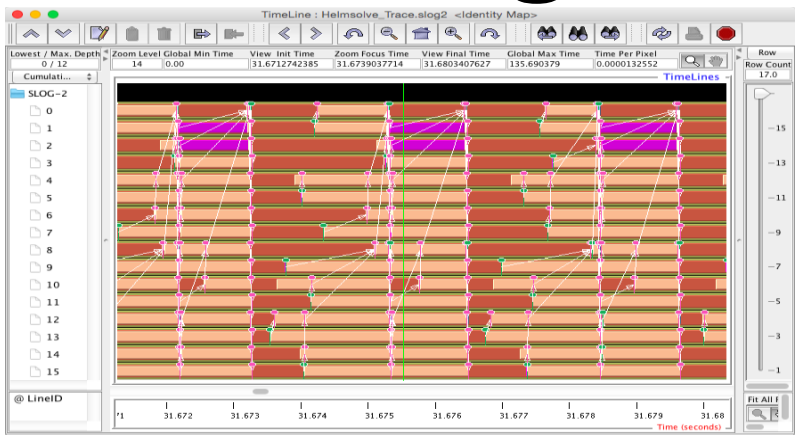
Profiling and Tracing

Profiling



- **Profiling** shows you **how much** (total) time was spent in each routine

Tracing



- Tracing shows you when the events take place on a timeline

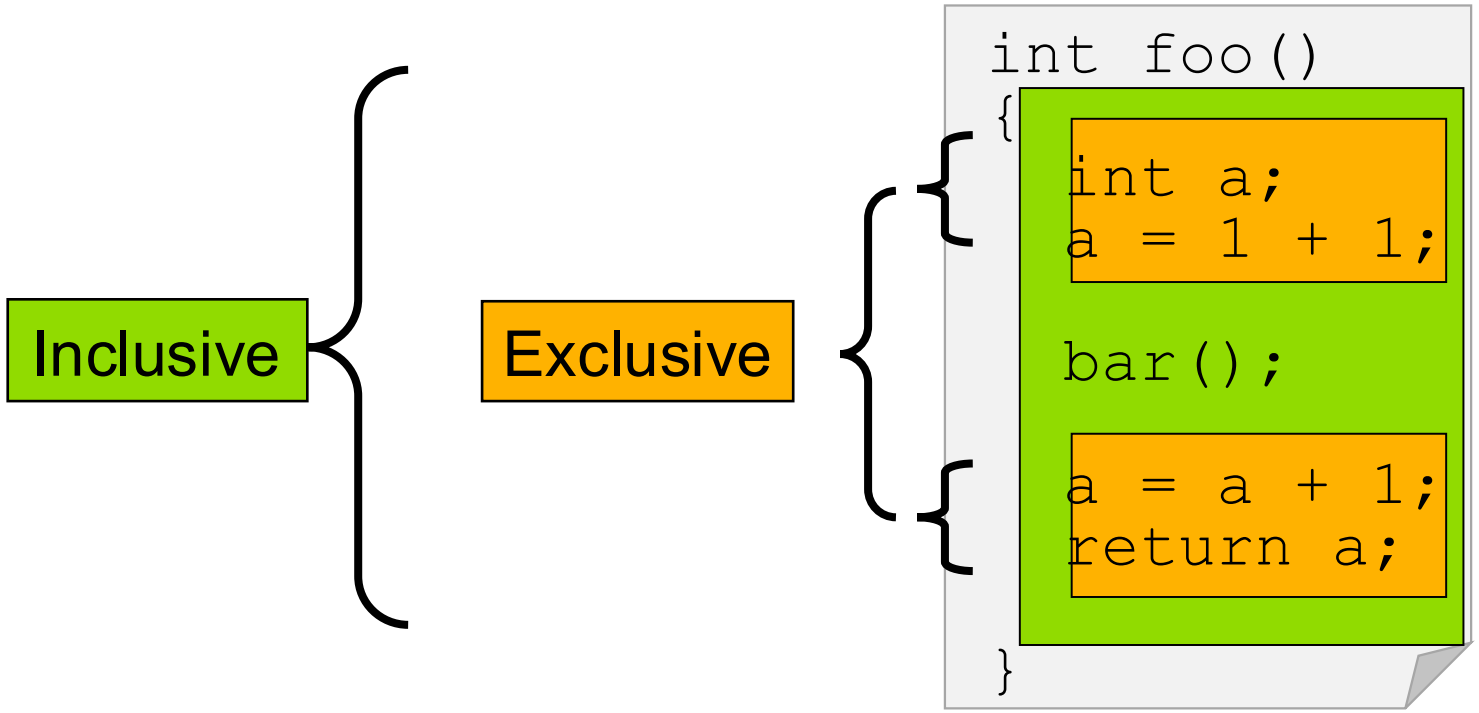
- Profiling and tracing

  Profiling shows you **how much** (total) time was spent in each routine

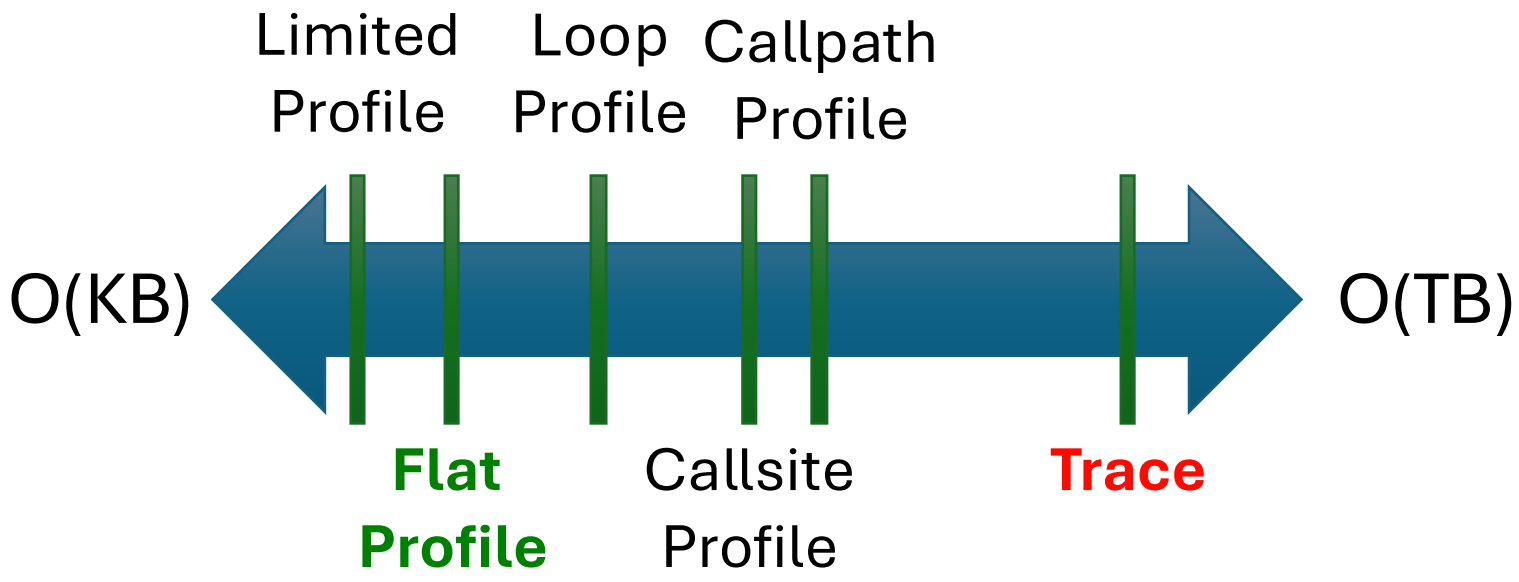
  Tracing shows you **when** the events take place on a timeline

Inclusive vs. Exclusive values

- Inclusive
  - Information of all sub-elements aggregated into single value
- Exclusive
  - Information cannot be subdivided further



How much data do you want?



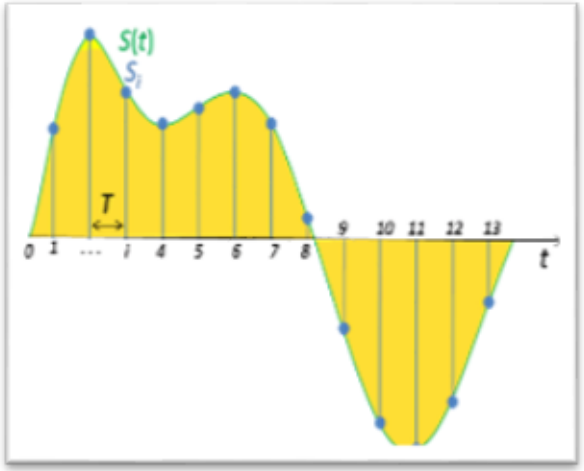
Performance Data Management

Direct via Probes

```
Call
START('potential')
// code
Call
STOP('potential')
```

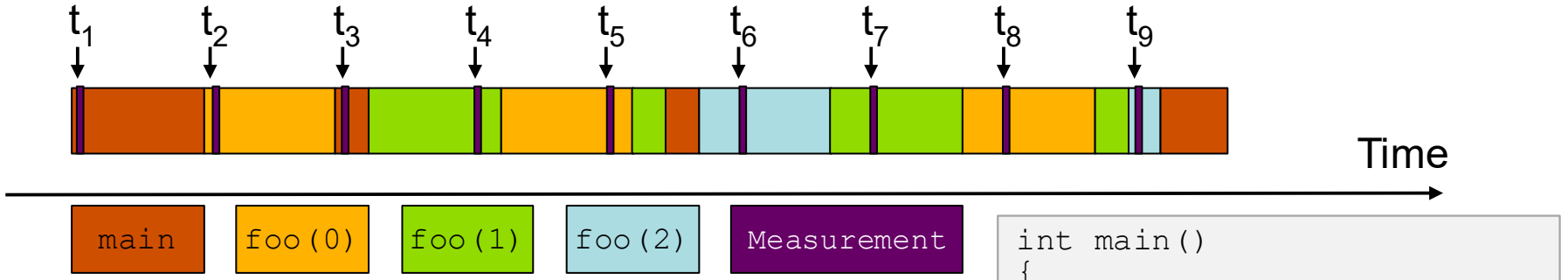
- Exact measurement
- Fine-grain control
- Calls inserted into code

Indirect via Sampling



- No code modification
- Minimal effort
- Relies on debug symbols (**-g**)

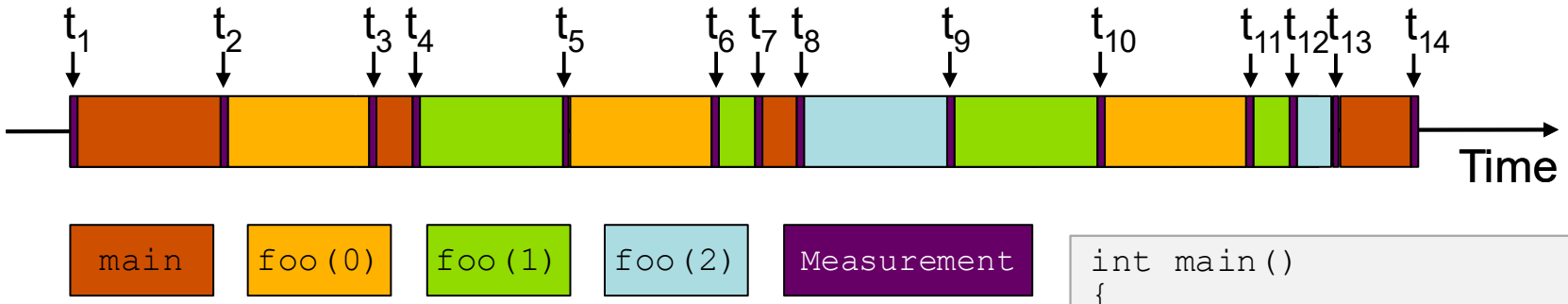
Sampling



- Running program is periodically interrupted to take measurement
  - Timer interrupt, OS signal, or HWC overflow
  - Service routine examines return-address stack
  - Addresses are mapped to routines using symbol table information
- Statistical inference of program behavior
  - Not very detailed information on highly volatile metrics
  - Requires long-running applications
- Works with unmodified executables

```
int main()
{
  int i;

  for (i=0; i < 3; i++)
    foo(i);

  return 0;
}

void foo(int i)
{

  if (i > 0)
    foo(i - 1);

}
```

Instrumentation



Measurement code is inserted such that every event of interest is captured directly

- Can be done in various ways

Advantage:

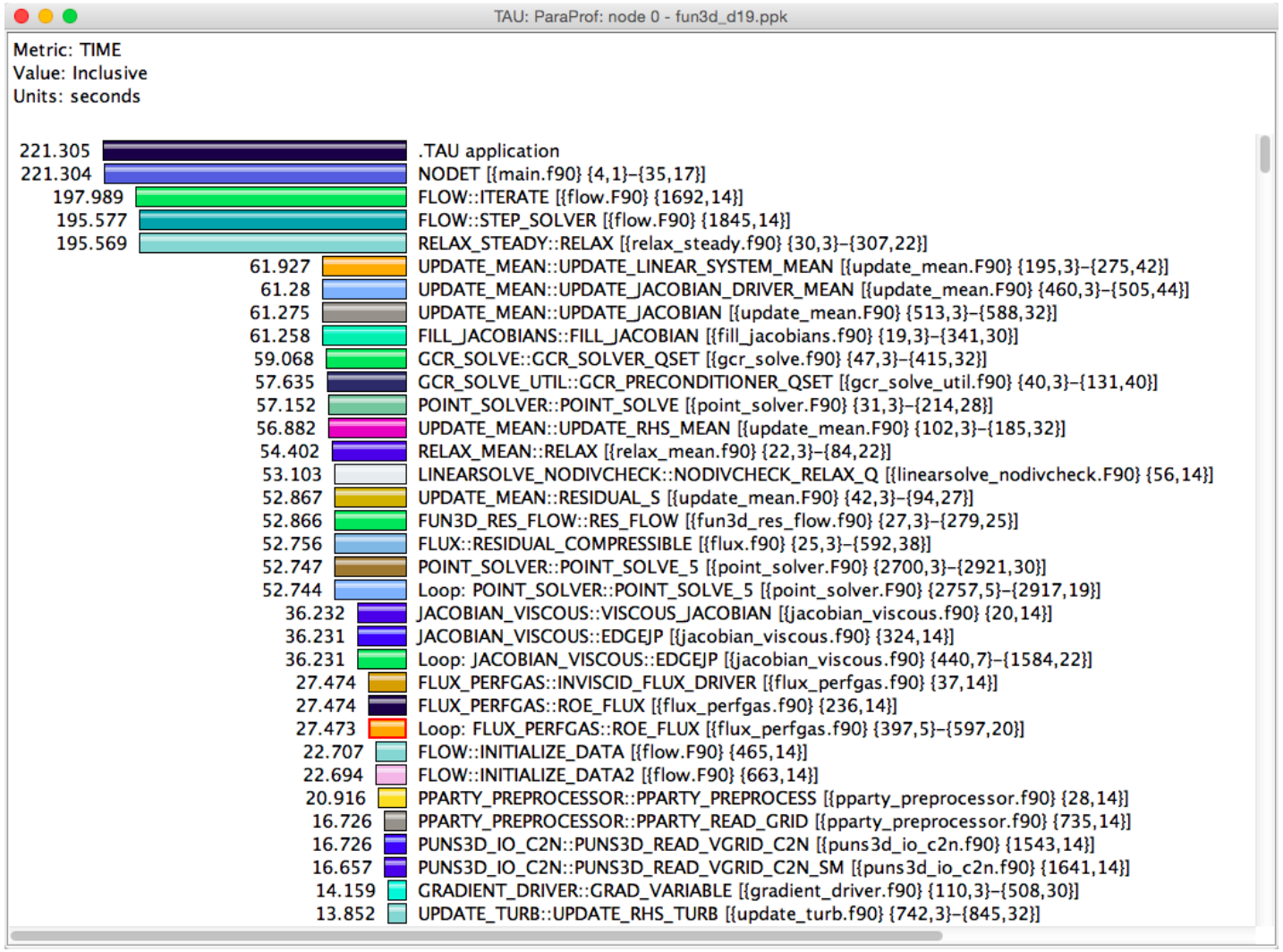
- Much more detailed information

Disadvantage:

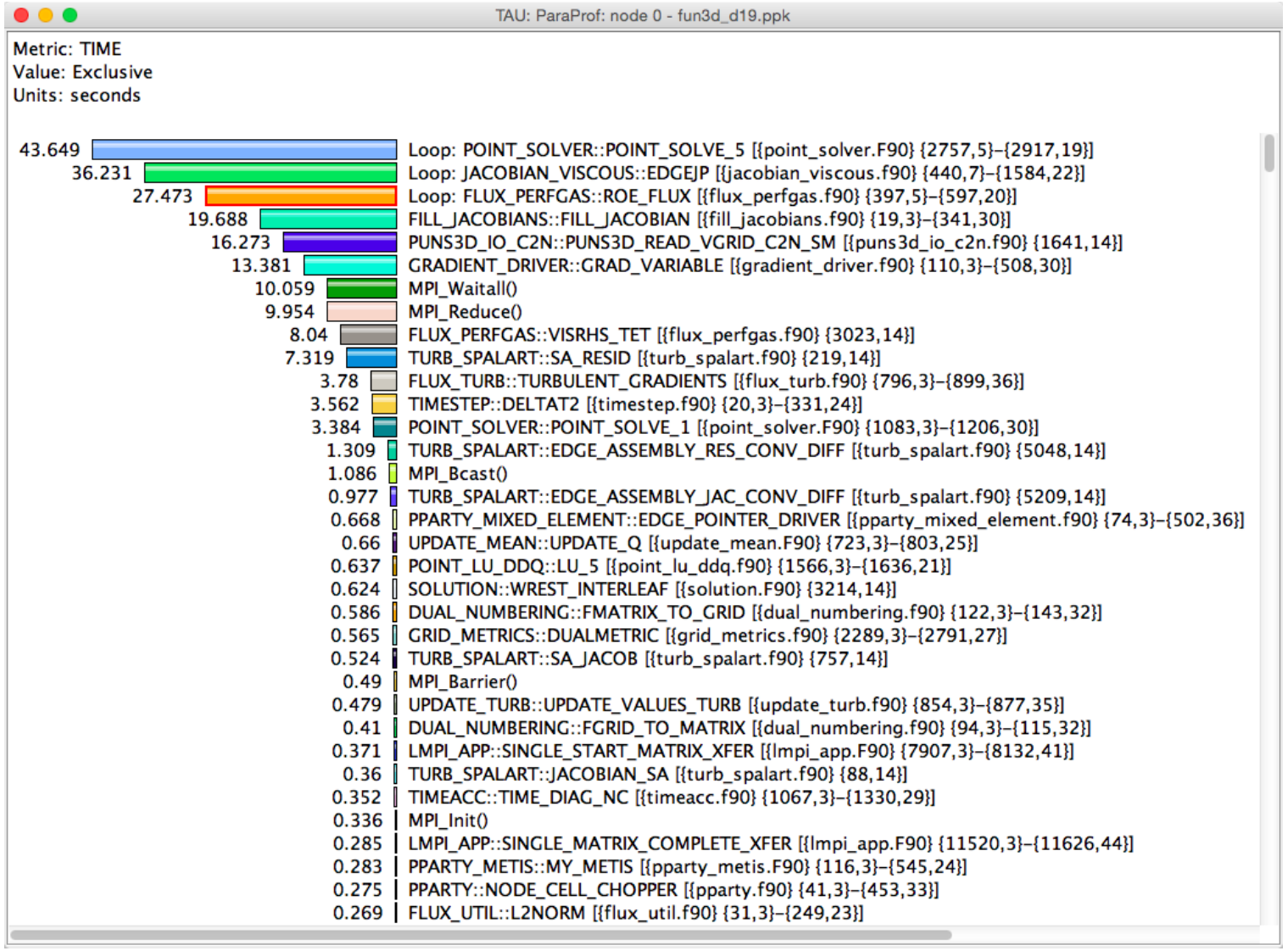
- Processing of source-code / executable necessary
- Large relative overheads for small functions

```
int main()
{
  int i;
  TAU_START("main");
  for (i=0; i < 3; i++)
    foo(i);
  TAU_STOP("main");
  return 0;
}

void foo(int i)
{
  TAU_START("foo");
  if (i > 0)
    foo(i - 1);
  TAU_STOP("foo");

}
```

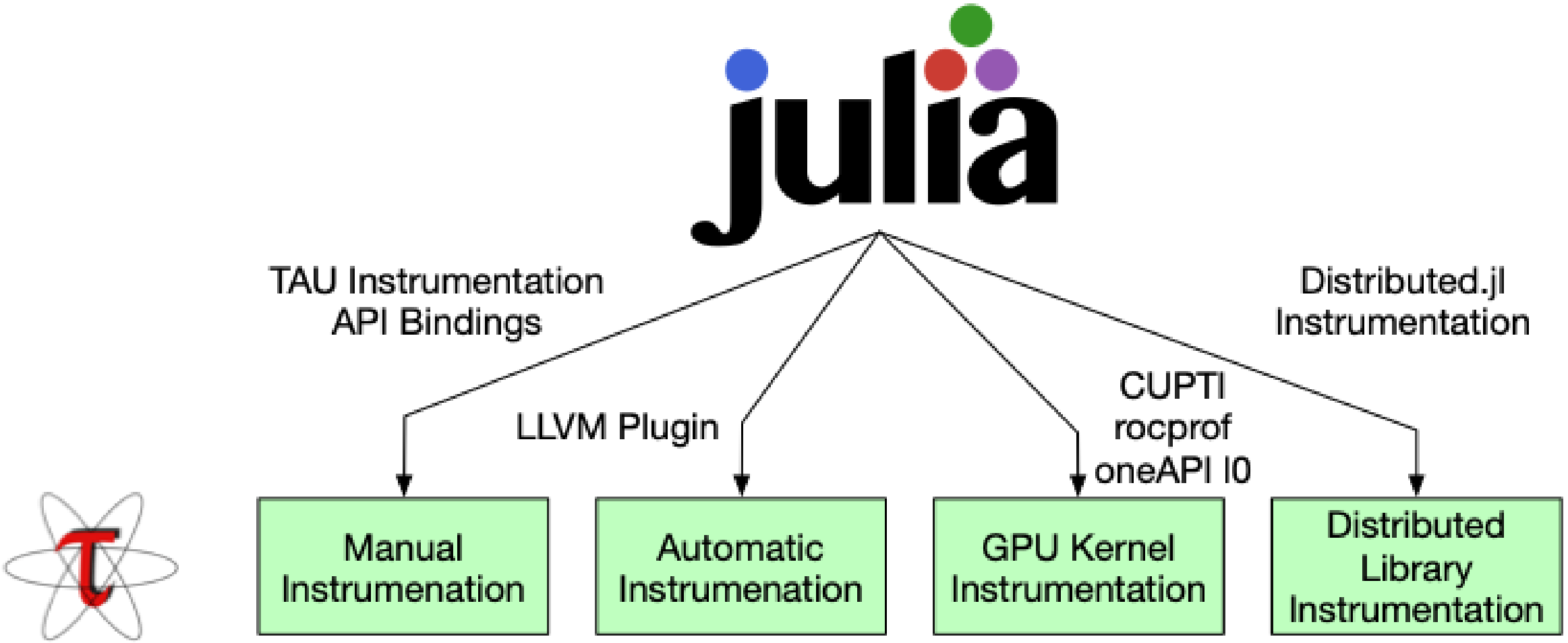
Inclusive Measurements



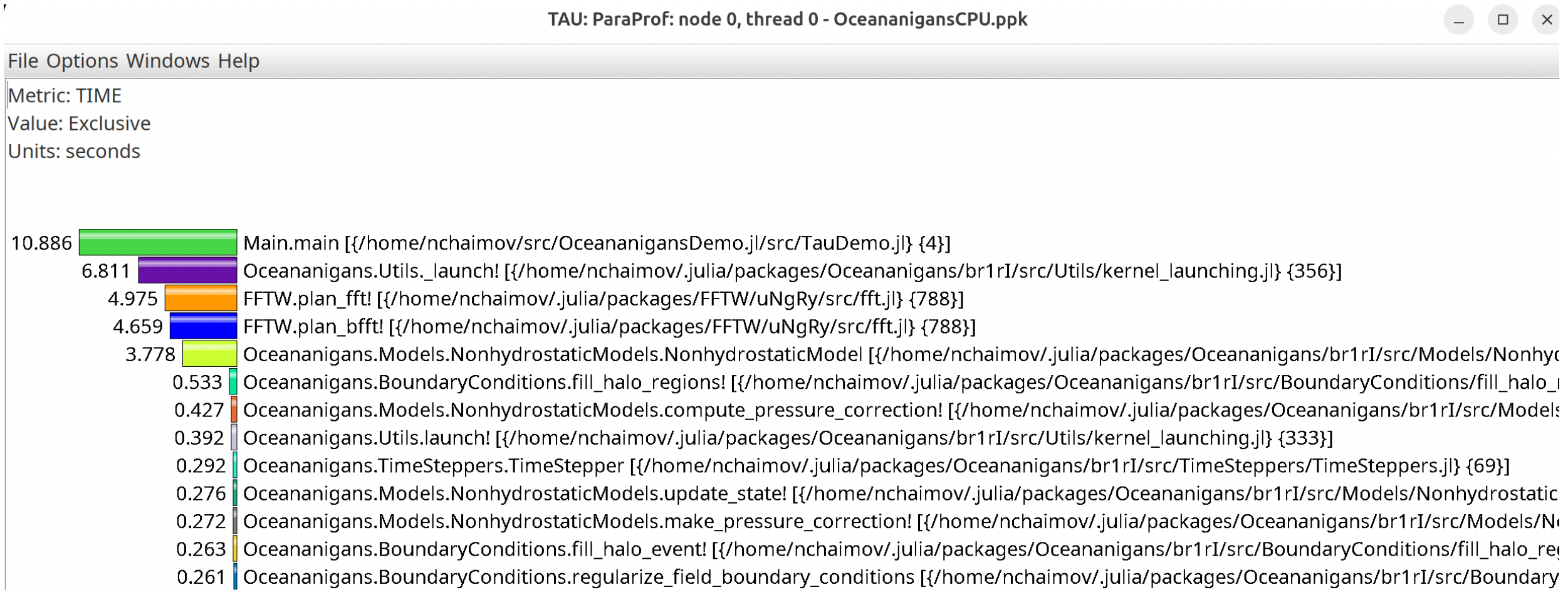
Exclusive Time



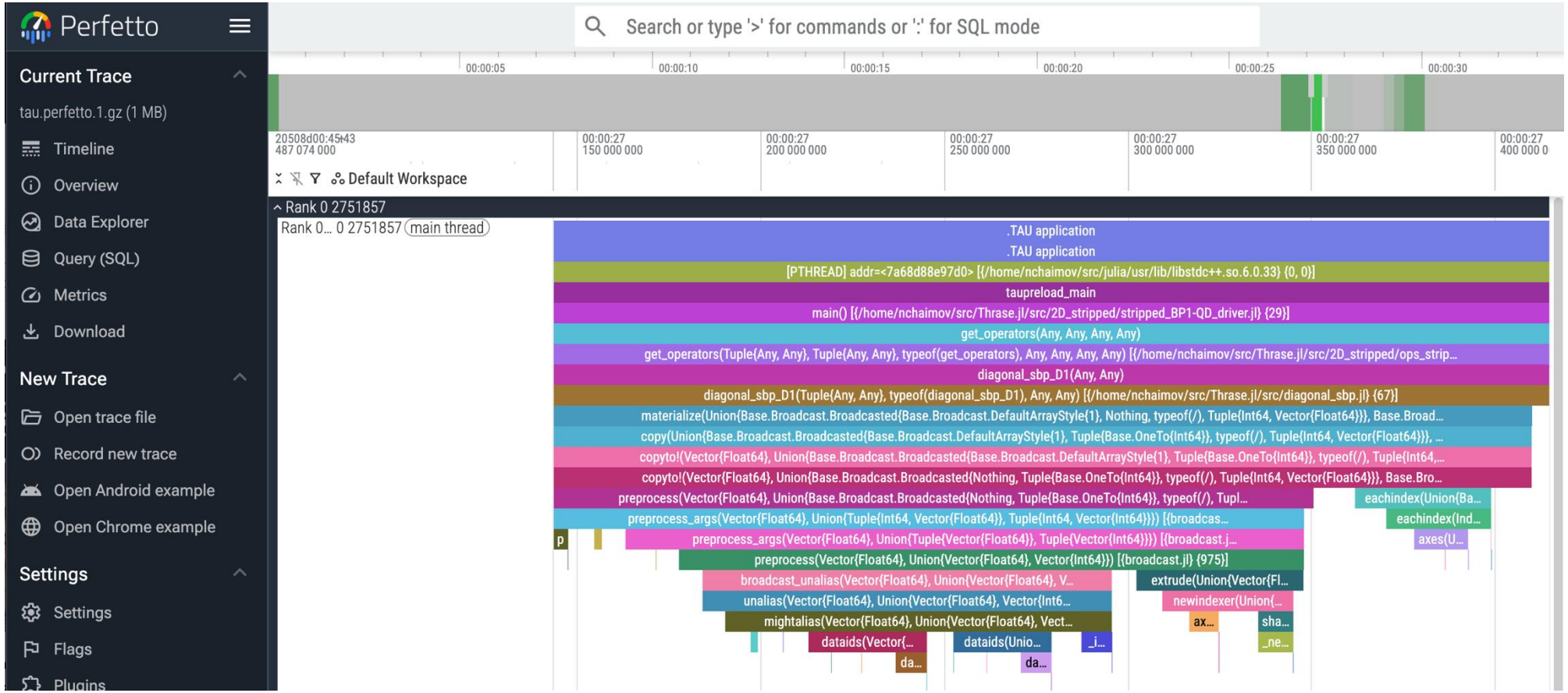
Instrumenting Julia applications using TAU with tau_julia



Profiling Julia applications using TAU with tau_julia

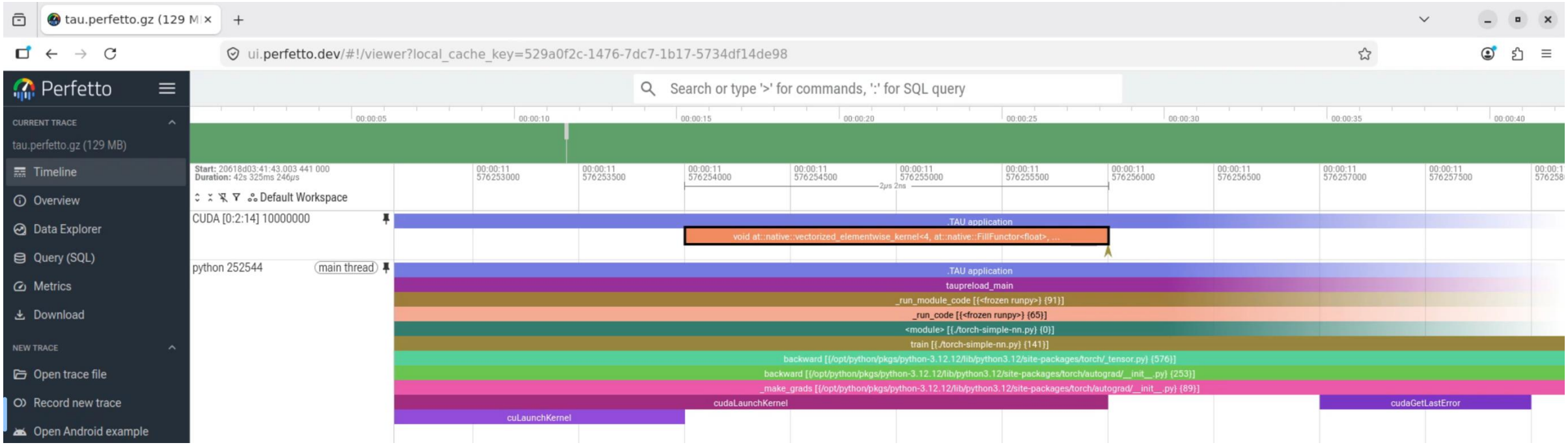


Tracing Julia applications using TAU with tau_julia



% export TAU_TRACE=1; export TAU_TRACE_FORMAT=perfetto
% mpirun –np 16 tau_julia ./foo.jl
Open tau.perfetto.gz in https://perfetto.dev (Trace Visualizer -> Open Trace)

Perfetto.dev Trace Browser: Python with tau_python




```
% export TAU_TRACE=1; export TAU_TRACE_FORMAT=perfetto
% mpirun -np 64 tau_python -cupti ./a.out;
Open https://perfetto.dev and load tau.perfetto.gz (Trace Visualier -> Open File)
```

Identifying Collective Wait States: Thread Callpath Relations Window

TAU: ParaProf: Call Path Data n,c,t, 118,0,0 - 128_d3d.ppk

Metric Name: TIME
Sorted By: Exclusive
Units: seconds

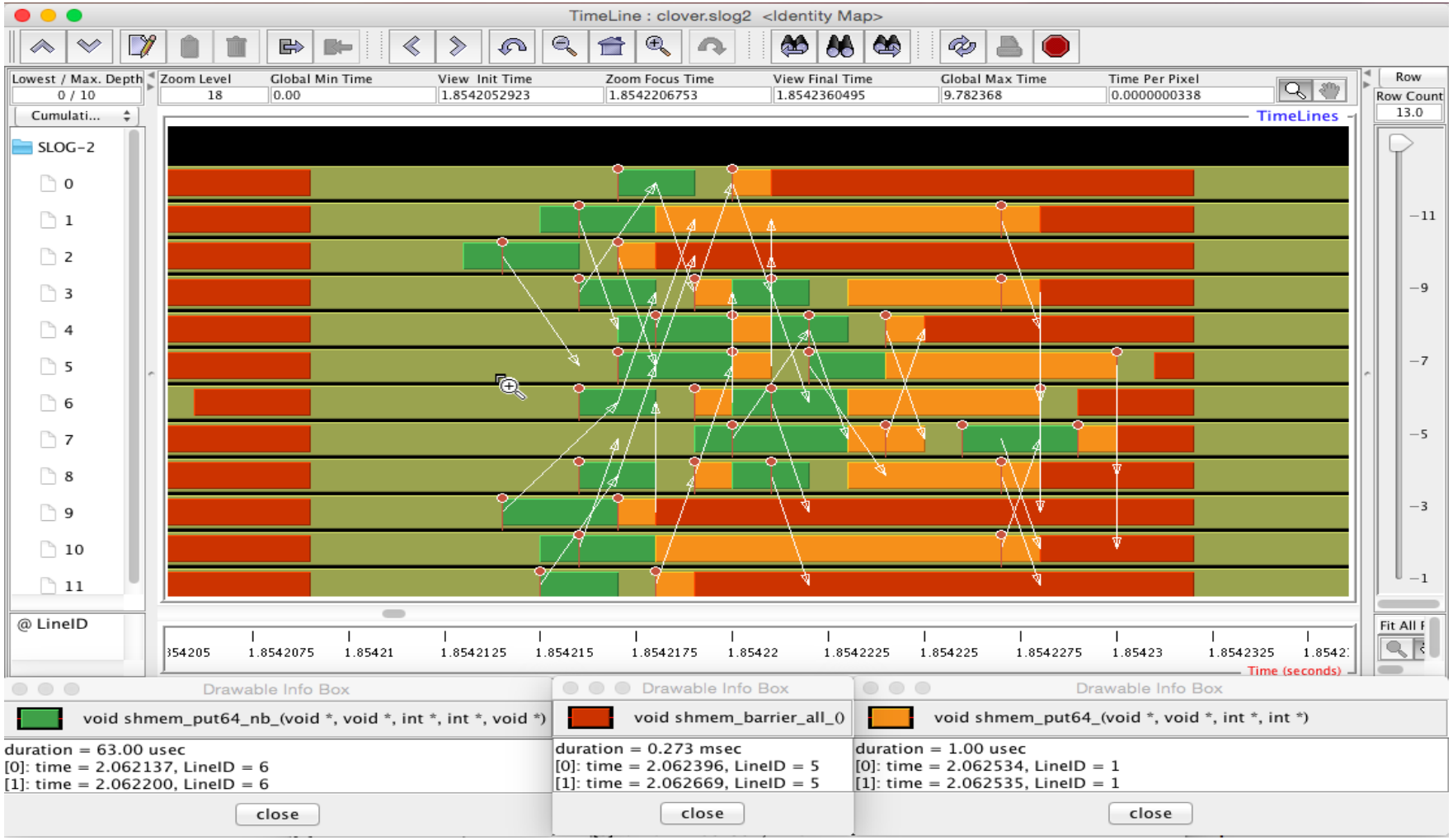
	Exclusive	Inclusive	Calls/Tot.Calls	Name[id]
	1099.614	1191.772	1/1	i:SETUP
-->	1099.614	1191.772	1	i:LOAD
	0.006	92.158	3/9543	MPI_Allreduce()
	9.8E-4	9.8E-4	11/15177	MPI_Gatherv()
	1.448	1.448	43/15177	MPI_Gather()
	15.353	15.353	46/15177	MPI_Alltoall()
	89.821	89.821	4311/15177	MPI_Bcast()
	6.777	6.777	195/15177	MPI_Allgather()
	68.678	68.678	991/15177	MPI_Reduce()
	9.179	9.179	12/15177	MPI_Comm_dup()
	0.125	0.125	25/15177	MPI_Allgatherv()
	382.861	382.861	9543/15177	MPI_Allreduce()
-->	574.243	574.243	15177	MPI Collective Sync
	2.507	2.508	10/186	DISTRIBUTE_F0G
	2.433	2.434	10/186	F_UPD_F0_SP
	5.156	5.158	20/186	F0_CHARGE_SEARCH_INDEX
	5.505	5.507	22/186	PULLBACK_WEIGHT
	24.86	24.872	102/186	UPDATE_PTL_WEIGHT
	0.473	0.473	2/186	MAIN_LOOP
	4.975	4.977	20/186	DIAG_f0_PORT1_PTL
-->	45.91	45.93	186	copy_ptl_to_device
	0.02	0.02	186/272	Kokkos::parallel_for set_buffer_particles_d [type = Cuda, device = 0]

MPI Collective Sync is the time spent (wasted) in a barrier operation inside a collective

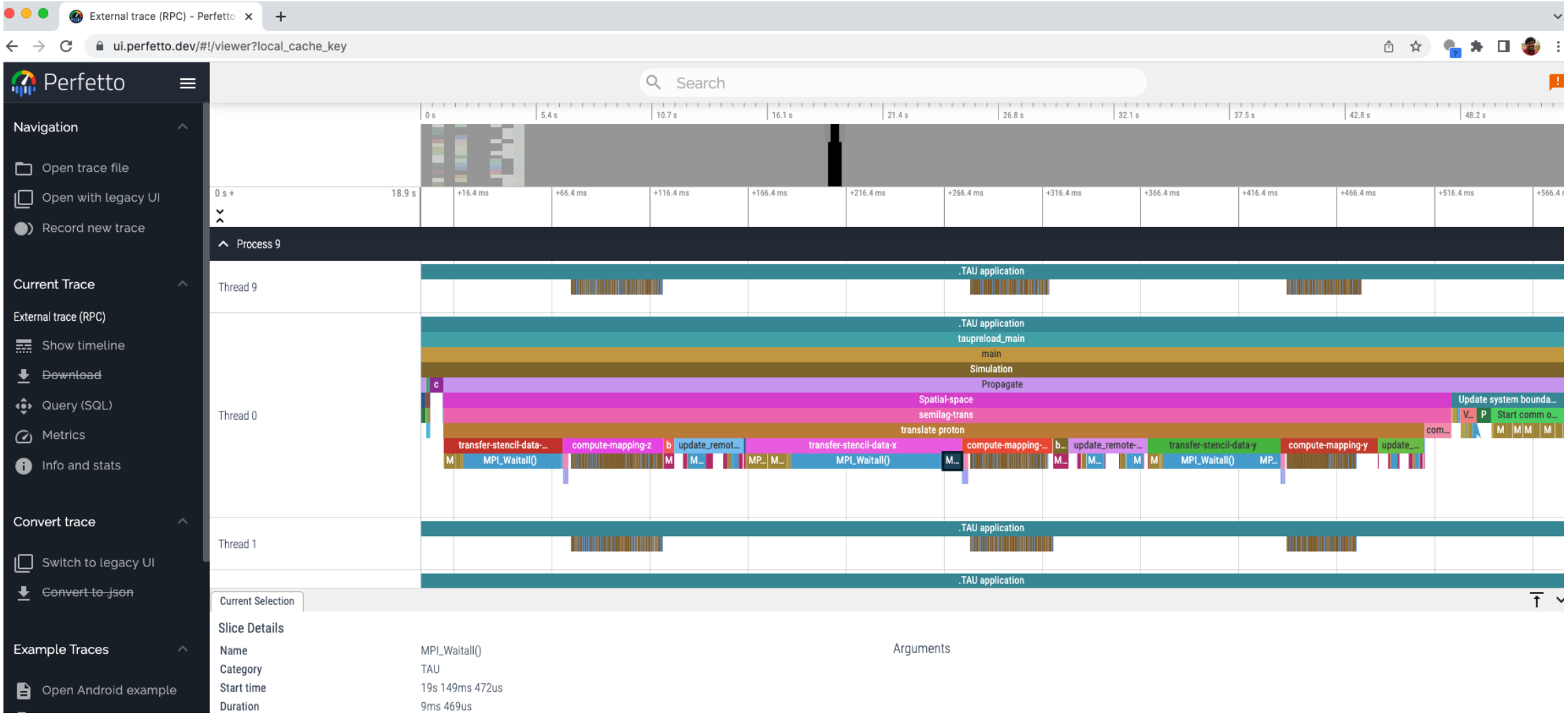
TAU's Runtime Environment Variables

Environment Variable	Default	Description
TAU_TRACE	0	Setting to 1 turns on tracing
TAU_CALLPATH	0	Setting to 1 turns on callpath profiling
TAU_TRACK_MEMORY_FOOTPRINT	0	Setting to 1 turns on tracking memory usage by sampling periodically the resident set size and high-water mark of memory usage
TAU_TRACK_POWER	0	Tracks power usage by sampling periodically.
TAU_CALLPATH_DEPTH	2	Specifies depth of callpath. Setting to 0 generates no callpath or routine information, setting to 1 generates flat profile and context events have just parent information (e.g., Heap Entry: foo)
TAU_SAMPLING	1	Setting to 1 enables event-based sampling.
TAU_TRACK_SIGNALS	0	Setting to 1 generate debugging callstack info when a program crashes
TAU_COMM_MATRIX	0	Setting to 1 generates communication matrix display using context events
TAU_THROTTLE	1	Setting to 0 turns off throttling. Throttles instrumentation in lightweight routines that are called frequently
TAU_THROTTLE_NUMCALLS	100000	Specifies the number of calls before testing for throttling
TAU_THROTTLE_PERCALL	10	Specifies value in microseconds. Throttle a routine if it is called over 100000 times and takes less than 10 usec of inclusive time per call
TAU_CALLSITE	0	Setting to 1 enables callsite profiling that shows where an instrumented function was called. Also compatible with tracing.
TAU_PROFILE_FORMAT	Profile	Setting to "merged" generates a single file. "snapshot" generates xml format
TAU_METRICS	TIME	Setting to a comma separated list generates other metrics. (e.g., ENERGY,TIME,P_VIRTUAL_TIME,PAPI_FP_INS,PAPI_NATIVE_<event>:<subevent>)

Tracing: Jumpshot [ANL] (ships with TAU)

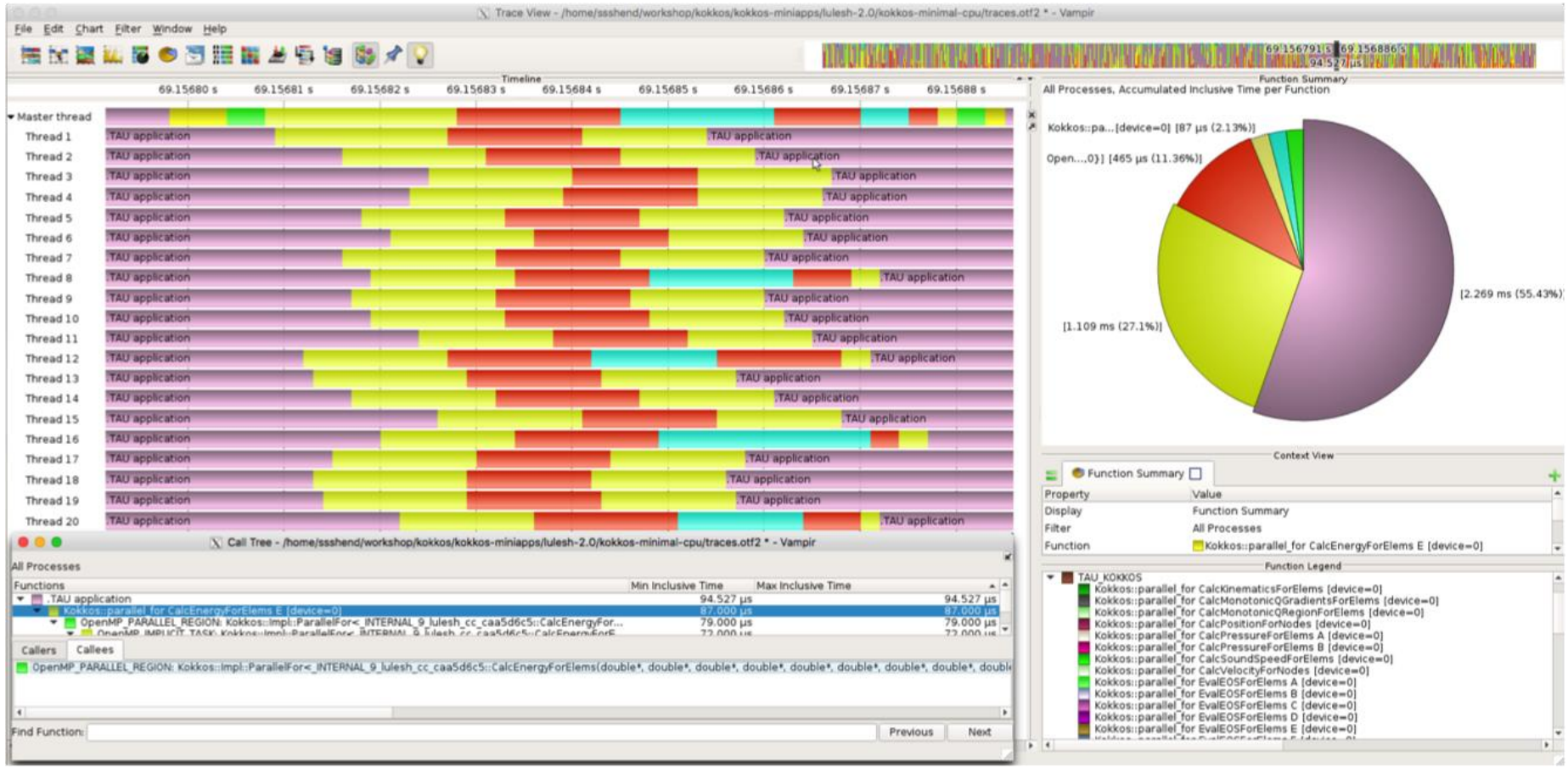


Perfetto.dev



export TAU_TRACE=1; export TAU_TRACE_FORMAT=perfetto; firefox https://perfetto.dev

Vampir [TU Dresden] Timeline: Kokkos



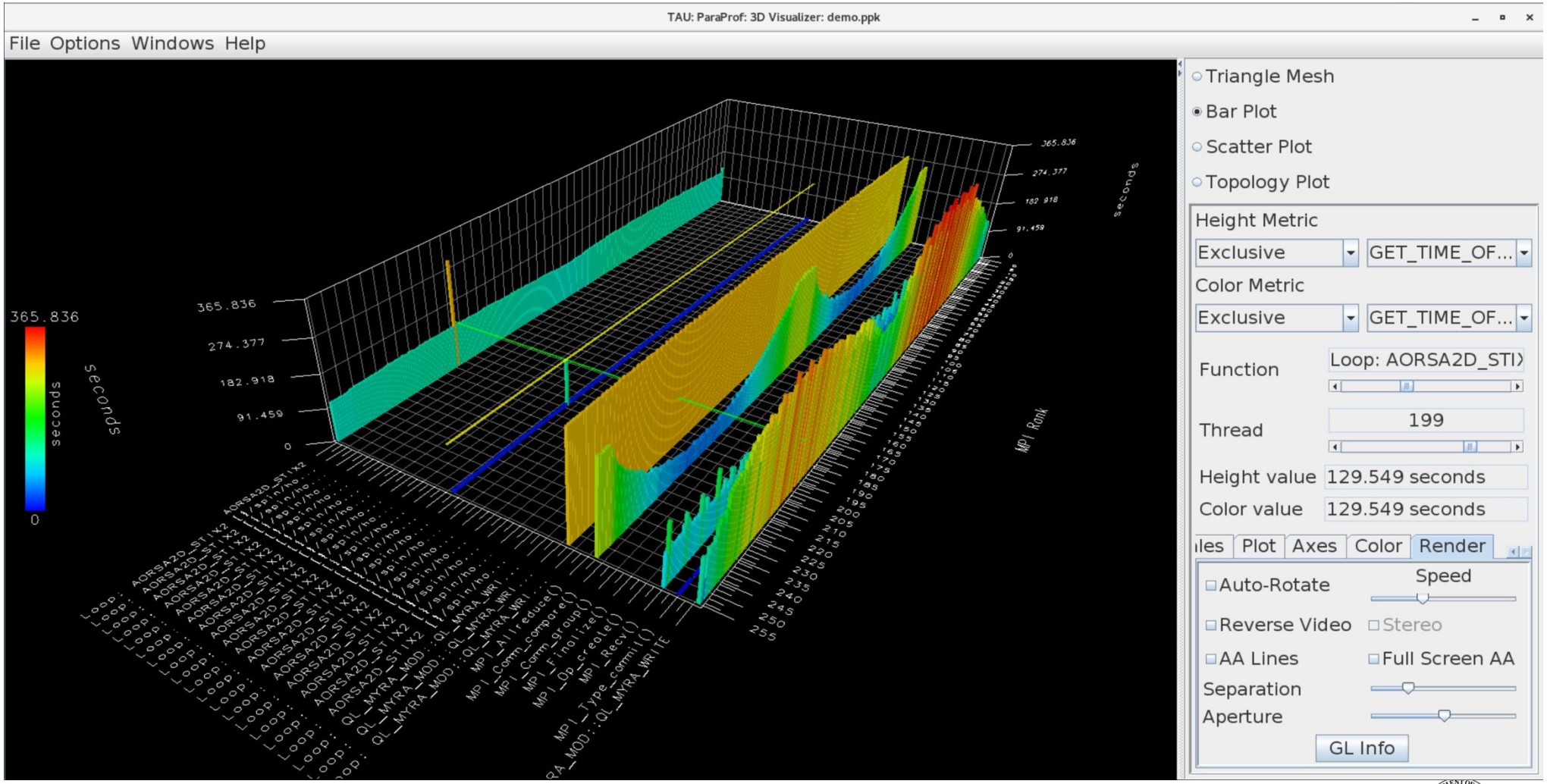
% export TAU_TRACE=1; export TAU_TRACE_FORMAT=otf2
% tau_exec -T ompt –ompt ./a.out % vampir traces.otf2 &

ParaProf Profile Browser

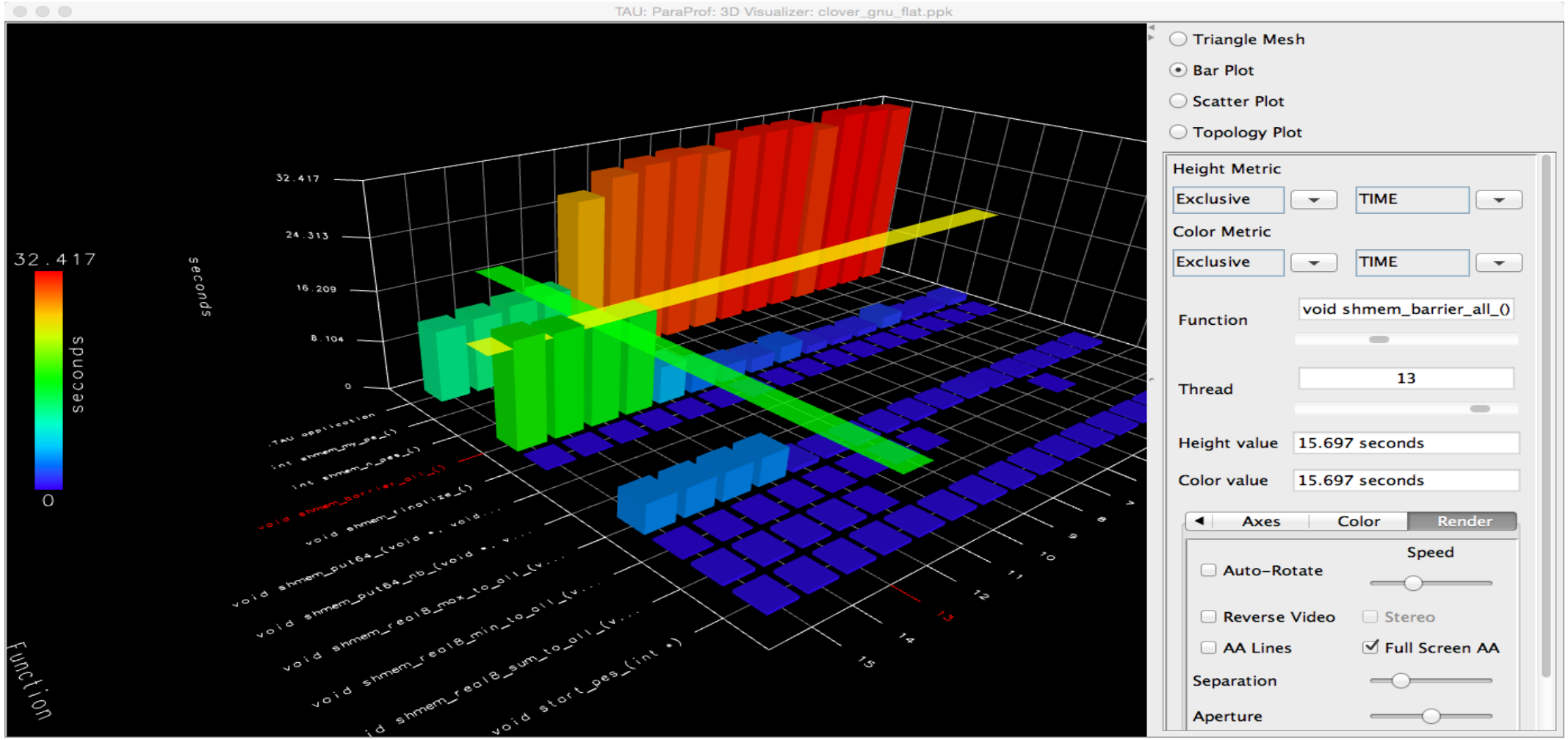

```
% paraprof
```

```
On a Mac if there are
black windows:
% paraprof –fix-xquartz
```

ParaProf 3D Profile Browser



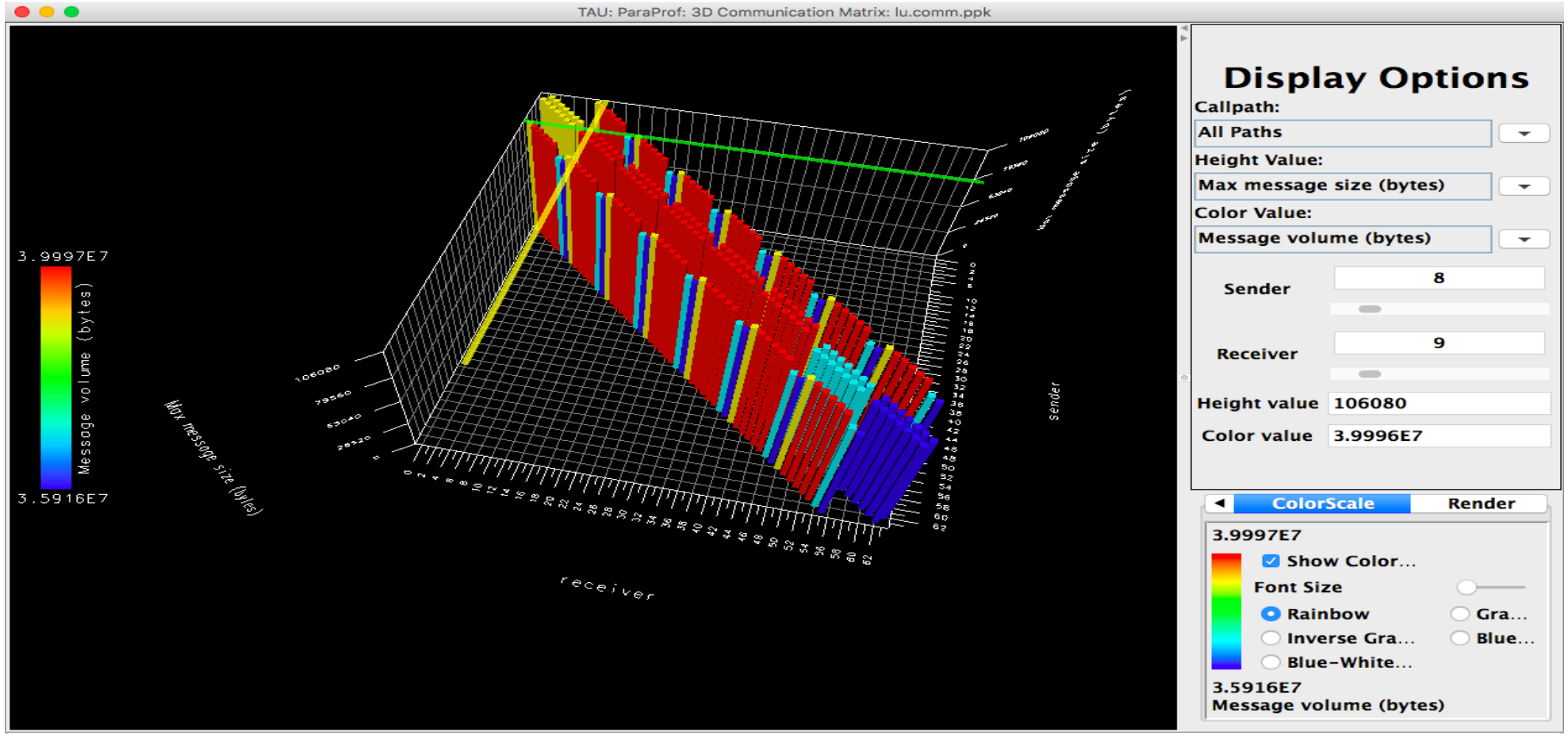
TAU – ParaProf 3D Visualization



% paraprof app.ppk

Windows -> 3D Visualization -> Bar Plot (right pane)

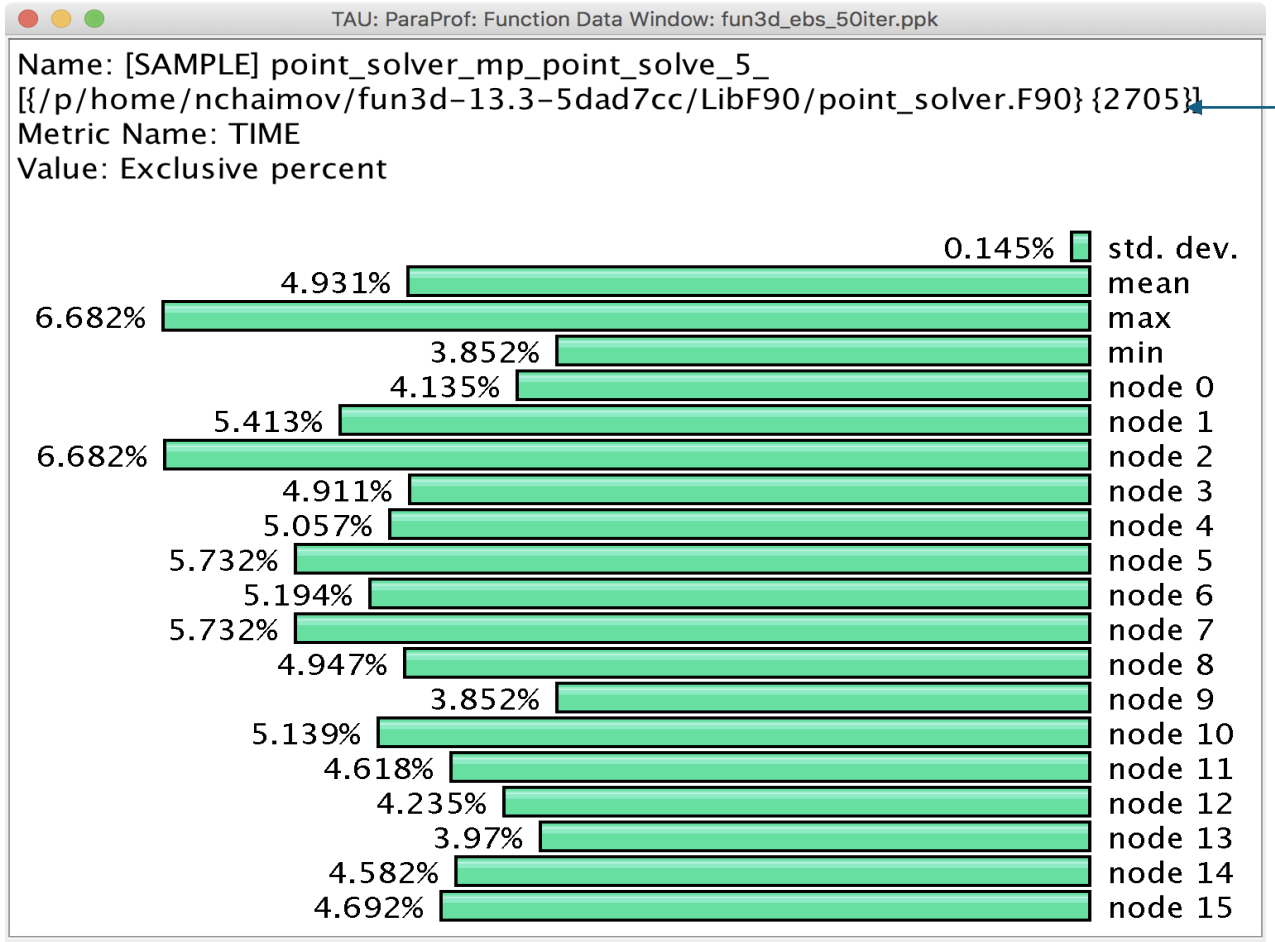
TAU – 3D Communication Window



% export TAU_COMM_MATRIX=1; mpirun ... tau_exec ./a.out

% paraprof ; Windows -> 3D Communication Matrix

Event Based Sampling (EBS)



File: point_solver.F90
Line: 2705

Uninstrumented!

```
% mpirun -n 16 tau_exec -ebs a.out
```

TAU's Runtime Environment Variables

Environment Variable	Default	Description
TAU_TRACE	0	Setting to 1 turns on tracing
TAU_CALLPATH	0	Setting to 1 turns on callpath profiling
TAU_TRACK_MEMORY_FOOTPRINT	0	Setting to 1 turns on tracking memory usage by sampling periodically the resident set size and high water mark of memory usage
TAU_TRACK_POWER	0	Tracks power usage by sampling periodically.
TAU_CALLPATH_DEPTH	2	Specifies depth of callpath. Setting to 0 generates no callpath or routine information, setting to 1 generates flat profile and context events have just parent information (e.g., Heap Entry: foo)
TAU_SAMPLING	1	Setting to 1 enables event-based sampling.
TAU_TRACK_SIGNALS	0	Setting to 1 generate debugging callstack info when a program crashes
TAU_COMM_MATRIX	0	Setting to 1 generates communication matrix display using context events
TAU_THROTTLE	1	Setting to 0 turns off throttling. Throttles instrumentation in lightweight routines that are called frequently
TAU_THROTTLE_NUMCALLS	100000	Specifies the number of calls before testing for throttling
TAU_THROTTLE_PERCALL	10	Specifies value in microseconds. Throttle a routine if it is called over 100000 times and takes less than 10 usec of inclusive time per call
TAU_CALLSITE	0	Setting to 1 enables callsite profiling that shows where an instrumented function was called. Also compatible with tracing.
TAU_PROFILE_FORMAT	Profile	Setting to "merged" generates a single file. "snapshot" generates xml format
TAU_METRICS	TIME	Setting to a comma separated list generates other metrics. (e.g., ENERGY,TIME,P_VIRTUAL_TIME,PAPI_FP_INS,PAPI_NATIVE_<event>:<subevent>)

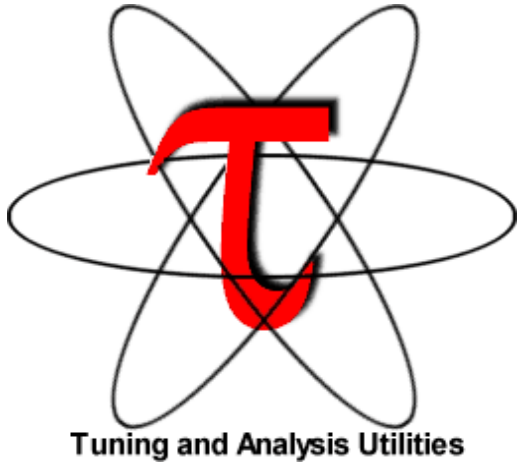
Runtime Environment Variables

Environment Variable	Default	Description
TAU_TRACE	0	Setting to 1 turns on tracing
TAU_TRACE_FORMAT	Default	Setting to “otf2” turns on TAU’s native OTF2 trace generation (configure with –otf=download) Setting to “perfetto” generates native Perfetto.dev trace tau.perfetto.gz.
TAU_EBS_UNWIND	0	Setting to 1 turns on unwinding the callstack during sampling (use with tau_exec –ebs or TAU_SAMPLING=1)
TAU_EBS_RESOLUTION	line	Setting to “function” or “file” changes the sampling resolution to function or file level respectively.
TAU_TRACK_LOAD	0	Setting to 1 tracks system load on the node
TAU_SELECT_FILE	Default	Setting to a file name, enables selective instrumentation based on exclude/include lists specified in the file.
TAU_OMPT_SUPPORT_LEVEL	basic	Setting to “full” improves resolution of OMPT TR6 regions on threads 1.. N-1. Also, “lowoverhead” option is available.
TAU_OMPT_RESOLVE_ADDRESS_EAGERLY	1	Setting to 1 is necessary for event-based sampling to resolve addresses with OMPT. Setting to 0 allows the user to do offline address translation.

Runtime Environment Variables

Environment Variable	Default	Description
TAU_TRACK_MEMORY_LEAKS	0	Tracks allocates that were not de-allocated (needs –optMemDbg or tau_exec –memory)
TAU_EBS_SOURCE	TIME	Allows using PAPI hardware counters for periodic interrupts for EBS (e.g., TAU_EBS_SOURCE=PAPI_TOT_INS when TAU_SAMPLING=1)
TAU_EBS_PERIOD	100000	Specifies the overflow count for interrupts
TAU_MEMDBG_ALLOC_MIN/MAX	0	Byte size minimum and maximum subject to bounds checking (used with TAU_MEMDBG_PROTECT_*)
TAU_MEMDBG_OVERHEAD	0	Specifies the number of bytes for TAU's memory overhead for memory debugging.
TAU_MEMDBG_PROTECT_BELOW/ABOVE	0	Setting to 1 enables tracking runtime bounds checking below or above the array bounds (requires –optMemDbg while building or tau_exec –memory)
TAU_MEMDBG_ZERO_MALLOC	0	Setting to 1 enables tracking zero byte allocations as invalid memory allocations.
TAU_MEMDBG_PROTECT_FREE	0	Setting to 1 detects invalid accesses to deallocated memory that should not be referenced until it is reallocated (requires –optMemDbg or tau_exec –memory)
TAU_MEMDBG_ATTEMPT_CONTINUE	0	Setting to 1 allows TAU to record and continue execution when a memory error occurs at runtime.
TAU_MEMDBG_FILL_GAP	Undefined	Initial value for gap bytes
TAU_MEMDBG_ALINGMENT	Sizeof(int)	Byte alignment for memory allocations
TAU_EVENT_THRESHOLD	0.5	Define a threshold value (e.g., .25 is 25%) to trigger marker events for min/max

Download TAU from U. Oregon



https://tau.uoregon.edu

https://e4s.io [TAU in Docker/Singularity containers]

https://paratoolspro.com [TAU on commercial cloud platforms]

for more information

Free download, open source, BSD license

Installing and Configuring TAU

- Installing PDT (if using source instrumentation; optional):

```
wget tau.uoregon.edu/pdt_lite.tgz
./configure –prefix=<dir>; make ; make install
```

- Installing TAU:

```
wget tau.uoregon.edu/tau.tgz;    tar zxf tau.tgz; cd tau-2.<ver>
wget http://tau.uoregon.edu/ext.tgz ; tar xf ext.tgz
./configure -bfd=download -pdt=<dir> -papi=<dir> -mpi
  –pthread –c++=mpicxx –cc=mpicc –fortran=mpif90
  –dwarf=download –unwind=download –otf=download
  –iowrapper –papi=<dir>
make install
```

- Using TAU for source instrumentation (not needed with tau_exec):

```
export TAU_MAKEFILE=<taudir>/x86_64/lib/Makefile.tau-<TAGS>
make CC=tau_cc.sh   CXX=tau_cxx.sh   F90=tau_f90.sh
```

Compile-Time Options

Optional parameters for the TAU_OPTIONS environment variable:
% tau_compiler.sh

-optVerbose	Turn on verbose debugging messages
-optCompInst	Use compiler based instrumentation
-optNoCompInst	Do not revert to compiler instrumentation if source instrumentation fails.
-optTrackIO	Wrap POSIX I/O call and calculates vol/bw of I/O operations (Requires TAU to be configured with *–iowrapper*)
-optTrackGOMP	Enable tracking GNU OpenMP runtime layer (used without –opari)
-optMemDbg	Enable runtime bounds checking (see TAU_MEMDBG_* env vars)
-optKeepFiles	Does not remove intermediate .pdb and .inst.* files
-optPreProcess	Preprocess sources (OpenMP, Fortran) before instrumentation
-optTauSelectFile=”<file>"	Specify selective instrumentation file for *tau_instrumentor*
-optTauWrapFile=”<file>"	Specify path to *link_options.tau* generated by *tau_gen_wrapper*
-optHeaderInst	Enable Instrumentation of headers
-optTrackUPCR	Track UPC runtime layer routines (used with tau_upc.sh)
-optLinking=""	Options passed to the linker. Typically $(TAU_MPI_FLIBS) $(TAU_LIBS) $(TAU_CXXLIBS)
-optCompile=""	Options passed to the compiler. Typically $(TAU_MPI_INCLUDE) $(TAU_INCLUDE) $(TAU_DEFS)
-optPdtF95Opts=""	Add options for Fortran parser in PDT (f95parse/gfparse) …

Compile-Time Options (contd.)

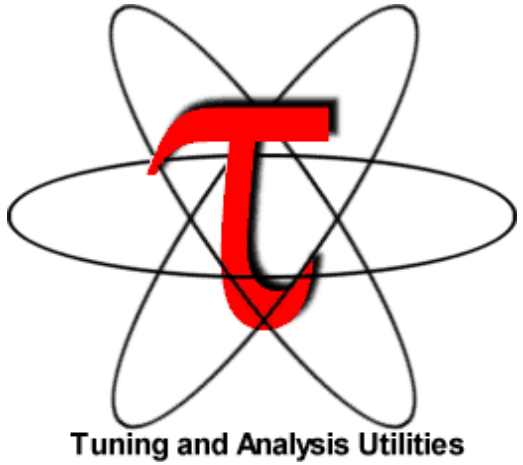
Optional parameters for the TAU_OPTIONS environment variable:
% tau_compiler.sh

-optShared	Use TAU's shared library (libTAU.so) instead of static library (default)
-optPdtCxxOpts=""	Options for C++ parser in PDT (cxxparse).
-optPdtF90Parser=""	Specify a different Fortran parser
-optPdtCleanscapeParser	Specify the Cleanscape Fortran parser instead of GNU gfparser
-optTau=""	Specify options to the tau_instrumentor
-optTrackDMAPP	Enable instrumentation of low-level DMAPP API calls on Cray
-optTrackPthread	Enable instrumentation of pthread calls

See tau_compiler.sh for a full list of TAU_OPTIONS.

…

Hands-On



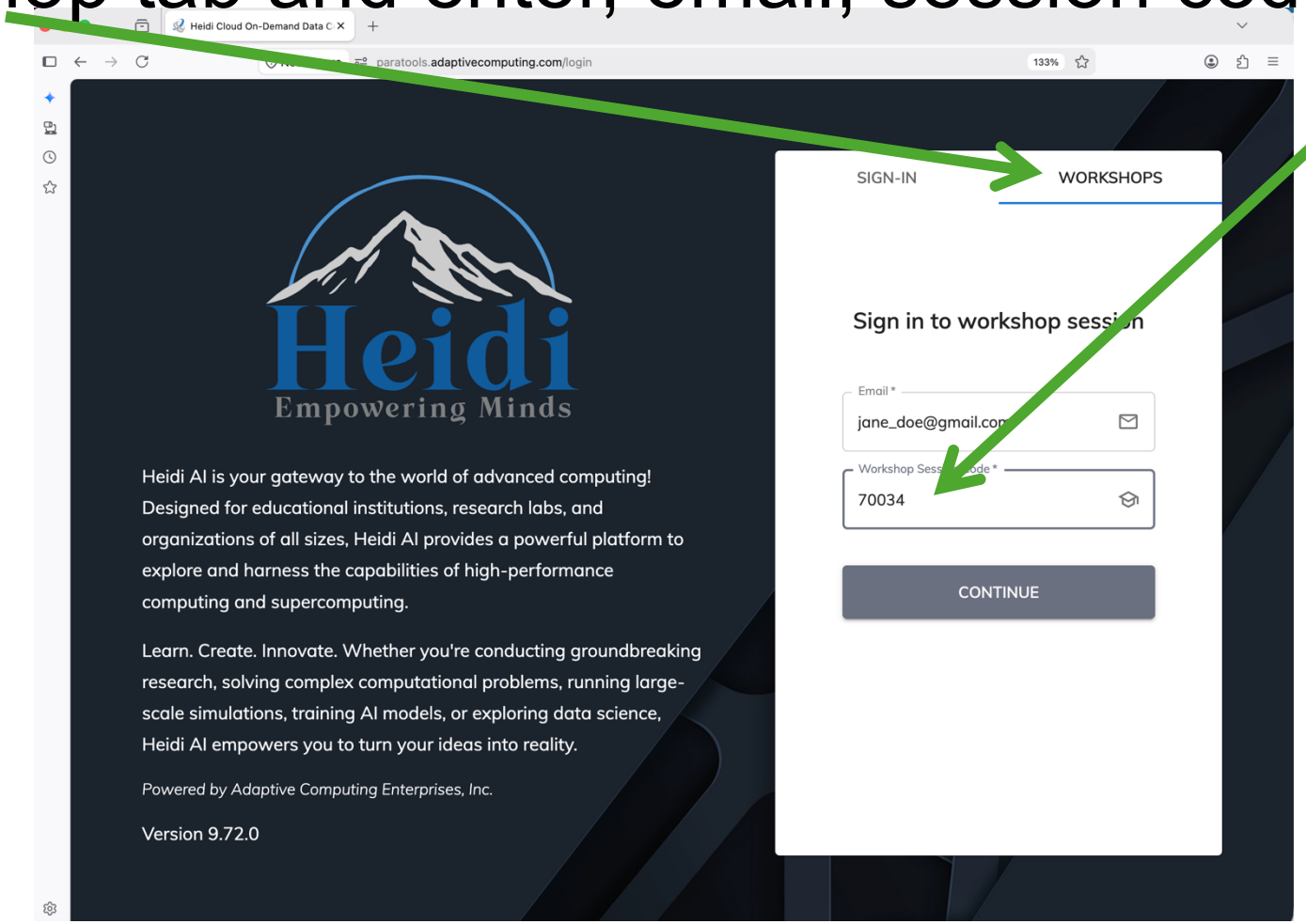
Cloud

Heidi from Adaptive Computing Enterprises, Inc.

ParaTools Pro for E4S™ image

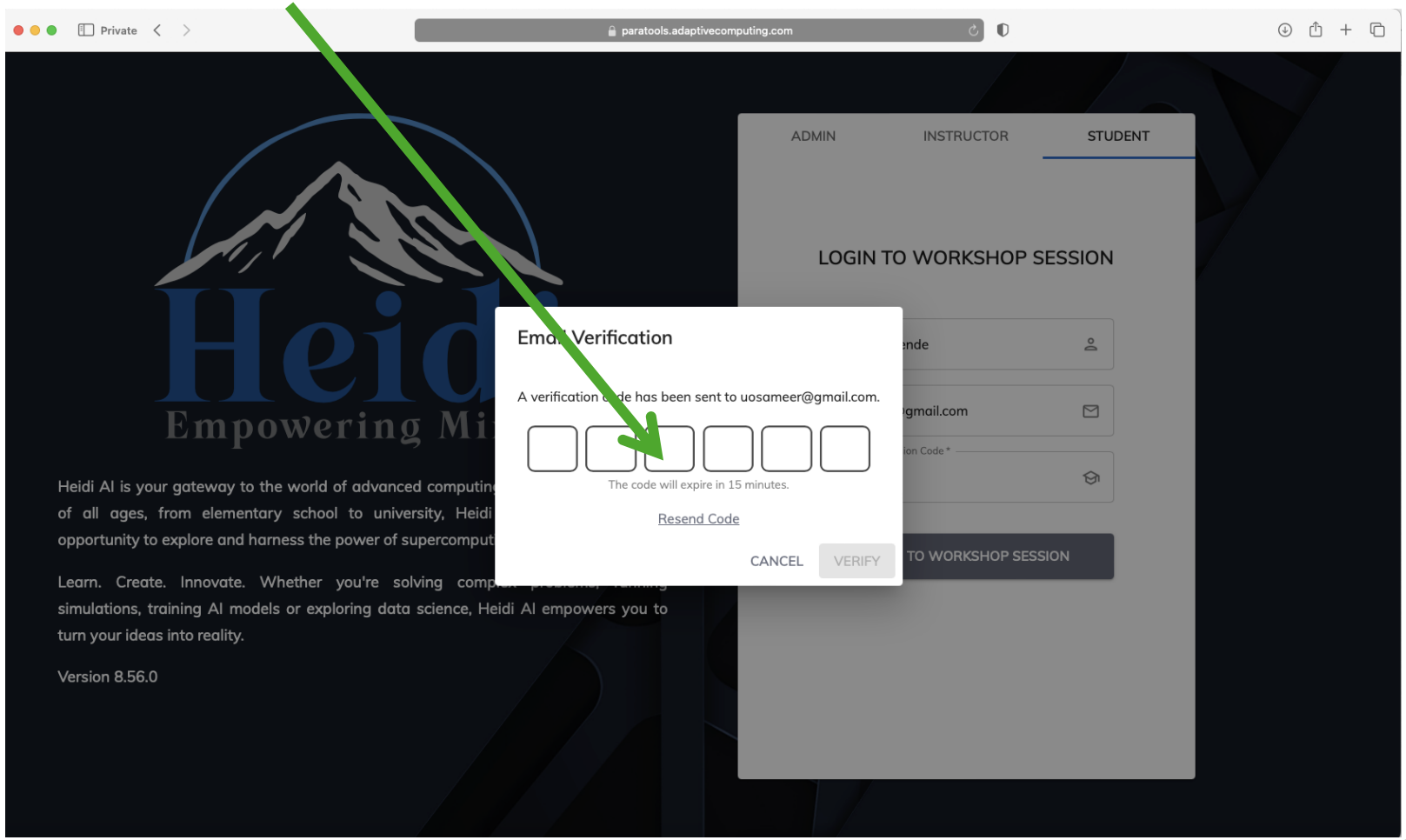
Connect to https://paratools.adaptivecomputing.com

- Use Workshop tab and enter, email, session code 70034



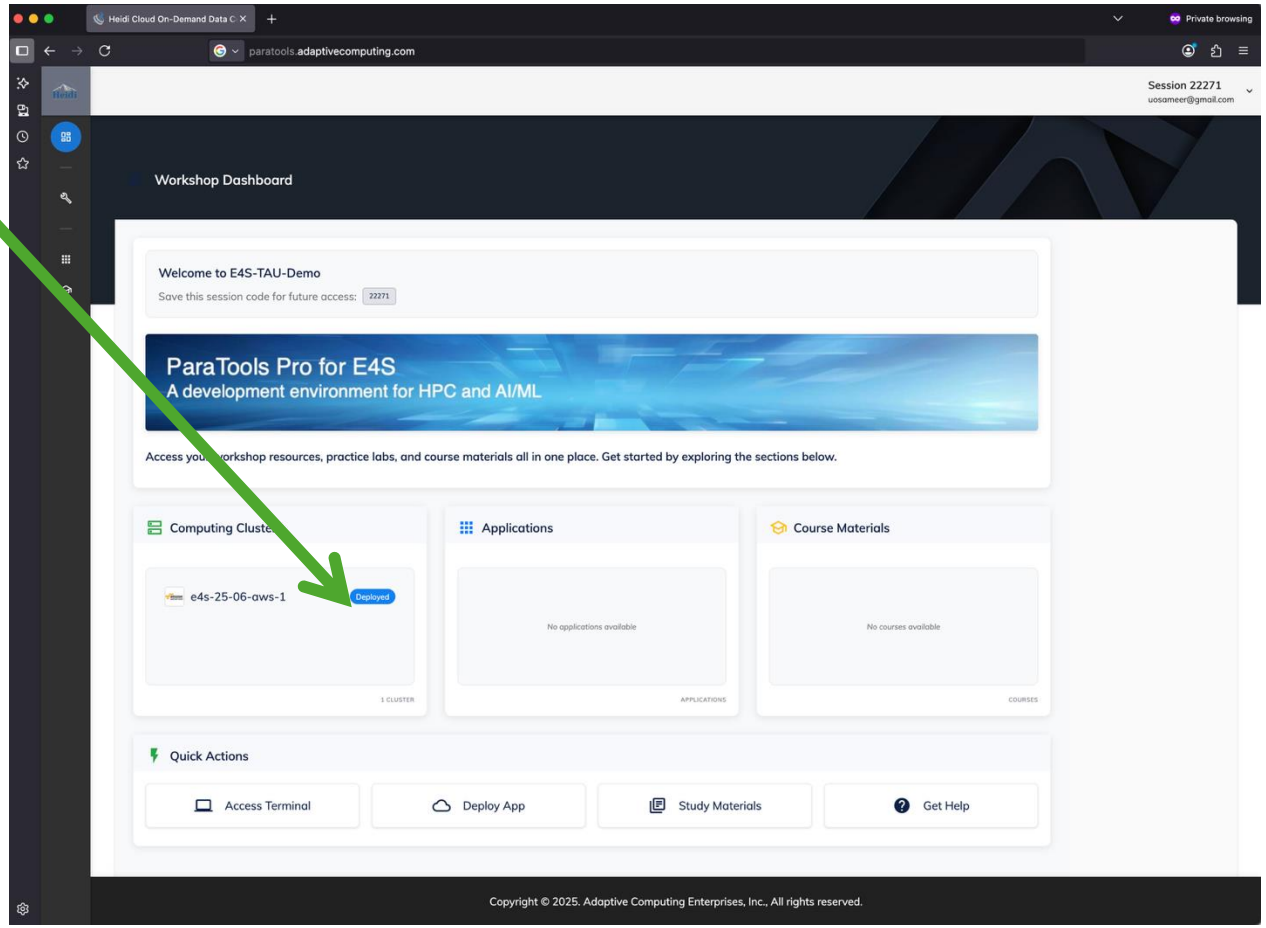
Connect to Workshops tab with code 70034

- Check your email, enter verification code at paratools.adaptivecomputing.com.



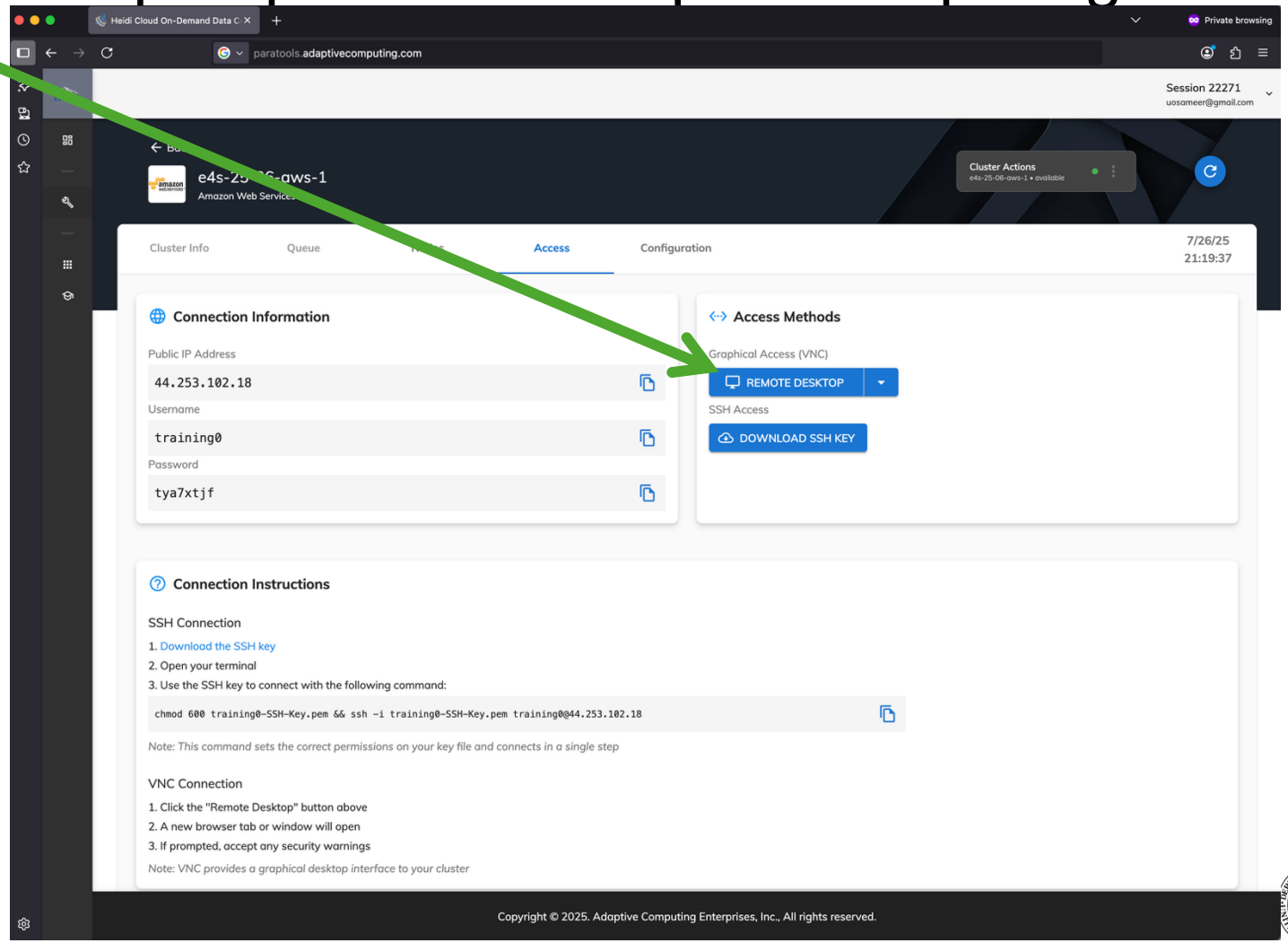
Connect to Workshops tab with code 70034

- Click cluster at https://paratools.adaptivecomputing.com



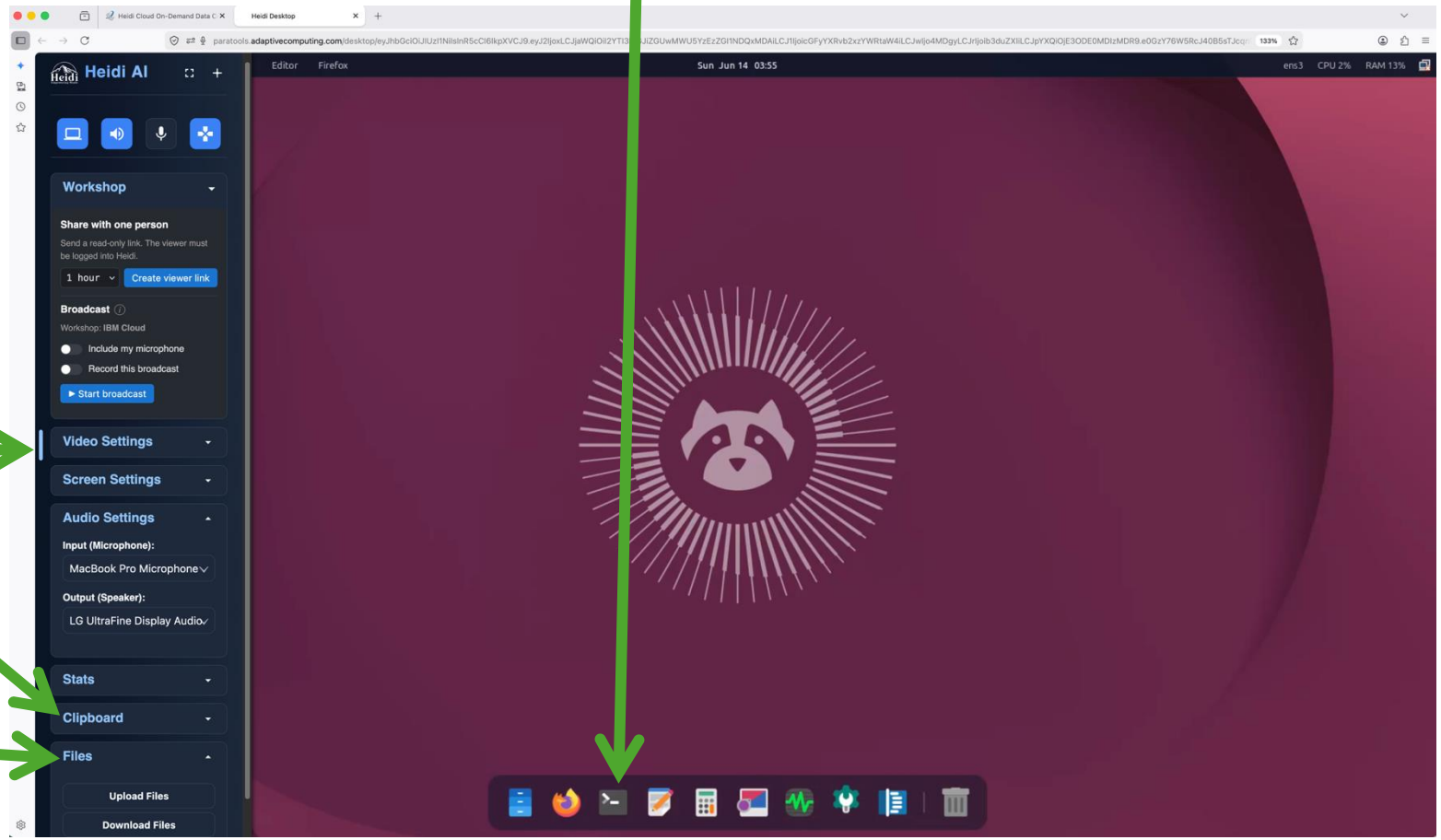
Connect to a Remote Desktop

- Click Remote Desktop at paratools.adaptivecomputing.com (70034)



Connect to Workshops tab with code 70034 at https://paratools.adaptivecomputing.com

- You should see this racoon. Click on Terminal.



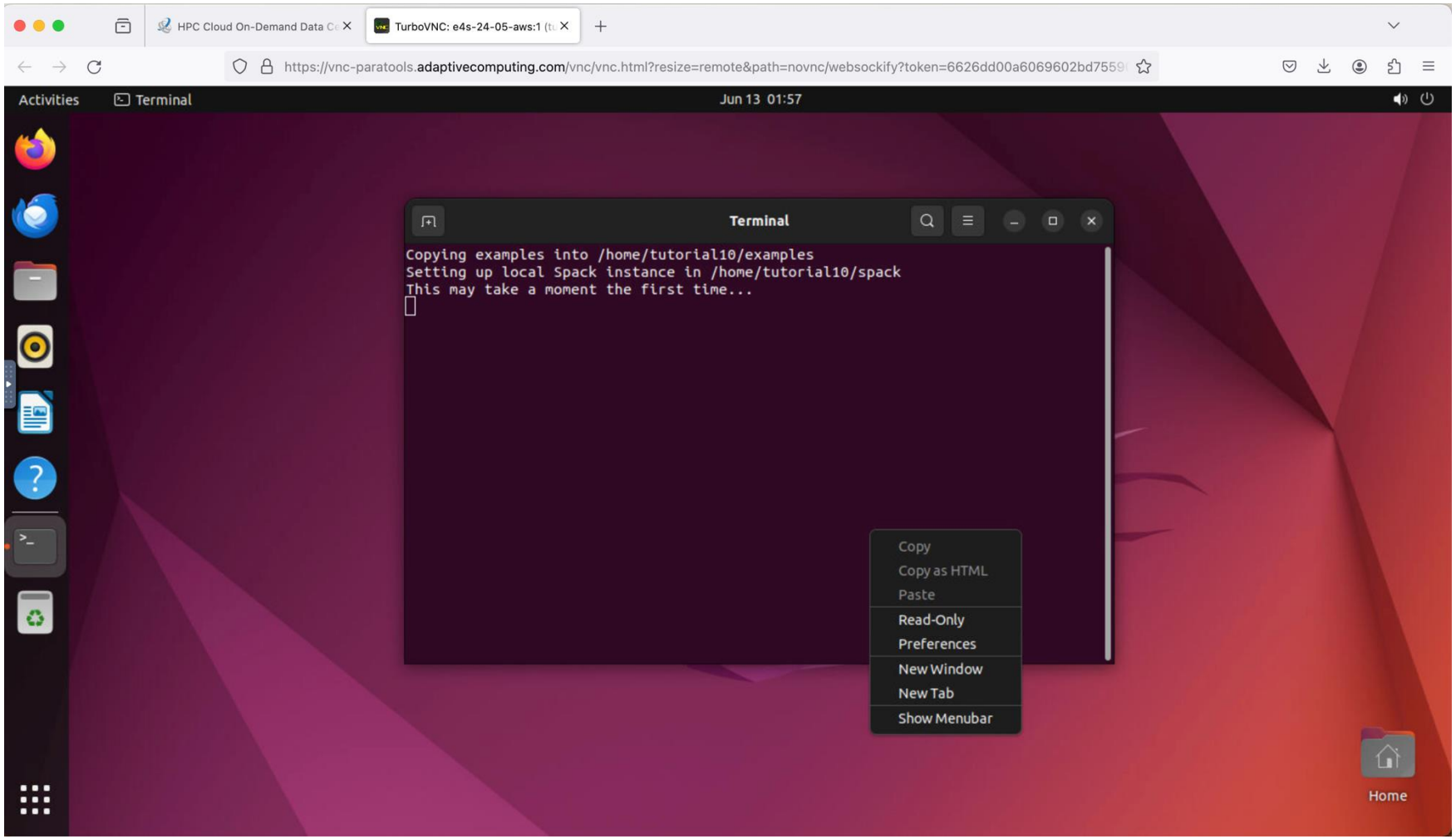
To copy text from other windows click on the this button to access the Clipboard

To upload/download files to Desktop, use this button

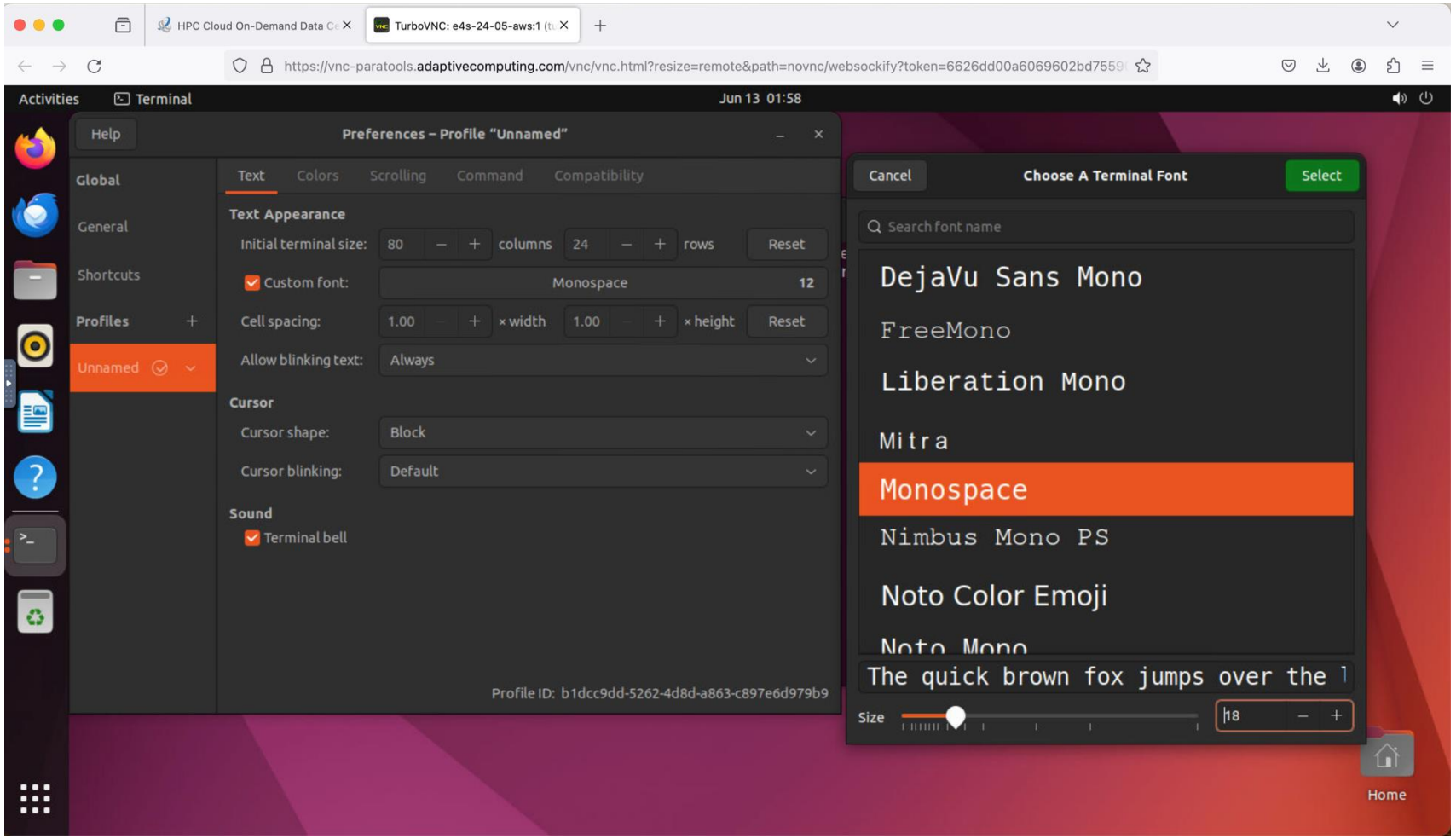
If this doesn't work for you!

Go to
https://uooddc.nic.uoregon.edu
workshops tab, enter
25724
as the code. Try again.

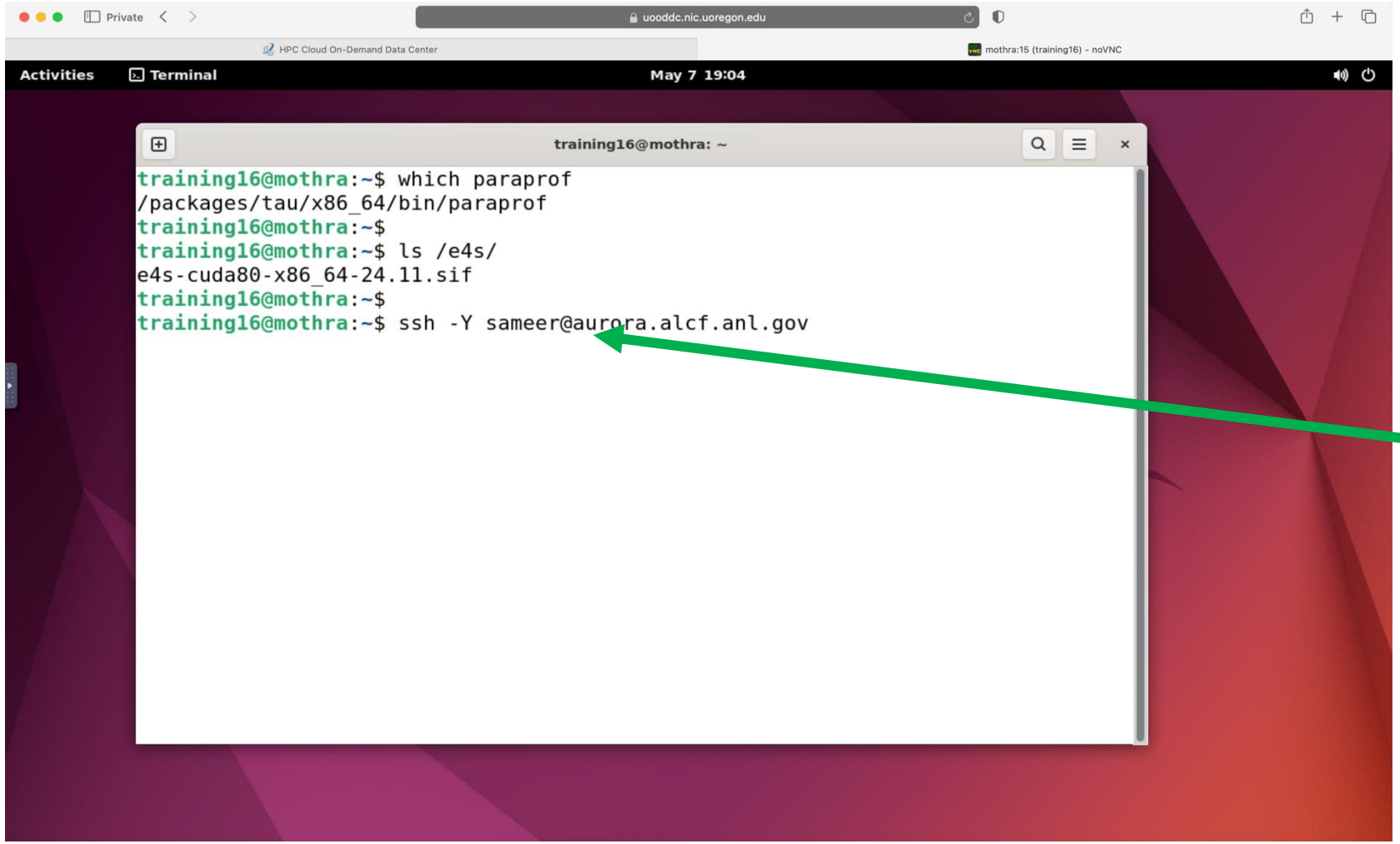
To increase font size right click and choose preferences



Choose font size after clicking Custom Font for Terminal



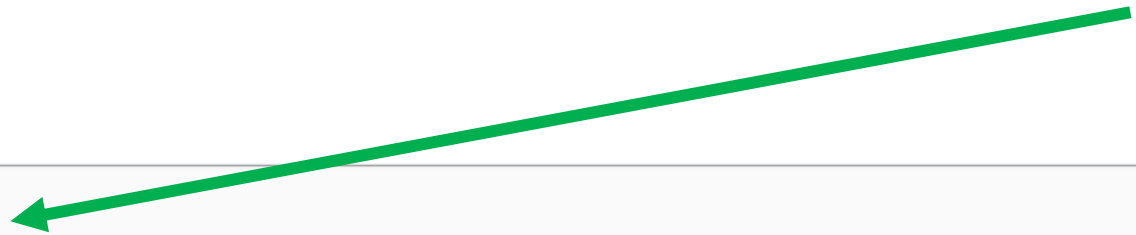
Login to Aurora.alcf.anl.gov



ssh using -Y

Add a directory to the default modules path to access tau module

module use /soft/modulefiles
module load tau



```
$ module use /soft/modulefiles
$ module load tau
Adding module path /soft/perftools/tau/modulefiles
$ ls $TAU/Makefile*
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-icpx-papi-ompt-python-pdt-openmp-l0metrics
/soft/perftools/tau/tau-2.35.2/x86_64/lib/Makefile.tau-level_zero-ittnotify-gptl-icpx-papi-ompt-mpi-python-pdt-openmp-l0metrics
$ qsub -I  -l walltime=1:29:00 -lfilesystems=home:flare -A ATPESC2026       -q ATPESC -l select=1 -X
qsub: waiting for job 8719717.aurora-pbs-0001.hostmgmt.cm.aurora.alcf.anl.gov to start
```

Login to Aurora.alcf.anl.gov

```
tar xf /soft/perftools/tau/tar/workshop.tgz
cd workshop; cat README
qsub -I  -l walltime=1:29:00 -lfilesystems=home:flare -A ATPESC2026
     -q ATPESC -l select=1 -X
module use /soft/modulefiles
module load tau
module load frameworks  # For Python. You may omit for MPI programs.

mpiexec -n 4 ./a.out
mpiexec -n 4 tau_exec -l0 -ebs ./a.out

mpiexec -n 4 tau_exec -l0 -ebs python ./foo.py
pprof -a  | more
paraprof

For large scale runs: export TAU_PROFILE_FORMAT="merged" and use
paraprof tauprofile.xml &
```

Using TAU on Frontier@OLCF

```
tar xf /sw/frontier/ums/ums002/paratools/tar/workshop.tgz
cd workshop; cat README
salloc -n 4 -A <ACCOUNT> -N 1 -t 0:55:00 -q debug -C nvme --gpus 2
module load ums ums002 tau
srun -n 4 ./a.out
srun -n 4 tau_exec -rocm -ebs ./a.out
srun -n 4 tau_exec -rocm_pc -ebs ./a.out
export TAU_METRICS=ROCM_SQ_WAVES    # see rocprofv3 -L for a complete list of counters
srun -n 4 tau_exec -rocm -ebs ./a.out

pprof -a  | more
paraprof --pack foo.ppk
On your desktop: % paraprof foo.ppk
```

Setup: Installing TAU on laptops

Prerequisites: Java in your path

- Microsoft Windows
  - Install Java from Oracle.com
    - http://tau.uoregon.edu/tau.exe
    - Install, click on a ppk file to launch paraprof
  - macOS (arm64, Apple Silicon M series)
    - http://tau.uoregon.edu/java_arm64.dmg
    - http://tau.uoregon.edu/tau_arm64.dmg
- macOS (x86_64)
  - Install Java 11.0.3:
    - Download and install http://tau.uoregon.edu/java.dmg
    - If you have multiple Java installations, add to your ~/.zshrc (or ~/.bashrc as appropriate):
    - export PATH=/Library/Java/JavaVirtualMachines/jdk-11.0.3.jdk/Contents/Home/bin:$PATH
  - Download and install TAU (copy to /Applications from dmg):
    - http://tau.uoregon.edu/tau.dmg
    - export PATH=/Applications/TAU/tau/apple/bin:$PATH
    - paraprof app.ppk &
  - Linux (http://tau.uoregon.edu/tau.tgz)
    - ./configure; make install; export PATH=<taudir>/x86_64/bin:$PATH; paraprof app.ppk &

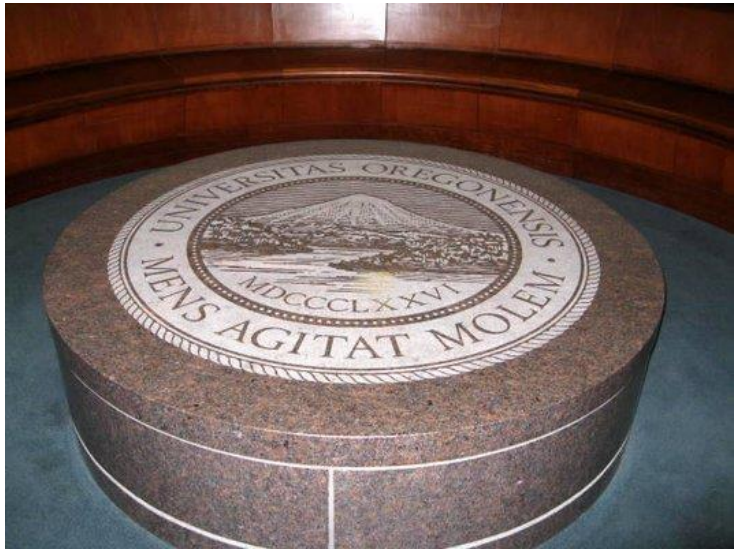
Using TAU on Aurora

```
% tar xf /soft/perftools/tau/tar/workshop.tgz; cd workshop; cat README
% qsub -I  -l walltime=0:29:00 -lfilesystems=home:flare -A ATPESC2026 -q ATPESC -l select=1 -X
% module use /soft/modulefiles; module load tau;
```

- Un-instrumented run with MPI % mpiexec -np N ./a.out
- Profiling an un-instrumented application (use tau_exec -ebs with any of the following for event-based sampling):
- MPI without GPUs: % mpiexec -np N tau_exec -ebs ./a.out
- DPC++/SYCL with MPI: % mpiexec -np N gpu_tile_compact.sh tau_exec -T level_zero -l0 ./a.out
- # Use -l0_pc instead of -l0 for sampling on GPU. export TAU_METRICS=L0_ComputeBasic (see tau_l0_avail)
- DPC++/SYCL without MPI: % tau_exec -T serial -l0 ./a.out
- OpenMP: export TAU_OMPT_SUPPORT_LEVEL=full
- OpenMP with MPI: % mpiexec -np N gpu_tile_compact.sh tau_exec tau_exec -ompt ./a.out
- OpenMP without MPI: % tau_exec -T serial -ompt./a.out

```
Analysis:  % pprof -a -m | more;  % paraprof (GUI)
Tracing:
Perfetto.dev:  % export TAU_TRACE=1; export TAU_FORMAT=perfetto; mpiexec -np N tau_exec ./a.out;
Jumpshot:  % export TAU_TRACE=1; mpiexec -np N gpu_tile_compact.sh tau_exec [Options]./a.out;
        % tau_treemerge.pl; tau2slog2 tau.trc tau.edf -o app.slog2; jumpshot app.slog2 &
```

Performance Research Laboratory, University of Oregon, Eugene



www.uoregon.edu

Suport Acknowledgments

- US Department of Energy (DOE)
  - ANL
  - Office of Science contracts, ECP
  - SciDAC, LBL contracts
  - LLNL-LANL-SNL ASC/NNSA contract
  - Battelle, PNNL and ORNL contract
- Department of Defense (DoD)
  - PETTT, HPCMP
- National Science Foundation (NSF)
  - CSSI2, SI2-SSI, Glassbox, E4S Workshop
- NASA SBIR Program
- Intel, AWS, IBM, OCI, GCP, NVIDIA, AMD
- CEA, France
- Partners:
  - University of Oregon
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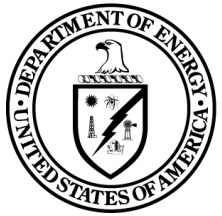
- https://science.osti.gov/ascr
- https://pesoproject.org
- https://ascr-step.org
- https://alcf.anl.gov
- https://hpsf.io
- https://www.energy.gov/technologytransitions/sbirsttr



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