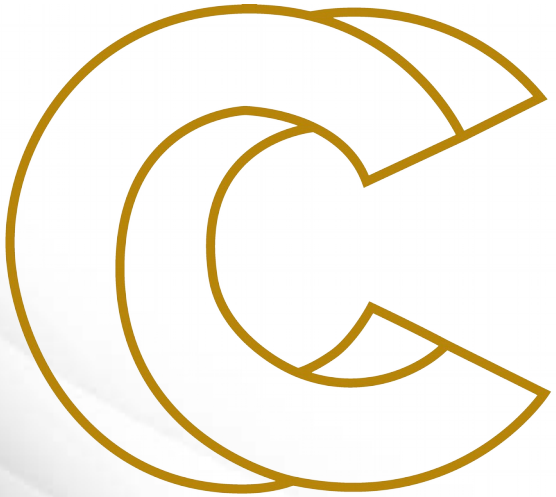
OpenMP and MPI applications

Profiling, performance evaluation and optimization



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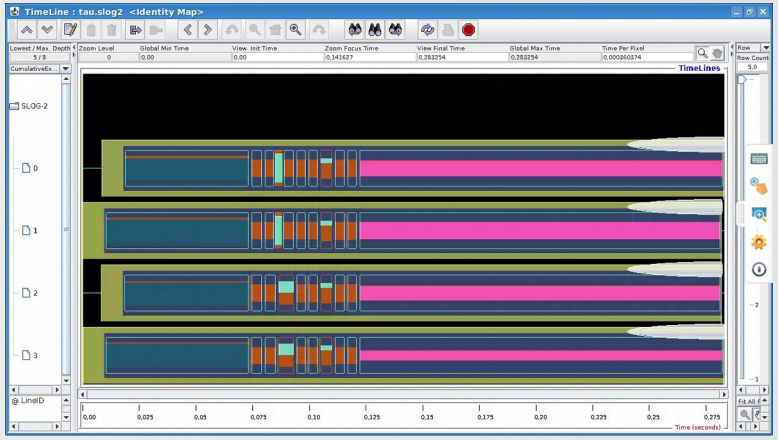
Methods for performance evaluation

- **Profiling**: gives information about time spent in each part or routine of the program

Metric: TIME
Value: Exclusive
Units: seconds

0,115	main [{/home/bogdanl/PTC_OpenMP_prof/examples/openmpi/simple-work/simple.c} {15,0}]
0,058	MPI_Finalize()
0,03	MPI_Init()
0,02	foo [{/home/bogdanl/PTC_OpenMP_prof/examples/openmpi/simple-work/simple.c} {8,0}] [THROTTLED]
0,01	.TAU application
2,0E-6	MPI_Get_processor_name()
0	MPI_Comm_size()
0	MPI_Comm_rank()

- **Tracing**: gives information about when events take place on a timeline



TAU performance system

- **TAU** (Tuning and Analysis Utilities):

https://www.cs.uoregon.edu/research/tau/home.php

- **scalable and flexible** performance analysis toolkit
- comprehensive **performance profiling and tracing**
- supports **all parallel programming/execution paradigms**:

  MPI, MPI-IO, OpenMP CPU, OpenMP GPU, OpenACC, CUDA, OpenCL etc.

TAU usage

- **Instrumentation**:
  - adding probes to perform measurements
  - source code instrumentation
  - wrapping external libraries (I/O, CUDA, OpenACC, OpenCL)
  - rewriting the binary executable
- **Measurement**:
  - profiling or tracing
  - direct instrumentation
  - sampling
  - throttling
- **Analysis:**
  - visualization of profiles and traces
  - 3D visualization
  - trace conversion tools

TAU Instrumentation

3 methods for **tracking the performance** of applications:

- **Dynamic instrumentation** through library pre-loading, e.g.:
  - `srun -n 4  tau_exec -T mpi ./a.out`
  - `mpirun -np 4 tau_exec -io ./a.out`
  - `tau_exec -io ./a.out`
- **Scripted compilation**, e.g.:
  - For C: compiler replaced with `tau_cc.sh`
  - For C++: compiler replaced with `tau_cxx.sh`
  - For Fortran: compiler replaced with `tau_f90.sh` or `tau_f77.sh`
- **Source transformation** using PDT (Program Database Toolkit): also needs to be installed

TAU Analysis

- TAU creates **one profile file per node** in a single location, **profile outputs** are named:

  `profile.0.0.0, profile.1.0.0, ...`
- **Text summary** of profile data with:

  `$ pprof`
- **2D and 3D visualization** of profile data with:

  `$ paraprof`
- TAU can also create **traces**:

  `tautrace.0.0.0.trc, tautrace.1.0.0.trc, ...`
- traces can be **converted and displayed** with external visualizers:

  `jumpshot` (included in TAU installation), `vampir` and others

TAU event types

TAU can measure several types of events:

- **Interval**: start-stop events (e.g.: function calls)
- **Atomic**: trigger at a single point with data (e.g.: memory allocation)
- **Context**: atomic events with executing context
- For atomic and context event types a **complete statistics of measurements** is given:

  total, samples, min/max/mean/standard deviation
- **inclusive vs. exclusive** measurements

Example 1: MPI profiling

Follow these steps on your `viz.hpc.fs.uni-lj.si` account:

- Load module and copy directory with examples:

```
$ module load tau
$ cp -r /home/leon//PTC_OpenMPI-MP_profiling /$HOME/PTC_OpenMPI-MP_profiling
```

- Go to work directory:

```
$ cd /$HOME/PTC_OpenMPI-MP_profiling/examples/openmpi/simple-work
```

- Compile the OpenMPI code (`simple.c`) with TAU script:

```
$ tau_cc.sh -tau_makefile=/opt/pkg/software/tau/2.29.1/x86_64/lib/Makefile.tau-mpi-openmp -tau_options=-optCompInst simple.c
```

- Generate profiles:

```
$ mpirun -np 4 tau_exec -io ./a.out
```

Example 1: MPI profiling (cont.)

- Use pprof **for text summary** of **profile** results:

```
$ pprof
```

Reading Profile files in profile.*

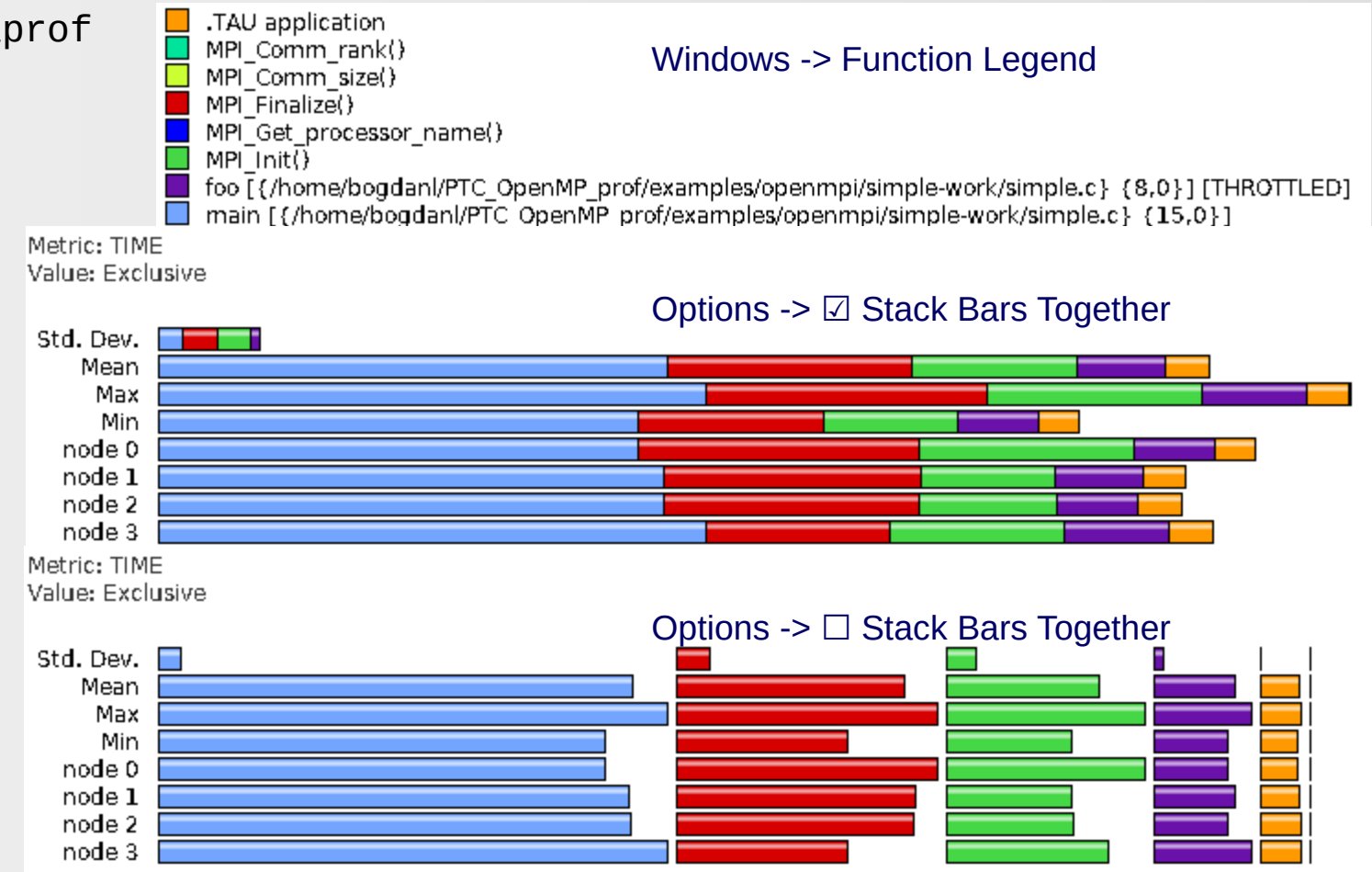
NODE 0;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	9	248	1	1	248395	.TAU application
96.2	108	239	1	100006	239062	main
25.6	63	63	1	0	63669	MPI_Finalize()
19.5	48	48	1	0	48506	MPI_Init()
7.3	18	18	100001	0	0	foo [THROTTLED]
0.0	0.002	0.002	1	0	2	MPI_Get_processor_name()
0.0	0.001	0.001	1	0	1	MPI_Comm_size()
0.0	0	0	1	0	0	MPI_Comm_rank()

Example 1: MPI profiling (cont.)

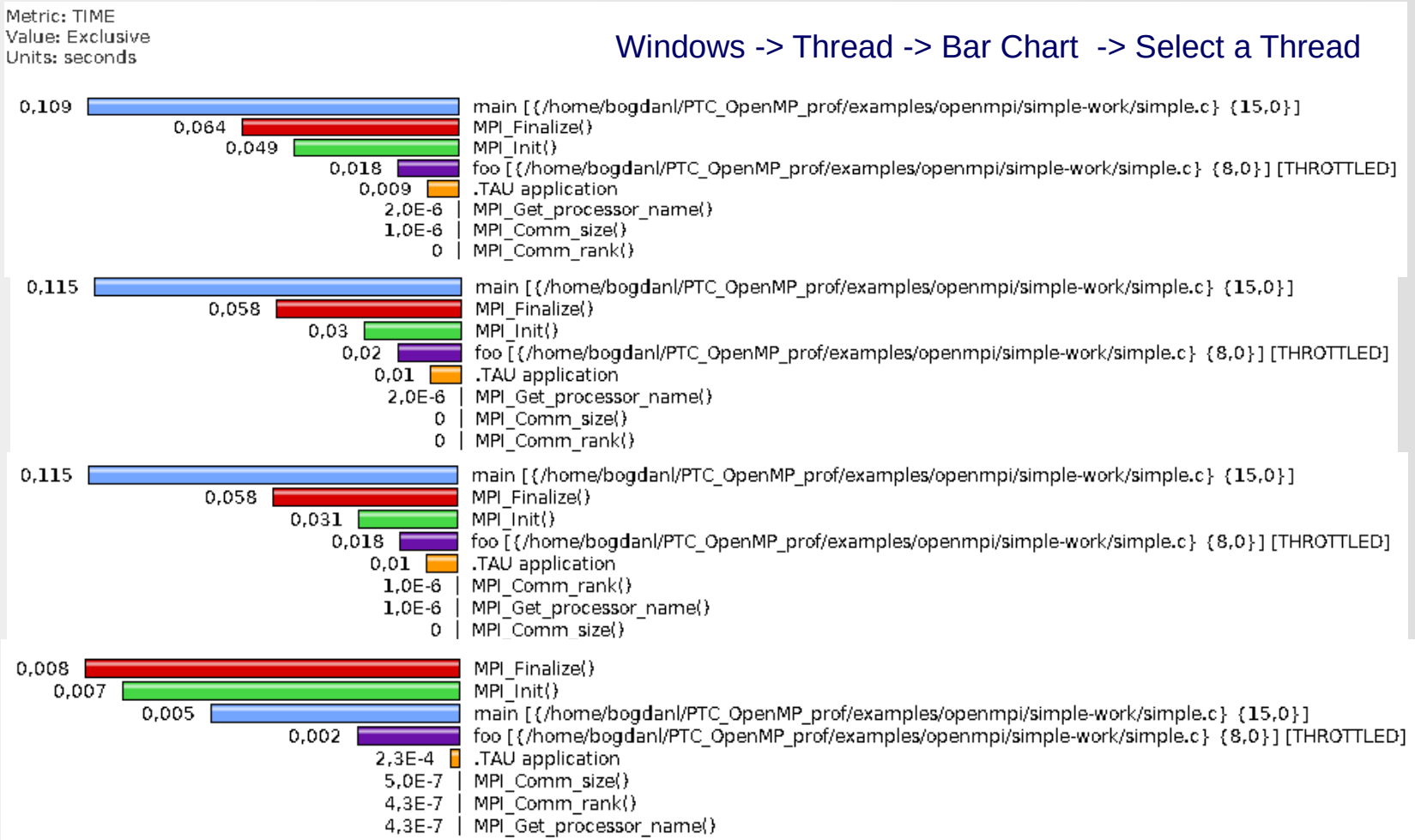
- Use paraprof for **visualizing profiles**:

```
$ paraprof
```



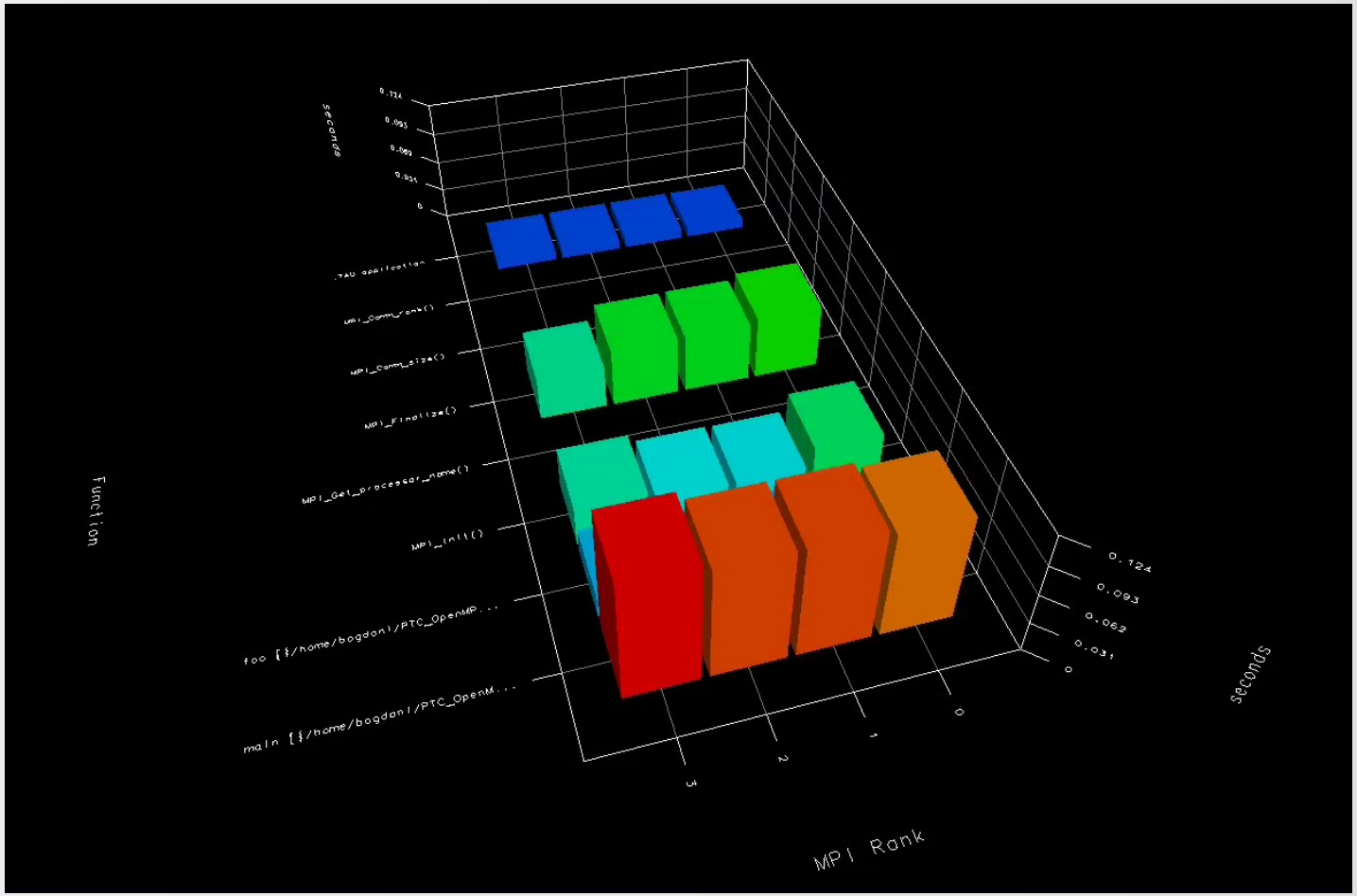
Example 1: MPI profiling (cont.)

Nodes (0, 1, 2 and 3) analysis:



Example 1: MPI profiling (cont.)

3D visualization of profiles in `paraprof`:



Example 2: Tracing MPI codes

Follow these steps on your `viz.hpc.fs.uni-lj.si` account:

- Go to work directory:

```
$ cd /$HOME/PTC_OpenMPI-MP_profiling/examples/openmpi/simple-work
```

- For the previous compiled example of the OpenMPI code (`simple.c`) generate traces with:

```
$ TAU_TRACE=1 mpirun -np 4 tau_exec -io ./a.out
```

- Merge traces and convert them to slog2 format:

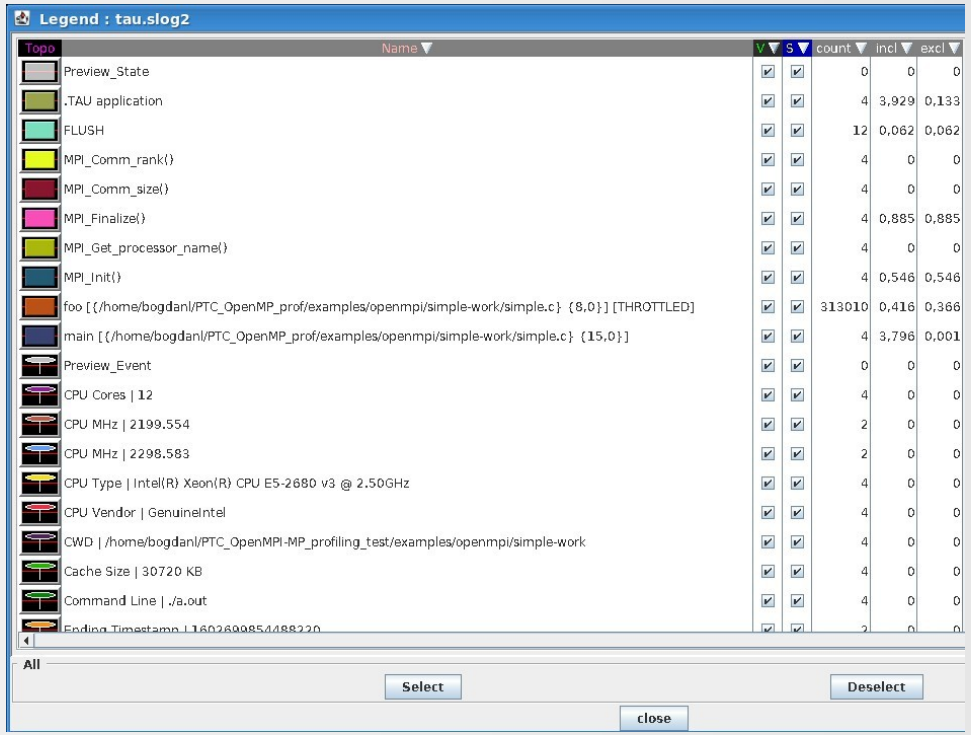
```
$ tau_treemerge.pl
$ tau2slog2 tau.trc tau.edf -o tau.slog2
```

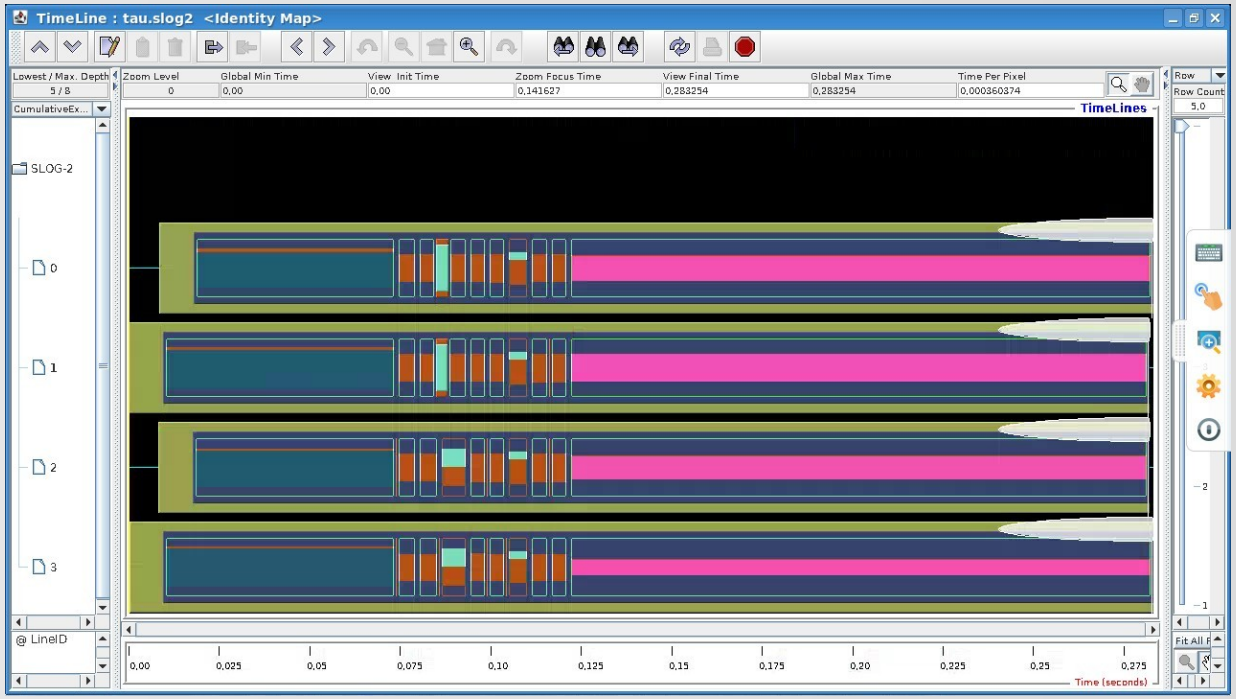
- Visualize traces:

```
$ jumpshot tau.slog2
```

Example 2: Tracing MPI codes (cont.)

Traces visualized with `jumpshot`





Example 3: Profiling OpenMP codes

Follow these steps on your `viz.hpc.fs.uni-lj.si` account:

- Go to work directory:

```
$ cd /$HOME/PTC_OpenMPI-MP_profiling/examples/openmp/pi_work
```

- Open `pi-openmp_profile.c` with text editor:

```
$ gedit pi-openmp_profile.c
```

Example 3: Profiling OpenMP codes (cont.)

Add TAU instrumentation code (in red) to the original code:

```
#include <stdio.h>
#include <math.h>
#include <Profile/Profiler.h>
extern void mytimer_(int *);

#define N 1000000

int main()
{
  int numpe;
  double area = 0.0;

  TAU_PROFILE_TIMER(mt, "main()", "int (int, char **)",
          TAU_DEFAULT);
  TAU_PROFILE_SET_NODE(0);
  TAU_PROFILE_START(mt);

  numpe = 1;
  mytimer_(0);

#pragma omp parallel for reduction(+:area)
  for(int i = 0; i < N; i++)
  {
    numpe = omp_get_num_threads();
    TAU_PROFILE_TIMER(fl, "For loop", " " , TAU_DEFAULT);
    TAU_PROFILE_START(fl);

    double x = (i+0.5)/N;
    area += sqrt(1.0 - x*x);

    TAU_PROFILE_STOP(fl);
  }

  mytimer_(&numpe);
  printf("Pi : %14lf\n", 4.0*area/N);
  TAU_PROFILE_STOP(mt);

  return 0;
}
```

Example 3: Profiling OpenMP codes (cont.)

- Build executable with TAU instrumentation and run it to get profiles:

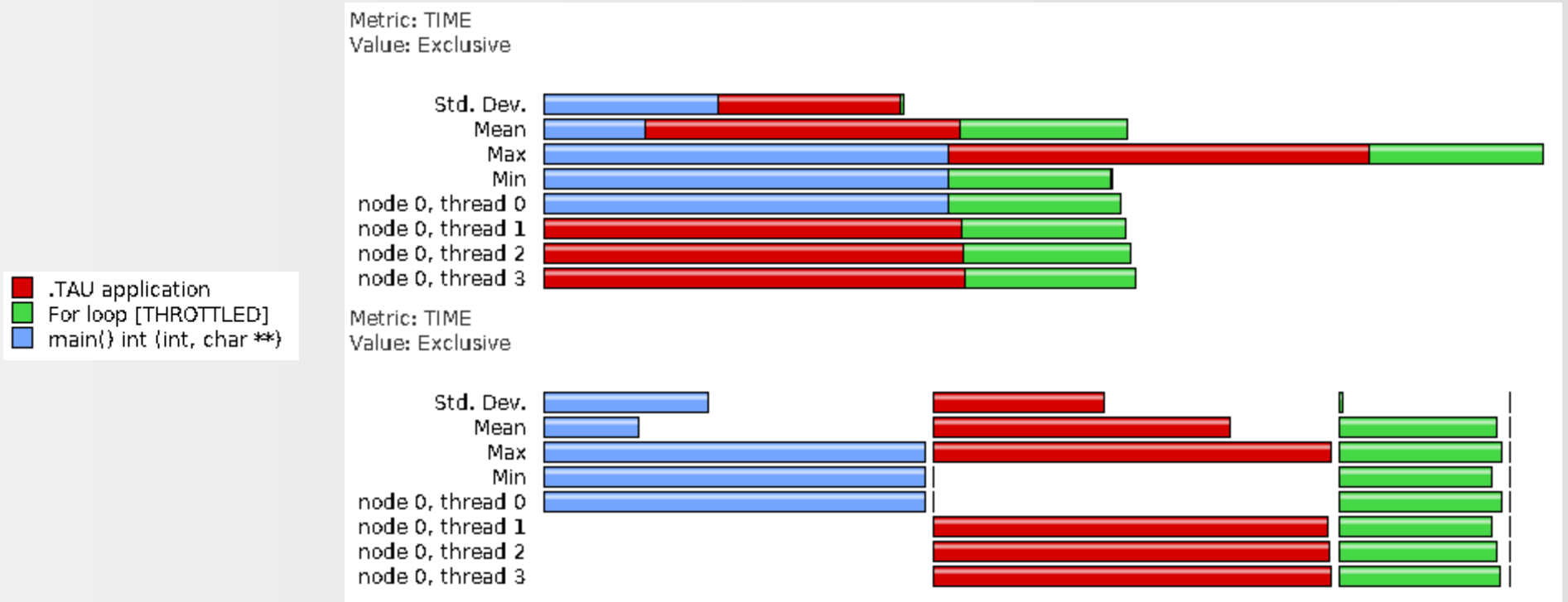
```
$ make
$ TAU_SET_NODE=0 OMP_NUM_THREADS=4 tau_exec -T openmp ./pi-openmp_profile
```

- Use `pprof` and `paraprof` to see the profiling results:

```
$ pprof
$ paraprof
```

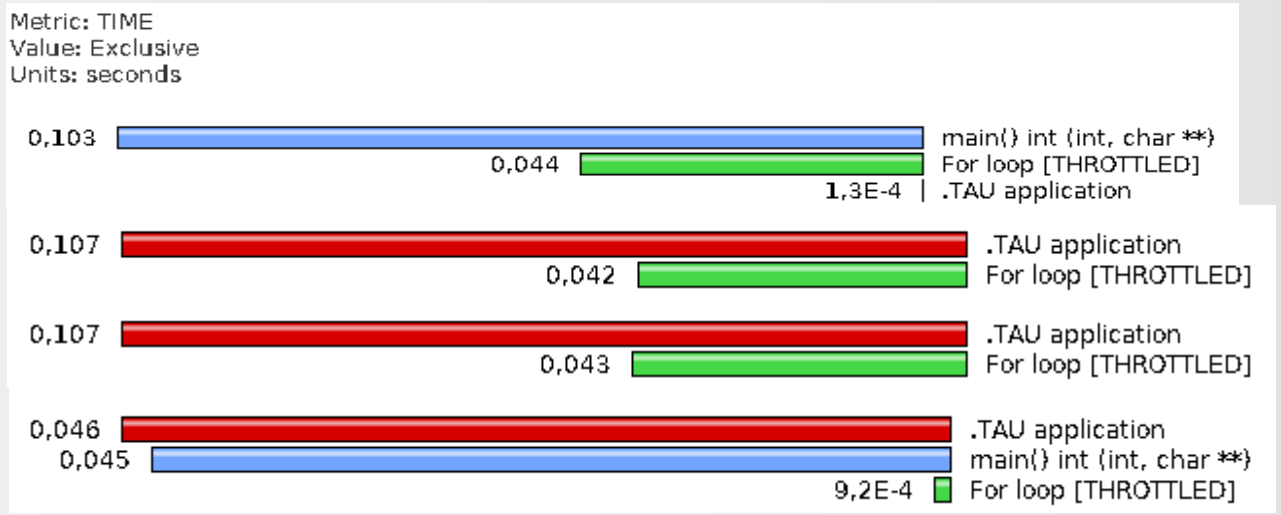
Example 3: Profiling OpenMP codes (cont.)

Profiling results with paraprof:

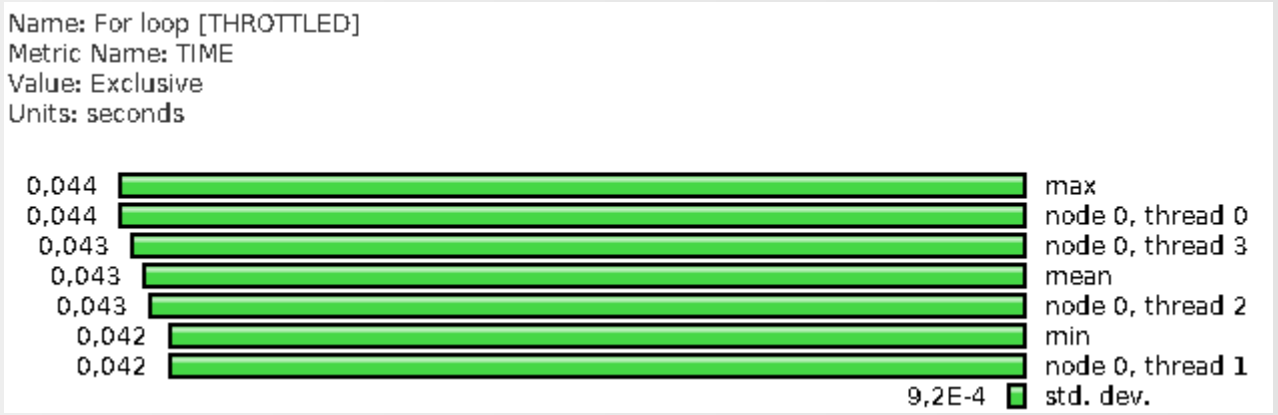


Example 3: Profiling OpenMP codes (cont.)

- Threads (0, 1, 2 and 3) analysis:



- Function (for loop) analysis:



Bonus example 1: CUDA profiling

Follow these steps on your `viz.hpc.fs.uni-lj.si` account:

- Load modules and start interactive session on GPU node:

```
$ module purge
$ module load tau/2.29.1-CUDA
$ module load jre
$ env --unset=LD_PRELOAD TMOUT=600 srun --time=1:0:0 --partition=gpu --x11 --
pty bash -i
```

- Go to work directory:

```
$ cd $HOME/PTC_OpenMPI-MP_profiling/examples/gpu/cuda/matmult
```

- Compile CUDA code (`matmult.cu`):

```
$ make
```

- Run profiling with TAU:

```
$ tau_exec -T serial -cupti ./matmult
```

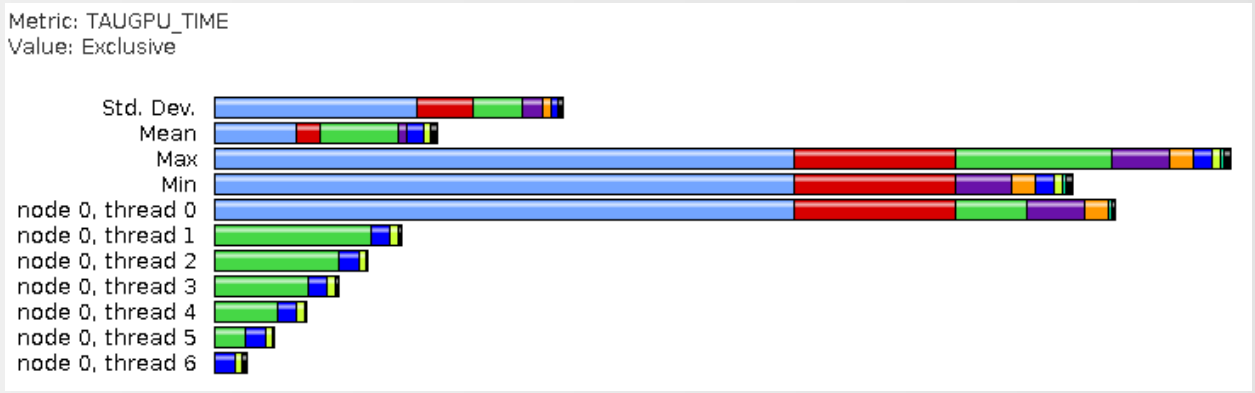
- Use pprof and paraprof to see the profiling results:

```
$ pprof
$ paraprof
```

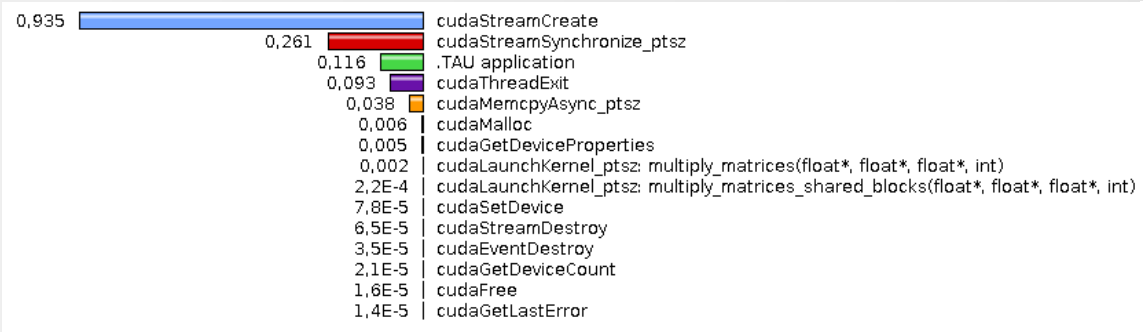
Bonus example 1: CUDA profiling (cont.)

Profiling results with `paraprof`:

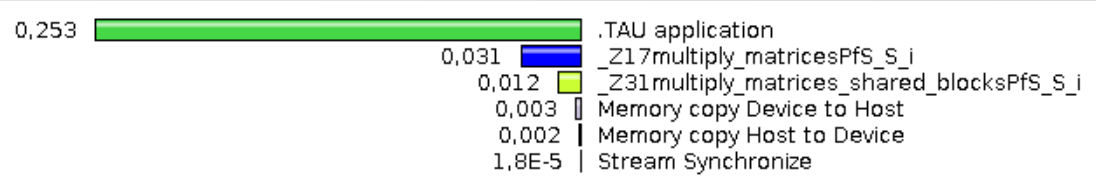
- Threads (1-6) represent GPUs in the node (6 in total)



- Thread 0 (CUDA API calls):



- Thread 1 (GPU 0 in the GPU node):



Bonus example 2: OpenCL profiling

Follow these steps on your `viz.hpc.fs.uni-lj.si` account:

- Go to work directory:

```
$ cd $HOME/PTC_OpenMPI-MP_profiling/examples/gpu/opencl
```

- Compile OpenCL code (`matmult.cpp`):

```
$ make
```

- Run profiling with TAU:

```
$ tau_exec -T serial -opencl ./matmult
```

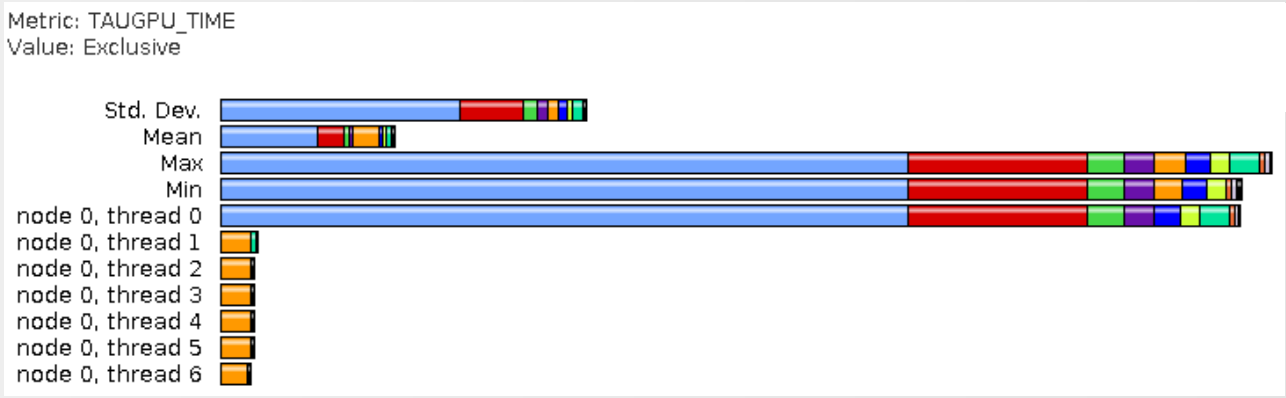
- Use pprof and paraprof to see the profiling results:

```
$ pprof
$ paraprof
```

Bonus example 2: OpenCL profiling (cont.)

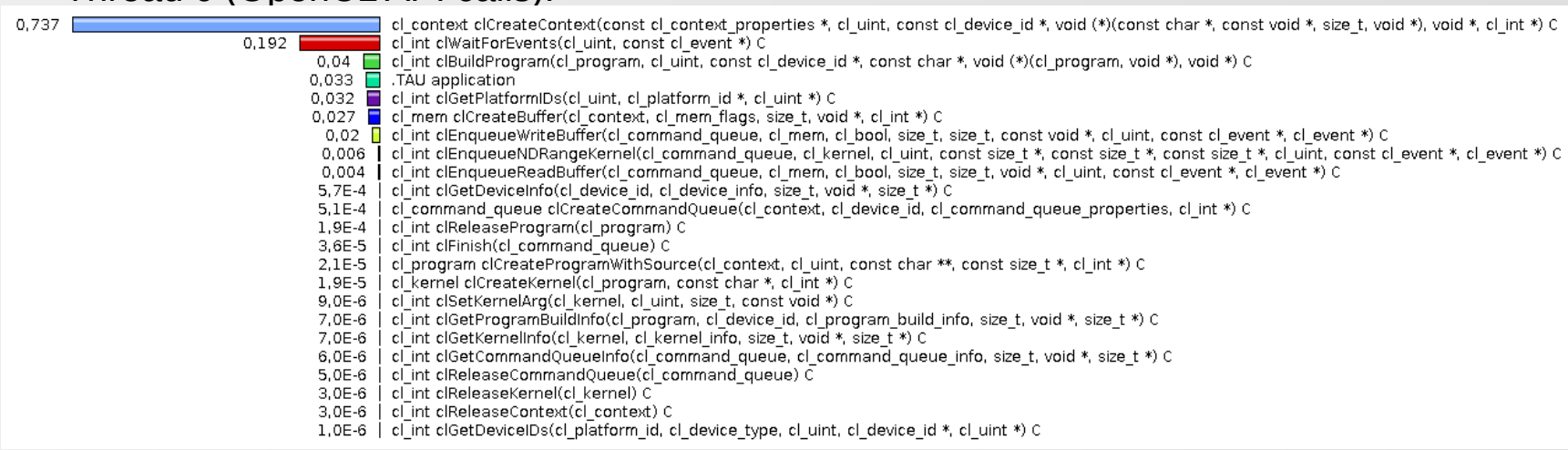
Profiling results with `paraprof`:

- Threads (1-6) represent GPUs in the node (6 in total)



- Thread 1 (GPU 0 in the GPU node):

- Thread 0 (OpenCL API calls):



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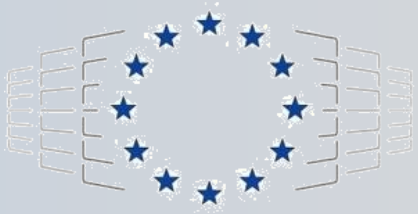
Thanks!



EuroHPC
Joint Undertaking

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