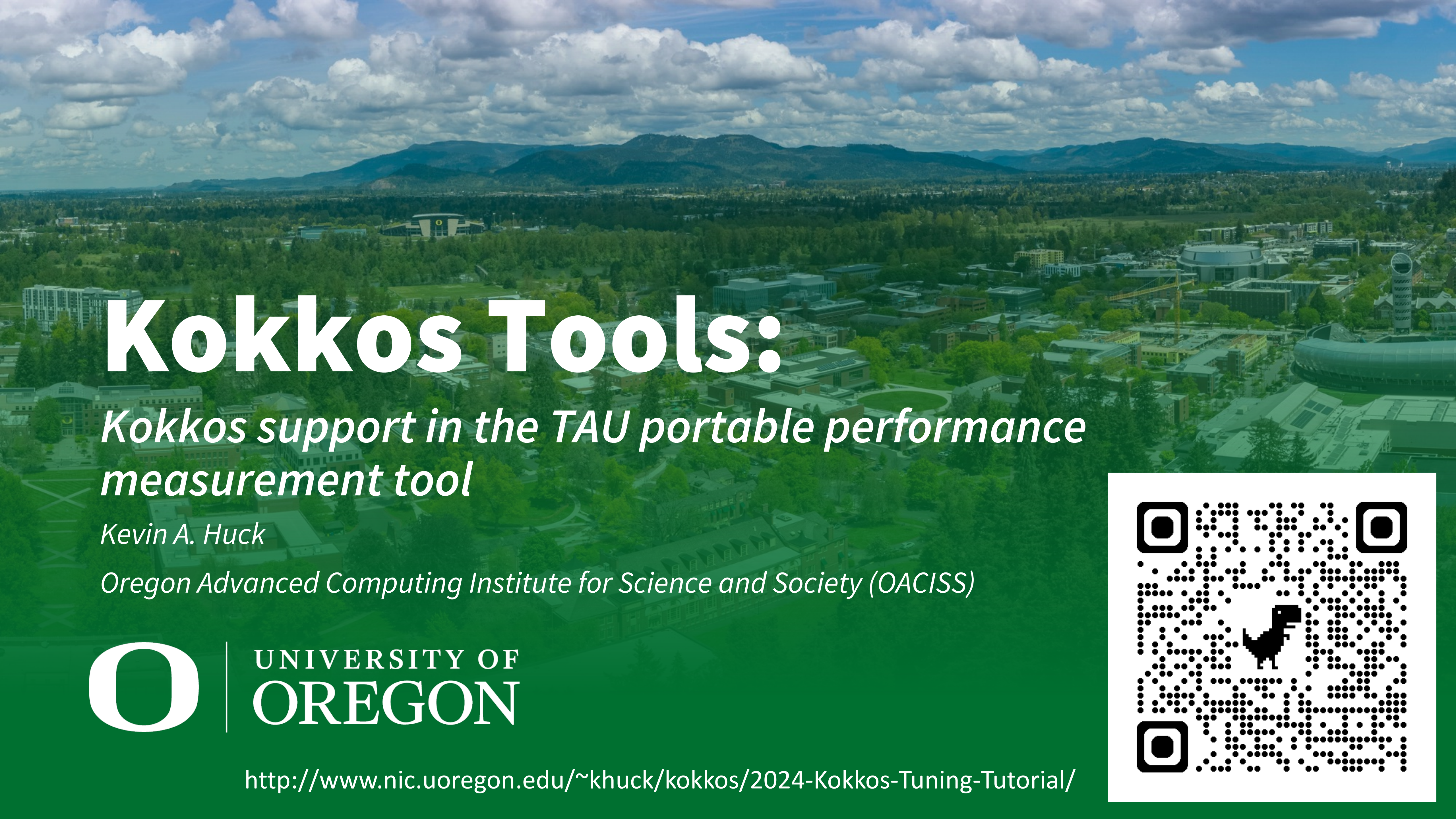

Kokkos Tools:

Kokkos support in the TAU portable performance measurement tool

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UNIVERSITY OF OREGON

http://www.nic.uoregon.edu/~khuck/kokkos/2024-Kokkos-Tuning-Tutorial/

TAU Performance System

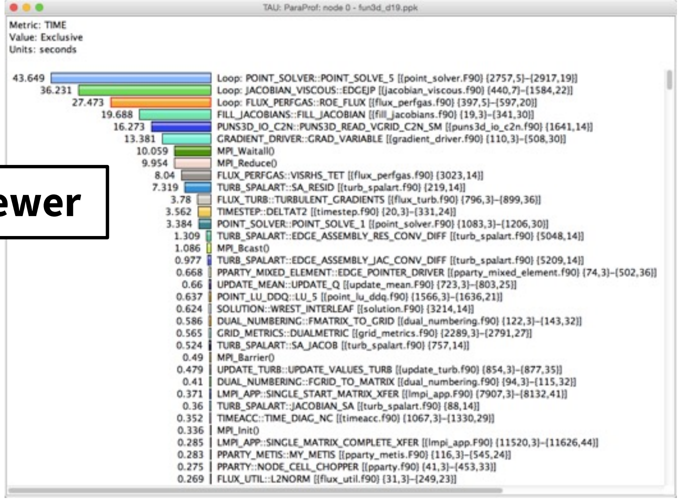
- **T**uning and **A**nalysis **U**tilities (29+ year project)
- Integrated performance toolkit:
  - Multi-level performance instrumentation
  - Highly configurable
  - Widely ported performance profiling / tracing system
  - Portable (java, python) visualization / exploration / analysis tools
- Supports all major HPC programming models
- MPI/SHMEM, OpenMP, OpenACC, CUDA, HIP, SYCL/OneAPI, **Kokkos**...
- Support for ML/AI frameworks: TensorFlow, pyTorch, Horovod
- Integrated with PAPI, LIKWID for hardware counter support
- https://tau.uoregon.edu or https://github.com/UO-OACISS/tau2 (public mirror)

Performance Measurement

- **Timers**
  - Requires instrumentation of some kind
    - Manual, automated
    - Source, compiler provided, binary
    - **Library callbacks**, API wrappers, weak symbol replacement
  - Simple to implement
- **Sampling**
  - Requires specialized system libraries / support
    - Periodic signals, signal handler
    - Call stack unwinding
  - No modification to executable/library needed
  - Potential to interfere with system support (signal handlers)
  - Can mix with timers to generate a hybrid profile

Profiling and Tracing

- **Profiling**: how much time was spent in each measured function on each thread in each process?
  - Collapses the time axis
  - No ordering or causal event information
  - Small summary per thread/process, regardless of execution time – only grows with number of timers & threads/processes
- **Tracing**: record all function entry & exit events on a timeline
  - Detailed view of what happened
  - The longer the program runs, the bigger the trace

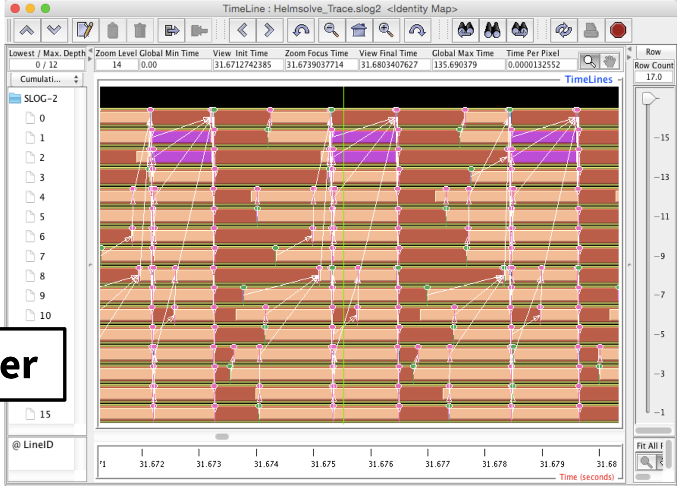


ParaProf profile viewer

TAU: ParaProf: node 0 - fun3d_d19.ppk

```
Metric: TIME
Value: Exclusive
Units: seconds

43.649  Loop: POINT_SOLVER::POINT_SOLVE_5 [{point_solver.F90} {2757,5}-{2917,19}]
36.231  Loop: JACOBIAN_VISCOUS::EDGEJP [{jacobian_viscous.f90} {440,7}-{1584,22}]
27.473  Loop: FLUX_PERFGAS::ROE_FLUX [{flux_perfgas.f90} {397,5}-{597,20}]
19.688  FILL_JACOBIANS::FILL_JACOBIAN [{fill_jacobians.f90} {19,3}-{341,30}]
16.273  PUNS3D_IO_C2N::PUNS3D_READ_VGRID_C2N_SM [{puns3d_io_c2n.f90} {1641,14}]
13.381  GRADIENT_DRIVER::GRAD_VARIABLE [{gradient_driver.f90} {110,3}-{508,30}]
10.059  MPI_Waitall()
 9.954  MPI_Reduce()
  8.04  FLUX_PERFGAS::VISRHS_TET [{flux_perfgas.f90} {3023,14}]
 7.319  TURB_SPALART::SA_RESID [{turb_spalart.f90} {219,14}]
  3.78  FLUX_TURB::TURBULENT_GRADIENTS [{flux_turb.f90} {796,3}-{899,36}]
 3.562  TIMESTEP::DELTAT2 [{timestep.f90} {20,3}-{331,24}]
 3.384  POINT_SOLVER::POINT_SOLVE_1 [{point_solver.F90} {1083,3}-{1206,30}]
 1.309  TURB_SPALART::EDGE_ASSEMBLY_RES_CONV_DIFF [{turb_spalart.f90} {5048,14}]
 1.086  MPI_Bcast()
 0.977  TURB_SPALART::EDGE_ASSEMBLY_JAC_CONV_DIFF [{turb_spalart.f90} {5209,14}]
 0.668  PPARTY_MIXED_ELEMENT::EDGE_POINTER_DRIVER [{pparty_mixed_element.f90} {74,3}-{502,36}]
  0.66  UPDATE_MEAN::UPDATE_Q [{update_mean.F90} {723,3}-{803,25}]
 0.637  POINT_LU_DDQ::LU_5 [{point_lu_ddq.f90} {1566,3}-{1636,21}]
 0.624  SOLUTION::WREST_INTERLEAF [{solution.F90} {3214,14}]
 0.586  DUAL_NUMBERING::FMATRIX_TO_GRID [{dual_numbering.f90} {122,3}-{143,32}]
 0.565  GRID_METRICS::DUALMETRIC [{grid_metrics.f90} {2289,3}-{2791,27}]
 0.524  TURB_SPALART::SA_JACOB [{turb_spalart.f90} {757,14}]
  0.49  MPI_Barrier()
 0.479  UPDATE_TURB::UPDATE_VALUES_TURB [{update_turb.f90} {854,3}-{877,35}]
  0.41  DUAL_NUMBERING::FGRID_TO_MATRIX [{dual_numbering.f90} {94,3}-{115,32}]
 0.371  LMPI_APP::SINGLE_START_MATRIX_XFER [{lmpi_app.F90} {7907,3}-{8132,41}]
  0.36  TURB_SPALART::JACOBIAN_SA [{turb_spalart.f90} {88,14}]
 0.352  TIMEACC::TIME_DIAG_NC [{timeacc.f90} {1067,3}-{1330,29}]
 0.336  MPI_Init()
 0.285  LMPI_APP::SINGLE_MATRIX_COMPLETE_XFER [{lmpi_app.F90} {11520,3}-{11626,44}]
 0.283  PPARTY_METIS::MY_METIS [{pparty_metis.F90} {116,3}-{545,24}]
 0.275  PPARTY::NODE_CELL_CHOPPER [{pparty.f90} {41,3}-{453,33}]
 0.269  FLUX_UTIL::L2NORM [{flux_util.f90} {31,3}-{249,23}]
```

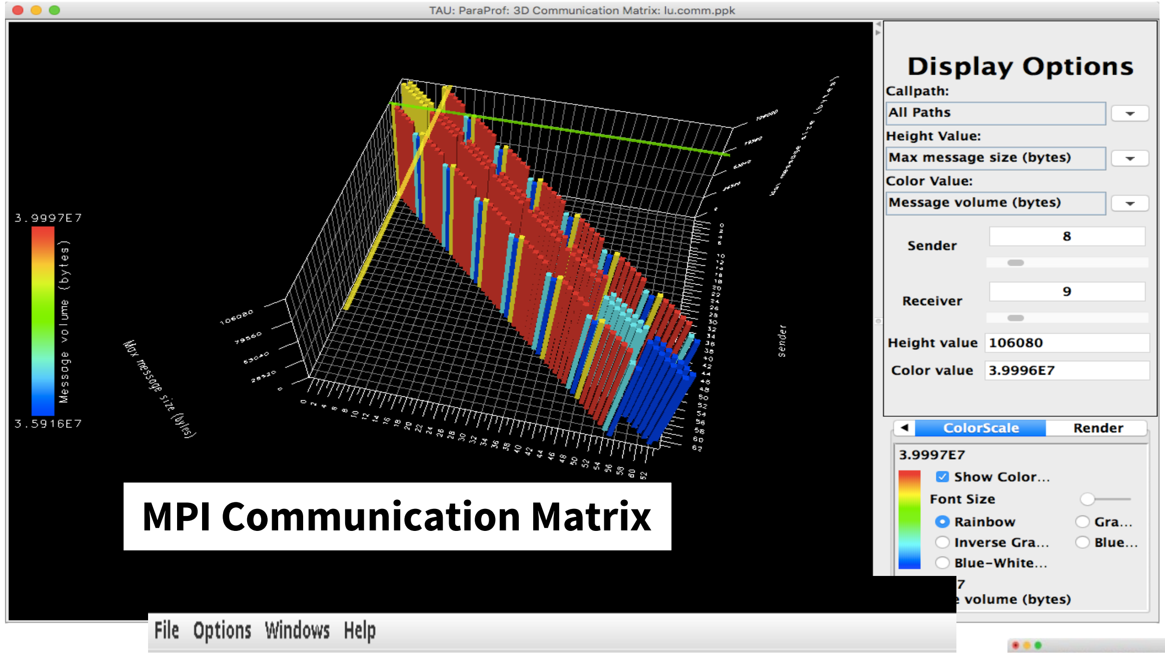


JumpShot trace viewer

TimeLine : Helmsolve_Trace.slog2 <Identity Map>

Lowest / Max. Depth	Zoom Level	Global Min Time	View Init Time	Zoom Focus Time	View Final Time	Global Max Time	Time Per Pixel	Row Count
0 / 12	14	0.00	31.6712742385	31.6739037714	31.6803407627	135.690379	0.0000132552	17.0

TAU Analysis Tools: ParaProf, Vampir



Display Options

Callpath: All Paths

Height Value: Max message size (bytes)

Color Value: Message volume (bytes)

Sender: 8

Receiver: 9

Height value: 106080

Color value: 3.9996E7

ColorScale | Render

3.9997E7

☑ Show Color...

Font Size

● Rainbow ○ Gra...

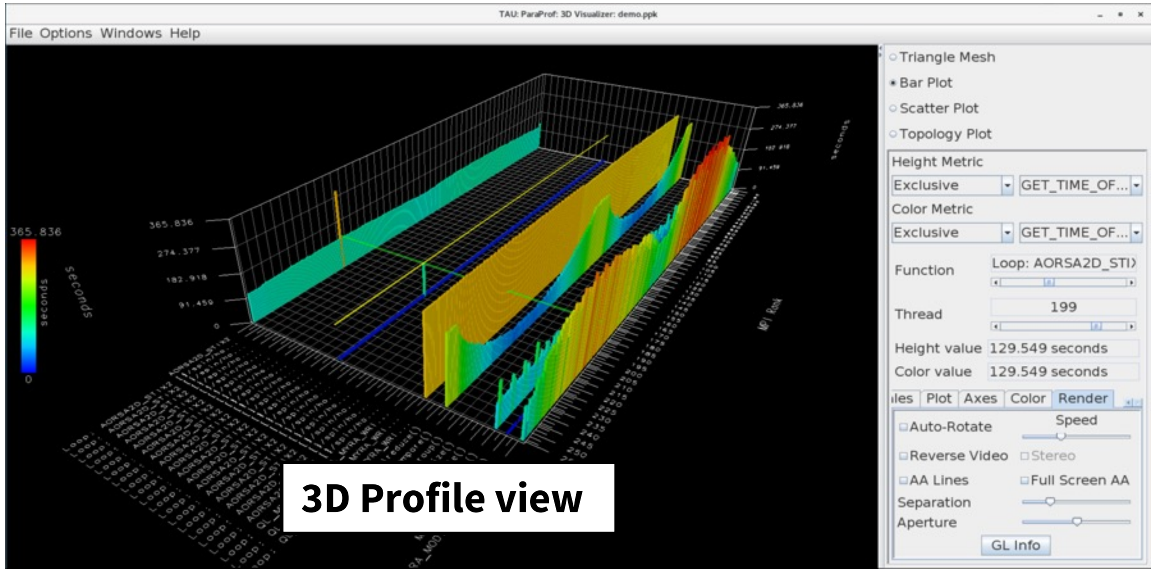
○ Inverse Gra... ○ Blue...

○ Blue-White...

...7

...volume (bytes)

MPI Communication Matrix


TAU: ParaProf: 3D Visualizer: demo.ppk
File Options Windows Help
365.836
274.377
182.918
91.459
0
seconds
MPI Rank

○ Triangle Mesh

● Bar Plot

○ Scatter Plot

○ Topology Plot

Height Metric: Exclusive | GET_TIME_OF...

Color Metric: Exclusive | GET_TIME_OF...

Function: Loop: AORSA2D_STI>

Thread: 199

Height value: 129.549 seconds

Color value: 129.549 seconds

...les | Plot | Axes | Color | Render

□ Auto-Rotate | Speed

□ Reverse Video □ Stereo

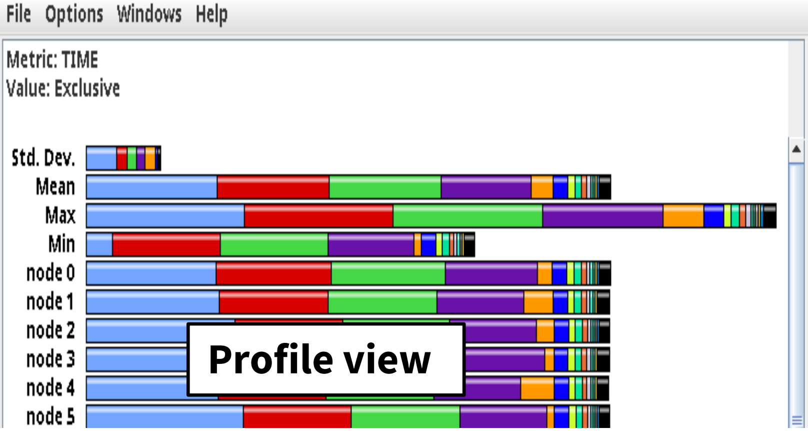
□ AA Lines □ Full Screen AA

Separation

Aperture

GL Info

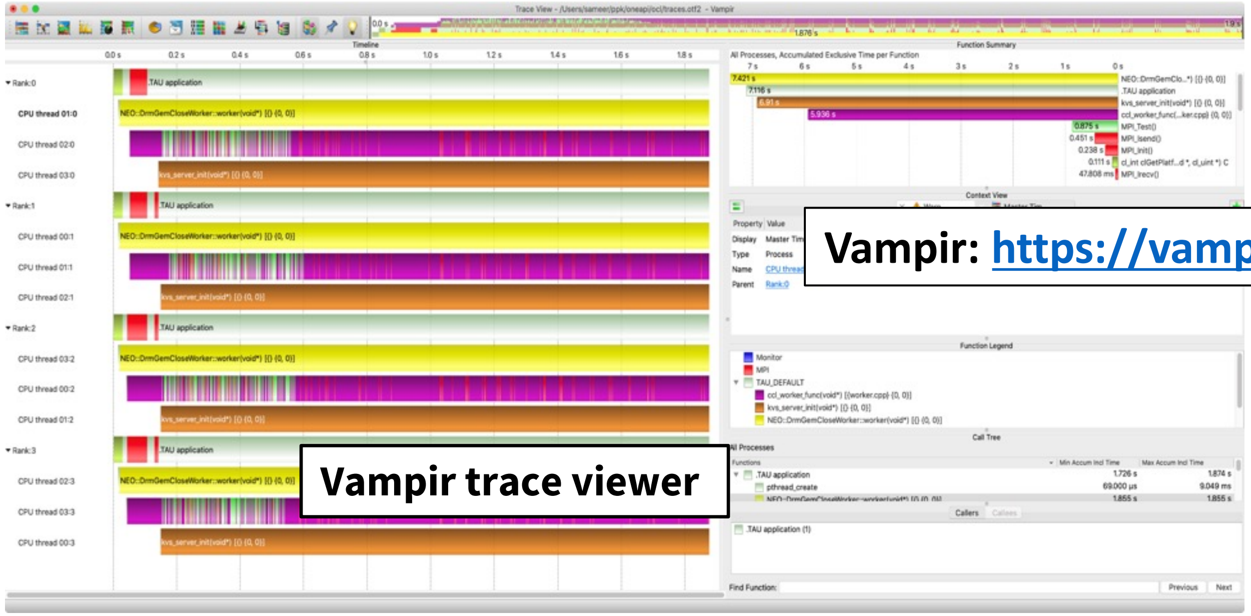
3D Profile view



Metric: TIME

Value: Exclusive

Profile view



Vampir: https://vampir.eu

Vampir trace viewer

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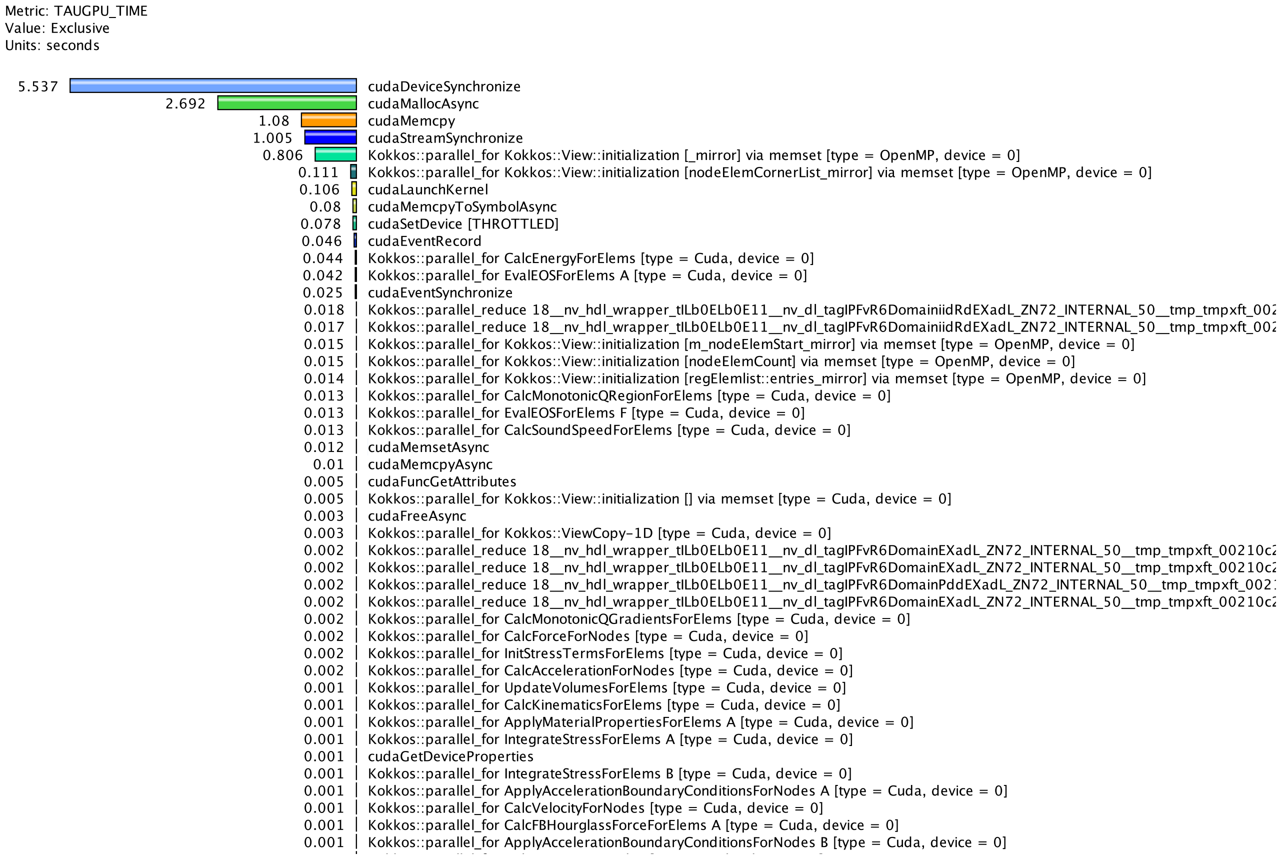
Kokkos support in TAU – since February, 2017

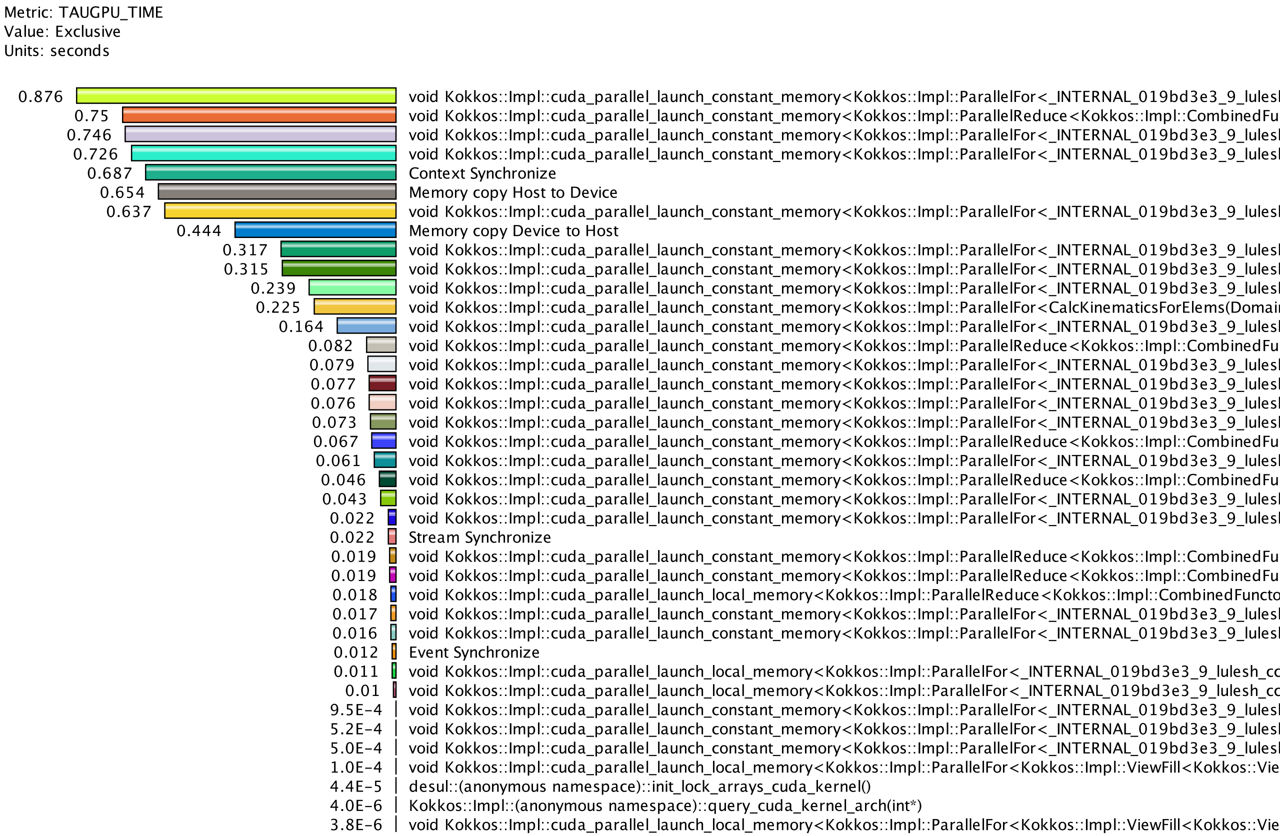
- TAU implements the Kokkos Profiling API (`Kokkos_Profiling_C_Interface.h`)
- TAU sets an environment variable KOKKOS_TOOLS_LIBS to tell Kokkos that it should enable profiling and enable function callbacks to the TAU implementations
- TAU implements
  - `kokkosp_[init|finalize]_library`
  - `kokkosp_[begin|end]_parallel_[for|scan|reduce]`
  - `kokkosp_[push|pop]_profile_region`
- Names for regions are passed to the tools to provide intelligent labels
- In addition, TAU also implements support for native Pthreads, OpenMP, OpenACC, CUDA, HIP, SYCL back-end measurement – no code changes necessary
- Fun fact: if you have a Raja application, and Raja is configured with `-DRAJA_ENABLE_RUNTIME_PLUGINS`, Raja implements the same callback API!

TAU Example – Kokkos Lulesh (from kokkos-miniapps)



```
Metric: TAUGPU_TIME
Value: Exclusive
Units: seconds

5.537   cudaDeviceSynchronize
2.692   cudaMallocAsync
1.08    cudaMemcpy
1.005   cudaStreamSynchronize
0.806   Kokkos::parallel_for Kokkos::View::initialization [_mirror] via memset [type = OpenMP, device = 0]
0.111   Kokkos::parallel_for Kokkos::View::initialization [nodeElemCornerList_mirror] via memset [type = OpenMP, device = 0]
0.106   cudaLaunchKernel
0.08    cudaMemcpyToSymbolAsync
0.078   cudaSetDevice [THROTTLED]
0.046   cudaEventRecord
0.044   Kokkos::parallel_for CalcEnergyForElems [type = Cuda, device = 0]
0.042   Kokkos::parallel_for EvalEOSForElems A [type = Cuda, device = 0]
0.025   cudaEventSynchronize
0.018   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainiidRdEXadL_ZN72_INTERNAL_50__tmp_tmpxft_002
0.017   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainiidRdEXadL_ZN72_INTERNAL_50__tmp_tmpxft_002
0.015   Kokkos::parallel_for Kokkos::View::initialization [m_nodeElemStart_mirror] via memset [type = OpenMP, device = 0]
0.015   Kokkos::parallel_for Kokkos::View::initialization [nodeElemCount] via memset [type = OpenMP, device = 0]
0.014   Kokkos::parallel_for Kokkos::View::initialization [regElemlist::entries_mirror] via memset [type = OpenMP, device = 0]
0.013   Kokkos::parallel_for CalcMonotonicQRegionForElems [type = Cuda, device = 0]
0.013   Kokkos::parallel_for EvalEOSForElems F [type = Cuda, device = 0]
0.013   Kokkos::parallel_for CalcSoundSpeedForElems [type = Cuda, device = 0]
0.012   cudaMemsetAsync
0.01    cudaMemcpyAsync
0.005   cudaFuncGetAttributes
0.005   Kokkos::parallel_for Kokkos::View::initialization [] via memset [type = Cuda, device = 0]
0.003   cudaFreeAsync
0.003   Kokkos::parallel_for Kokkos::ViewCopy-1D [type = Cuda, device = 0]
0.002   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainEXadL_ZN72_INTERNAL_50__tmp_tmpxft_00210c2
0.002   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainEXadL_ZN72_INTERNAL_50__tmp_tmpxft_00210c2
0.002   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainPddEXadL_ZN72_INTERNAL_50__tmp_tmpxft_0021
0.002   Kokkos::parallel_reduce 18__nv_hdl_wrapper_tILb0ELb0E11__nv_dl_tagIPFvR6DomainEXadL_ZN72_INTERNAL_50__tmp_tmpxft_00210c2
0.002   Kokkos::parallel_for CalcMonotonicQGradientsForElems [type = Cuda, device = 0]
0.002   Kokkos::parallel_for CalcForceForNodes [type = Cuda, device = 0]
0.002   Kokkos::parallel_for InitStressTermsForElems [type = Cuda, device = 0]
0.002   Kokkos::parallel_for CalcAccelerationForNodes [type = Cuda, device = 0]
0.001   Kokkos::parallel_for UpdateVolumesForElems [type = Cuda, device = 0]
0.001   Kokkos::parallel_for CalcKinematicsForElems [type = Cuda, device = 0]
0.001   Kokkos::parallel_for ApplyMaterialPropertiesForElems A [type = Cuda, device = 0]
0.001   Kokkos::parallel_for IntegrateStressForElems A [type = Cuda, device = 0]
0.001   cudaGetDeviceProperties
0.001   Kokkos::parallel_for IntegrateStressForElems B [type = Cuda, device = 0]
0.001   Kokkos::parallel_for ApplyAccelerationBoundaryConditionsForNodes A [type = Cuda, device = 0]
0.001   Kokkos::parallel_for CalcVelocityForNodes [type = Cuda, device = 0]
0.001   Kokkos::parallel_for CalcFBHourglassForceForElems A [type = Cuda, device = 0]
0.001   Kokkos::parallel_for ApplyAccelerationBoundaryConditionsForNodes B [type = Cuda, device = 0]
```



```
Metric: TAUGPU_TIME
Value: Exclusive
Units: seconds

0.876   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.75    void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.746   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.726   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.687   Context Synchronize
0.654   Memory copy Host to Device
0.637   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.444   Memory copy Device to Host
0.317   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.315   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.239   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.225   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<CalcKinematicsForElems(Domai
0.164   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.082   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.079   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.077   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.076   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.073   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.067   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.061   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.046   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.043   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.022   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.022   Stream Synchronize
0.019   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.019   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFu
0.018   void Kokkos::Impl::cuda_parallel_launch_local_memory<Kokkos::Impl::ParallelReduce<Kokkos::Impl::CombinedFuncto
0.017   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.016   void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
0.012   Event Synchronize
0.011   void Kokkos::Impl::cuda_parallel_launch_local_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesh_cc
0.01    void Kokkos::Impl::cuda_parallel_launch_local_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesh_cc
9.5E-4  void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
5.2E-4  void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
5.0E-4  void Kokkos::Impl::cuda_parallel_launch_constant_memory<Kokkos::Impl::ParallelFor<_INTERNAL_019bd3e3_9_lulesl
1.0E-4  void Kokkos::Impl::cuda_parallel_launch_local_memory<Kokkos::Impl::ParallelFor<Kokkos::Impl::ViewFill<Kokkos::Vie
4.4E-5  desul::(anonymous namespace)::init_lock_arrays_cuda_kernel()
4.0E-6  Kokkos::Impl::(anonymous namespace)::query_cuda_kernel_arch(int*)
3.8E-6  void Kokkos::Impl::cuda_parallel_launch_local_memory<Kokkos::Impl::ParallelFor<Kokkos::Impl::ViewFill<Kokkos::Vie
```

Main thread launching kernels

Virtual thread with CUDA activity

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Intel Xeon system with NVIDIA A100, size 256, 100 iterations, one rank

PerfStubs side note…

- PerfStubs is a “frictionless” instrumentation library
  - https://github.com/UO-OACISS/perfstubs
  - One source file, three headers
  - Provides a plugin interface for performance tools
  - Can be compiled away if desired
- Integrated into several libraries (so far) as a git submodule
  - CAMTIMERS
  - PETSc
  - Ginkgo
  - ADIOS2
  - Others?
- Provides runtime integration with TAU & APEX

Boehme, Huck, Madsen, Weidendorfer,
“The Case for a Common Instrumentation Interface for HPC Codes”
https://doi.org/10.1109/ProTools49597.2019.00010, 2019

Acknowledgements

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RAPIDS

ECP EXASCALE COMPUTING PROJECT

Thanks! Questions?