Performance Evaluation using the TAU Performance System

Sameer Shende
University of Oregon

August 17, 2016, 11am

Ohio Supercomputing Center, The Ohio State University
Columbus, OH

ParaTools

UNIVERSITY OF OREGON

Acknowledgments

- Hari Subramoni, OSU
- Khaled Hamidouche
- D.K. Panda, OSU
- Allen D. Malony, UO
- Auréle Maheo, UO
- Srinivasan Ramesh, UO
- Wyatt Spear, UO
- Soren Rasmussen, UO
- Kevin Huck, UO

TAU Performance System®

- **Tuning and Analysis Utilities (22+ year project)**
- **Comprehensive performance profiling and tracing**
  - Integrated, scalable, flexible, portable
  - Targets all parallel programming/execution paradigms

- **Integrated performance toolkit**
  - Instrumentation, measurement, analysis, visualization
  - Widely-ported performance profiling / tracing system
  - Performance data management and data mining
  - Open source (BSD-style license)
  - Uses performance and control variables to interface with MVAPICH2
- **Integrates with application frameworks**
- **http://tau.uoregon.edu**

Understanding Application Performance using TAU

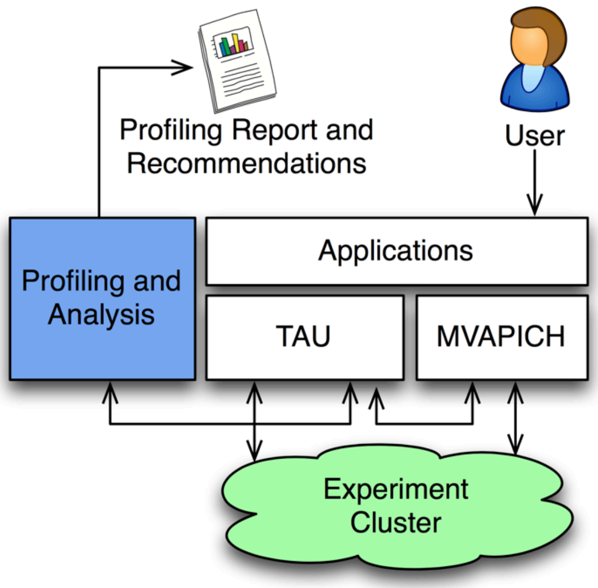
- **How much time** is spent in each application routine and outer *loops*? Within loops, what is the contribution of each *statement*?
- **How many instructions** are executed in these code regions? Floating point, Level 1 and 2 *data cache misses*, hits, branches taken?
- **What is the memory usage** of the code? When and where is memory allocated/de-allocated? Are there any memory leaks?
- **What are the I/O characteristics** of the code? What is the peak read and write *bandwidth* of individual calls, total volume?
- **What is the contribution of each *phase*** of the program? What is the time wasted/spent waiting for collectives, and I/O operations in Initialization, Computation, I/O phases?
- **How does the application *scale***? What is the efficiency, runtime breakdown of performance across different core counts?
- **How can I tune MPI for better performance?** What performance and control does MVAPICH2 export to observe and control its performance?

MVAPICH2

MVAPICH

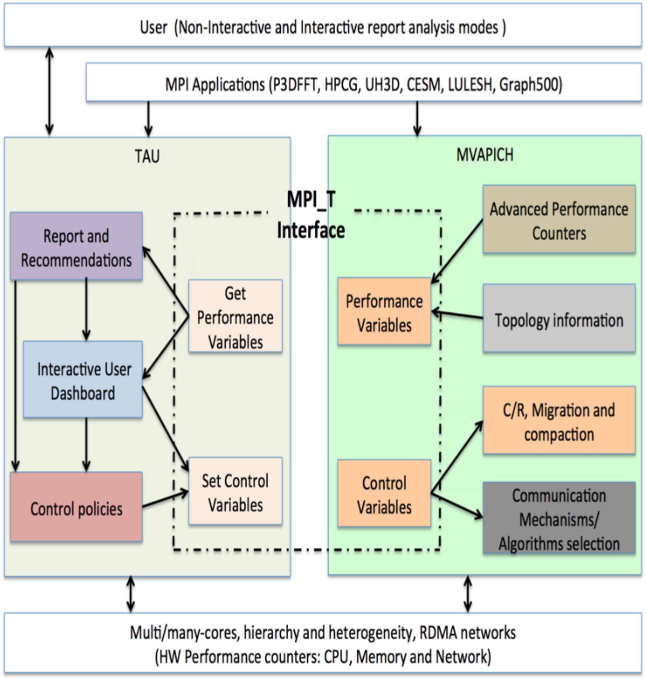
- High performance open-source MPI for InfiniBand, 10-40Gig/iWARP, and RoCE
- MVAPICH (MPI-1), MVAPICH2 (MPI-2.2 and MPI-3.0), Available since 2002
- MPI, OpenSHMEM, UPC, CAF or Hybrid (MPI + PGAS) Applications
- OpenSHMEM Calls CAF Calls UPC MPI Calls Calls
- Unified MVAPICH2-X Runtime InfiniBand, RoCE, iWARP
- Unified communication runtime for MPI, UPC, OpenSHMEM, CAF Available with MVAPICH2-X 1.9 (2012) onwards!
- http://mvapich.cse.ohio-state.edu

MVAPICH2 and TAU



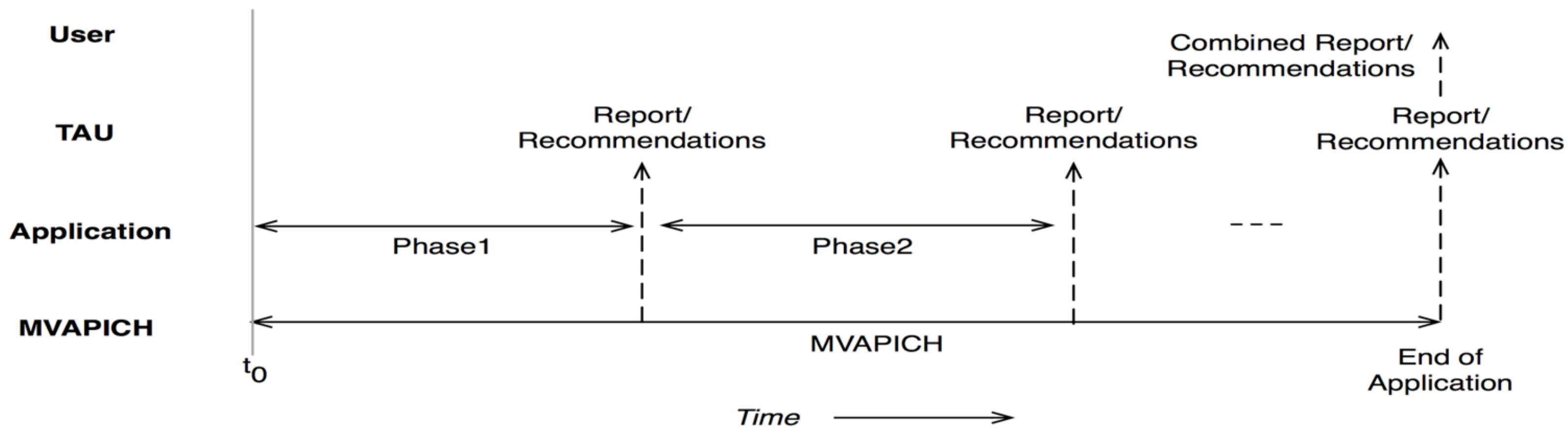
- **TAU and MVAPICH2 are enhanced with the ability to generate recommendations and engineering performance report**
- **MPI libraries like MVAPICH2 are now "reconfigurable" at runtime**
- **TAU and MVAPICH2 communicate using the MPI-T interface**

MPI_T Interface



- Enhance existing support for MPI_T in MVAPICH2 to expose a richer set of performance and control variables
- Get and display MPI Performance Variables (PVARs) made available by the runtime in TAU
- Control the runtime's behavior via MPI Control Variables (CVARs)
- Add support to MVAPICH2 and TAU for interactive performance engineering sessions

Non-Interactive Mode



- **Performance data collected by TAU**
  - Support for PVARs and CVARs
  - Setting CVARs to control MVAPICH2
  - Studying performance data in TAU's ParaProf profile browser

Enhancing MPI_T Support

- **Introduced support for new MPI_T based CVARs to MVAPICH2**
  - MPIR_CVAR_MAX_INLINE_MSG_SZ
    - Controls the message size up to which “inline” transmission of data is supported by MVAPICH2
  - MPIR_CVAR_VBUF_POOL_SIZE
    - Controls the number of internal communication buffers (VBUFs) MVAPICH2 allocates initially. Also, MPIR_CVAR_VBUF_POOL_REDUCED_VALUE[1] ([2…n])
  - MPIR_CVAR_VBUF_SECONDARY_POOL_SIZE
    - Controls the number of VBUFs MVAPICH2 allocates when there are no more free VBUFs available
  - MPIR_CVAR_IBA_EAGER_THRESHOLD
    - Controls the message size where MVAPICH2 switches from eager to rendezvous protocol for large messages
- **TAU enhanced with support for setting MPI_T CVARs in a non-interactive mode for uninstrumented applications**

MVAPICH2

- **Several new MPI_T based PVARs added to MVAPICH2**
  - mv2_vbuf_max_use, mv2_total_vbuf_memory etc
- **Enhanced TAU with support for tracking of MPI_T PVARs and CVARs for uninstrumented applications**
  - ParaProf, TAU's visualization front end, enhanced with support for displaying PVARs and CVARs
  - TAU provides tau_exec, a tool to transparently instrument MPI routines
    - Uninstrumented:
      % mpirun –np 1024 ./a.out
    - Instrumented:
      % mpirun –np 1024 tau_exec [options] ./a.out
      % paraprof

PVARs Exposed by MVAPICH2

TAU: ParaProf Manager

File Options Help

Applications
Standard Applications
Default App
Default Exp
lulesh.ppk
TIME
Default (jdbc:h2:/home

TrialField	Value
MPI_T PVAR[0]: mem_allocated	Current level of allocated memory within the MPI library
MPI_T PVAR[10]: mv2_num_2level_comm_success	Number of successful 2-level comm creations
MPI_T PVAR[11]: mv2_num_shmem_coll_calls	Number of times MV2 shared-memory collective calls were invoked
MPI_T PVAR[12]: mpit_progress_poll	CH3 RDMA progress engine polling count
MPI_T PVAR[13]: mv2_smp_read_progress_poll	CH3 SMP read progress engine polling count
MPI_T PVAR[14]: mv2_smp_write_progress_poll	CH3 SMP write progress engine polling count
MPI_T PVAR[15]: mv2_smp_read_progress_poll_success	Unsucessful CH3 SMP read progress engine polling count
MPI_T PVAR[16]: mv2_smp_write_progress_poll_succ...	Unsucessful CH3 SMP write progress engine polling count
MPI_T PVAR[17]: rdma_ud_retransmissions	CH3 RDMA UD retransmission count
MPI_T PVAR[18]: mv2_coll_bcast_binomial	Number of times MV2 binomial bcast algorithm was invoked
MPI_T PVAR[19]: mv2_coll_bcast_scatter_doubling_all...	Number of times MV2 scatter+double allgather bcast algorithm was invoked
MPI_T PVAR[1]: mem_allocated	Maximum level of memory ever allocated within the MPI library
MPI_T PVAR[20]: mv2_coll_bcast_scatter_ring_allgather	Number of times MV2 scatter+ring allgather bcast algorithm was invoked
MPI_T PVAR[21]: mv2_coll_bcast_scatter_ring_allgath...	Number of times MV2 scatter+ring allgather shm bcast algorithm was invoked
MPI_T PVAR[22]: mv2_coll_bcast_shmem	Number of times MV2 shmem bcast algorithm was invoked
MPI_T PVAR[23]: mv2_coll_bcast_knomial_internode	Number of times MV2 knomial internode bcast algorithm was invoked
MPI_T PVAR[24]: mv2_coll_bcast_knomial_intranode	Number of times MV2 knomial intranode bcast algorithm was invoked
MPI_T PVAR[25]: mv2_coll_bcast_mcast_internode	Number of times MV2 mcast internode bcast algorithm was invoked
MPI_T PVAR[26]: mv2_coll_bcast_pipelined	Number of times MV2 pipelined bcast algorithm was invoked
MPI_T PVAR[27]: mv2_coll_alltoall_inplace	Number of times MV2 in-place alltoall algorithm was invoked
MPI_T PVAR[28]: mv2_coll_alltoall_bruck	Number of times MV2 brucks alltoall algorithm was invoked
MPI_T PVAR[29]: mv2_coll_alltoall_rd	Number of times MV2 recursive-doubling alltoall algorithm was invoked
MPI_T PVAR[2]: num_malloc_calls	Number of MPIT_malloc calls
MPI_T PVAR[30]: mv2_coll_alltoall_sd	Number of times MV2 scatter-destination alltoall algorithm was invoked
MPI_T PVAR[31]: mv2_coll_alltoall_pw	Number of times MV2 pairwise alltoall algorithm was invoked
MPI_T PVAR[32]: mpit_alltoallv_mv2_pw	Number of times MV2 pairwise alltoallv algorithm was invoked
MPI_T PVAR[33]: mv2_coll_allreduce_shm_rd	Number of times MV2 shm rd allreduce algorithm was invoked
MPI_T PVAR[34]: mv2_coll_allreduce_shm_rs	Number of times MV2 shm rs allreduce algorithm was invoked
MPI_T PVAR[35]: mv2_coll_allreduce_shm_intra	Number of times MV2 shm intra allreduce algorithm was invoked
MPI_T PVAR[36]: mv2_coll_allreduce_intra_p2p	Number of times MV2 intra p2p allreduce algorithm was invoked
MPI_T PVAR[37]: mv2_coll_allreduce_2lvl	Number of times MV2 two-level allreduce algorithm was invoked
MPI_T PVAR[38]: mv2_coll_allreduce_shmem	Number of times MV2 shmem allreduce algorithm was invoked
MPI_T PVAR[39]: mv2_coll_allreduce_mcast	Number of times MV2 multicast-based allreduce algorithm was invoked
MPI_T PVAR[3]: num_calloc_calls	Number of MPIT_calloc calls
MPI_T PVAR[40]: mv2_reg_cache_hits	Number of registration cache hits
MPI_T PVAR[41]: mv2_reg_cache_misses	Number of registration cache misses
MPI_T PVAR[42]: mv2_vbuf_allocated	Number of VBUFs allocated
MPI_T PVAR[43]: mv2_vbuf_allocated_array	Number of VBUFs allocated
MPI_T PVAR[44]: mv2_vbuf_freed	Number of VBUFs freed
MPI_T PVAR[45]: mv2_ud_vbuf_allocated	Number of UD VBUFs allocated
MPI_T PVAR[46]: mv2_ud_vbuf_freed	Number of UD VBUFs freed
MPI_T PVAR[47]: mv2_vbuf_free_attempts	Number of time we attempted to free VBUFs
MPI_T PVAR[48]: mv2_vbuf_free_attempt_success_time	Average time for number of times we sucessfully freed VBUFs
MPI_T PVAR[49]: mv2_vbuf_free_attempt_success_time	Average time for number of times we sucessfully freed VBUFs
MPI_T PVAR[4]: num_memalign_calls	Number of MPIT_memalign calls
MPI_T PVAR[50]: mv2_vbuf_allocate_time	Average time for number of times we allocated VBUFs
MPI_T PVAR[51]: mv2_vbuf_allocate_time	Average time for number of times we allocated VBUFs

CVARs Exposed by MVAPICH2

TAU: ParaProf Manager

File Options Help

- Applications
  - Standard Applications
    - Default App
      - Default Exp
        - lulesh.ppk
          - TIME
  - Default (jdbc:h2:/home

TrialField	Value
Local Time	2016-08-16T10:11:04-07:00
MPI Processor Name	cerberus.nic.uoregon.edu
MPIR_CVAR_ABORT_ON_LEAKED_HANDLES	If true, MPI will call MPI_Abort at MPI_Finalize if any MPI object handles have been leaked. For example,...
MPIR_CVAR_ALLGATHERV_PIPELINE_MSG_SIZE	The smallest message size that will be used for the pipelined, large-message, ring algorithm in the MPI_...
MPIR_CVAR_ALLGATHER_LONG_MSG_SIZE	For MPI_Allgather and MPI_Allgatherv, the long message algorithm will be used if the send buffer size is ...
MPIR_CVAR_ALLGATHER_SHORT_MSG_SIZE	For MPI_Allgather and MPI_Allgatherv, the short message algorithm will be used if the send buffer size is...
MPIR_CVAR_ALLREDUCE_SHORT_MSG_SIZE	the short message algorithm will be used if the send buffer size is <= this value (in bytes)
MPIR_CVAR_ALLTOALL_MEDIUM_MSG_SIZE	the medium message algorithm will be used if the per-destination message size (sendcount*size(sendtyp...
MPIR_CVAR_ALLTOALL_SHORT_MSG_SIZE	the short message algorithm will be used if the per-destination message size (sendcount*size(sendtype)) ...
MPIR_CVAR_ALLTOALL_THROTTLE	max no. of irecvs/isends posted at a time in some alltoall algorithms. Setting it to 0 causes all irecvs/isen...
MPIR_CVAR_ASYNC_PROGRESS	If set to true, MPICH will initiate an additional thread to make asynchronous progress on all communicati...
MPIR_CVAR_BCAST_LONG_MSG_SIZE	Let's define short messages as messages with size < MPIR_CVAR_BCAST_SHORT_MSG_SIZE, and mediu...
MPIR_CVAR_BCAST_MIN_PROCS	Let's define short messages as messages with size < MPIR_CVAR_BCAST_SHORT_MSG_SIZE, and mediu...
MPIR_CVAR_BCAST_SHORT_MSG_SIZE	Let's define short messages as messages with size < MPIR_CVAR_BCAST_SHORT_MSG_SIZE, and mediu...
MPIR_CVAR_CH3_EAGER_MAX_MSG_SIZE	This cvar controls the message size at which CH3 switches from eager to rendezvous mode.
MPIR_CVAR_CH3_ENABLE_HCOLL	If true, enable HCOLL collectives.
MPIR_CVAR_CH3_INTERFACE_HOSTNAME	If non-NULL, this cvar specifies the IP address that other processes should use when connecting to this pr...
MPIR_CVAR_CH3_NOLOCAL	If true, force all processes to operate as though all processes are located on another node. For example,...
MPIR_CVAR_CH3_ODD_EVEN_CLIQUES	If true, odd procs on a node are seen as local to each other, and even procs on a node are seen as local t...
MPIR_CVAR_CH3_PORT_RANGE	The MPIR_CVAR_CH3_PORT_RANGE environment variable allows you to specify the range of TCP ports ...
MPIR_CVAR_CH3_RMA_ACC_IMMED	Use the immediate accumulate optimization
MPIR_CVAR_CH3_RMA_GC_NUM_COMPLETED	Threshold for the number of completed requests the runtime finds before it stops trying to find more co...
MPIR_CVAR_CH3_RMA_GC_NUM_TESTED	Threshold for the number of RMA requests the runtime tests before it stops trying to check more reques...
MPIR_CVAR_CH3_RMA_LOCK_IMMED	Issue a request for the passive target RMA lock immediately. Default behavior is to defer the lock reque...
MPIR_CVAR_CH3_RMA_MERGE_LOCK_OP_UNLOCK	Enable/disable an optimization that merges lock, op, and unlock messages, for single-operation passive ta...
MPIR_CVAR_CH3_RMA_NREQUEST_NEW_THRESHOLD	Threshold for the number of new requests since the last attempt to complete pending requests. Higher ...
MPIR_CVAR_CH3_RMA_NREQUEST_THRESHOLD	Threshold at which the RMA implementation attempts to complete requests while completing RMA oper...
MPIR_CVAR_CHOP_ERROR_STACK	If >0, truncate error stack output lines this many characters wide. If 0, do not truncate, and if <0 use a ...
MPIR_CVAR_COLL_ALIAS_CHECK	Enable checking of aliasing in collective operations
MPIR_CVAR_COMM_SPLIT_USE_QSORT	Use qsort(3) in the implementation of MPI_Comm_split instead of bubble sort.
MPIR_CVAR_CTXID_EAGER_SIZE	The MPIR_CVAR_CTXID_EAGER_SIZE environment variable allows you to specify how many words in th...
MPIR_CVAR_DEBUG_HOLD	If true, causes processes to wait in MPI_Init and MPI_Initthread for a debugger to be attached. Once the ...
MPIR_CVAR_DEFAULT_THREAD_LEVEL	Sets the default thread level to use when using MPI_INIT.
MPIR_CVAR_DUMP_PROVIDERS	If true, dump provider information at init
MPIR_CVAR_ENABLE_COLL_FT_RET	DEPRECATED! Will be removed in MPICH-3.2 Collectives called on a communicator with a failed process...
MPIR_CVAR_ENABLE_SMP_ALLREDUCE	Enable SMP aware allreduce.
MPIR_CVAR_ENABLE_SMP_BARRIER	Enable SMP aware barrier.
MPIR_CVAR_ENABLE_SMP_BCAST	Enable SMP aware broadcast (See also: MPIR_CVAR_MAX_SMP_BCAST_MSG_SIZE)
MPIR_CVAR_ENABLE_SMP_COLLECTIVES	Enable SMP aware collective communication.
MPIR_CVAR_ENABLE_SMP_REDUCE	Enable SMP aware reduce.
MPIR_CVAR_ERROR_CHECKING	If true, perform checks for errors, typically to verify valid inputs to MPI routines. Only effective when M...
MPIR_CVAR_GATHERV_INTER_SSEND_MIN_PROCS	Use Ssend (synchronous send) for intercommunicator MPI_Gatherv if the "group B" size is >= this value....
MPIR_CVAR_GATHER_INTER_SHORT_MSG_SIZE	use the short message algorithm for intercommunicator MPI_Gather if the send buffer size is < this value...
MPIR_CVAR_GATHER_VSMALL_MSG_SIZE	use a temporary buffer for intracommunicator MPI_Gather if the send buffer size is < this value (in bytes...
MPIR_CVAR_IBA_EAGER_THRESHOLD	0 (old) -> 204800 (new), This set the switch point between eager and rendezvous protocol
MPIR_CVAR_MAX_INLINE_SIZE	This set the maximum inline size for data transfer
MPIR_CVAR_MAX_SMP_ALLREDUCE_MSG_SIZE	Maximum message size for which SMP-aware allreduce is used. A value of '0' uses SMP-aware allreduce ...

Using MVAPICH2 and TAU

- To set CVARs or read PVARs using TAU for an uninstrumented binary:

  % export TAU_TRACK_MPI_T_PVARS=1

  % export TAU_MPI_T_CVAR_METRICS=

  MPIR_CVAR_VBUF_POOL_REDUCED_VALUE[1],

  MPIR_CVAR_IBA_EAGER_THRESHOLD

  % export TAU_MPI_T_CVAR_VALUES=32,64000

  % export PATH=/path/to/tau/x86_64/bin:$PATH

  % mpirun -np 1024 *tau_exec -T mvapich2* ./a.out

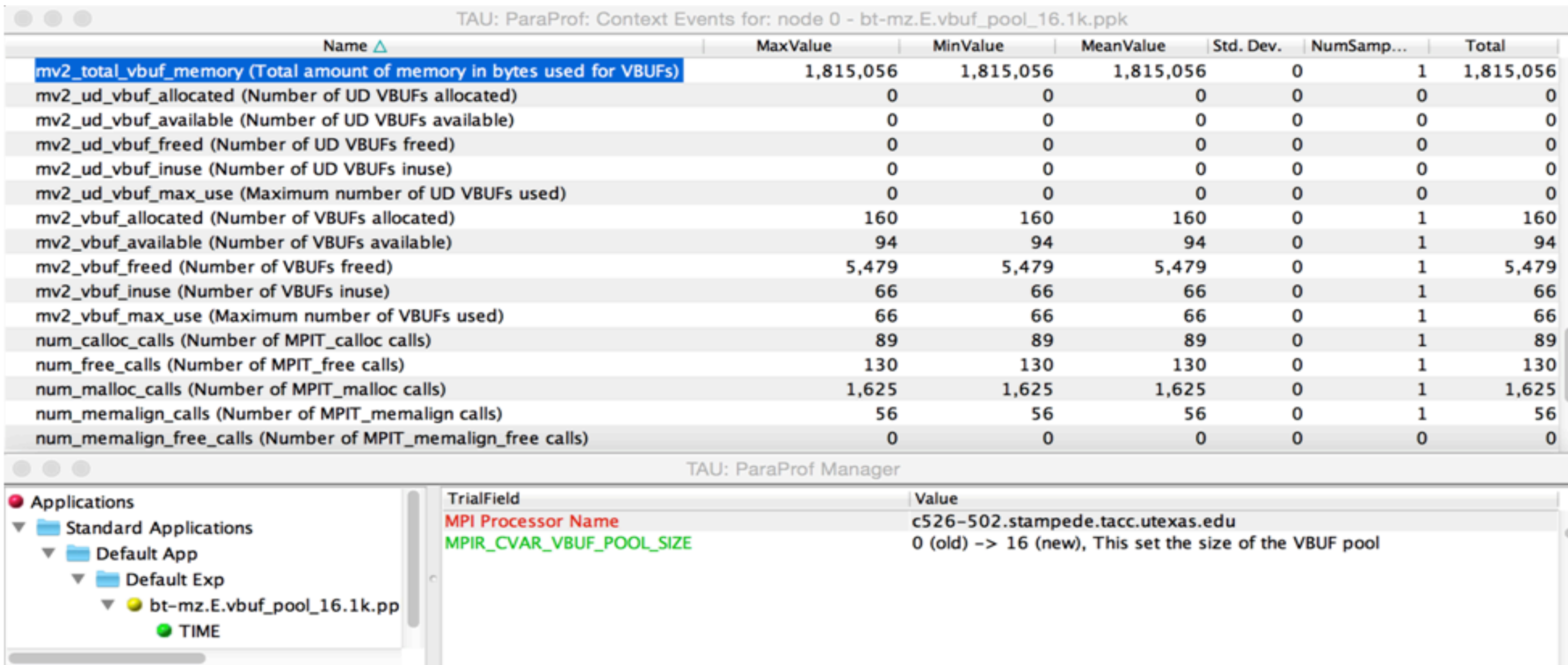
  % paraprof

VBUF usage without CVARs

TAU: ParaProf: Context Events for: node 0 - mpit_withoutcvar_bt.C.1k.ppk

Name △	MaxValue	MinValue	MeanValue	Std. Dev.	NumSamples	Total
mv2_total_vbuf_memory (Total amount of memory in bytes used for VBUFs)	3,313,056	3,313,056	3,313,056	0	1	3,313,056
mv2_ud_vbuf_allocated (Number of UD VBUFs allocated)	0	0	0	0	0	0
mv2_ud_vbuf_available (Number of UD VBUFs available)	0	0	0	0	0	0
mv2_ud_vbuf_freed (Number of UD VBUFs freed)	0	0	0	0	0	0
mv2_ud_vbuf_inuse (Number of UD VBUFs inuse)	0	0	0	0	0	0
mv2_ud_vbuf_max_use (Maximum number of UD VBUFs used)	0	0	0	0	0	0
mv2_vbuf_allocated (Number of VBUFs allocated)	320	320	320	0	1	320
mv2_vbuf_available (Number of VBUFs available)	255	255	255	0	1	255
mv2_vbuf_freed (Number of VBUFs freed)	25,545	25,545	25,545	0	1	25,545
mv2_vbuf_inuse (Number of VBUFs inuse)	65	65	65	0	1	65
mv2_vbuf_max_use (Maximum number of VBUFs used)	65	65	65	0	1	65
num_calloc_calls (Number of MPIT_calloc calls)	89	89	89	0	1	89
num_free_calls (Number of MPIT_free calls)	47,801	47,801	47,801	0	1	47,801
num_malloc_calls (Number of MPIT_malloc calls)	49,258	49,258	49,258	0	1	49,258
num_memalign_calls (Number of MPIT_memalign calls)	34	34	34	0	1	34
num_memalign_free_calls (Number of MPIT_memalign_free calls)	0	0	0	0	0	0

VBUF usage with CVARs

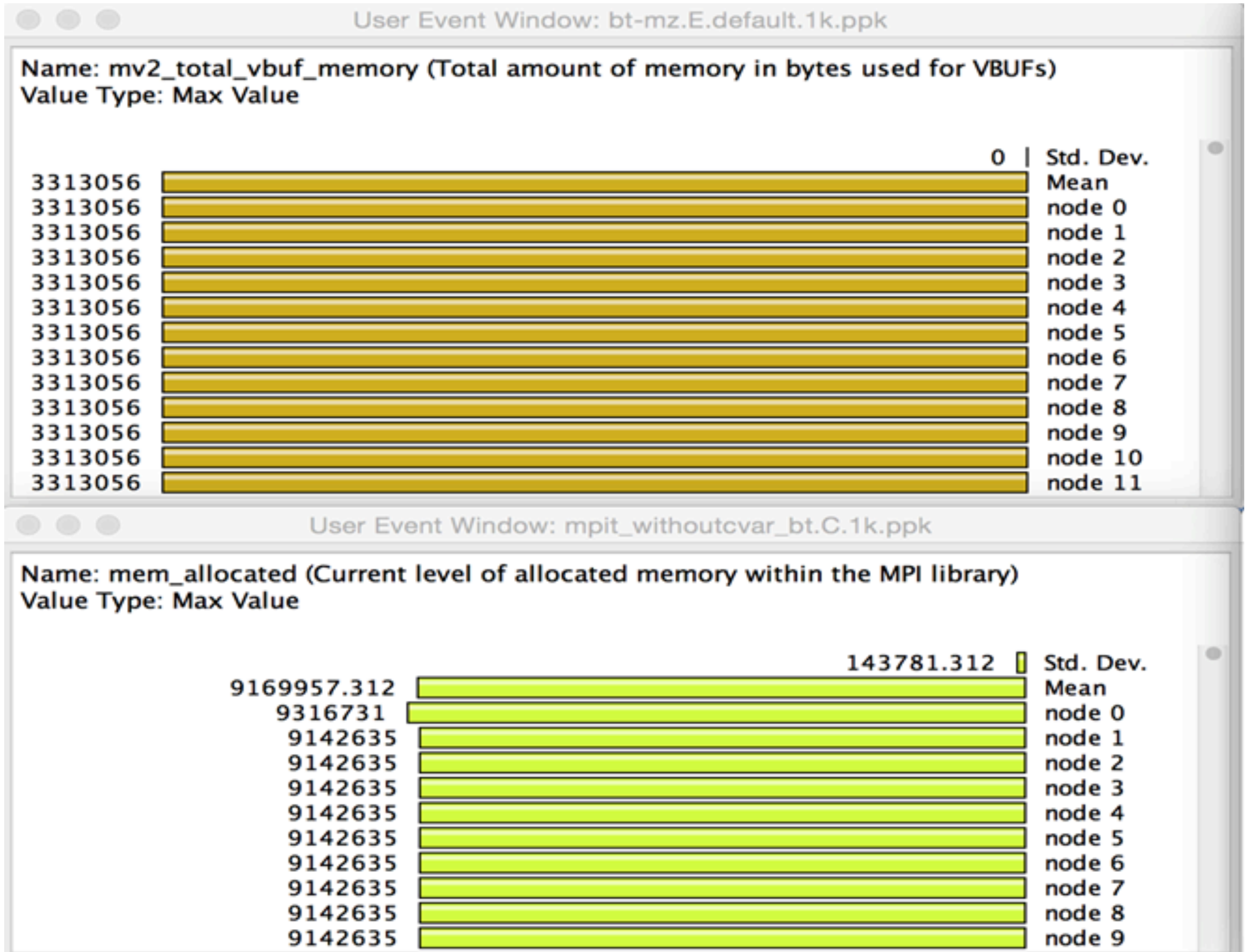


Name	MaxValue	MinValue	MeanValue	Std. Dev.	NumSamp...	Total
mv2_total_vbuf_memory (Total amount of memory in bytes used for VBUFs)	1,815,056	1,815,056	1,815,056	0	1	1,815,056
mv2_ud_vbuf_allocated (Number of UD VBUFs allocated)	0	0	0	0	0	0
mv2_ud_vbuf_available (Number of UD VBUFs available)	0	0	0	0	0	0
mv2_ud_vbuf_freed (Number of UD VBUFs freed)	0	0	0	0	0	0
mv2_ud_vbuf_inuse (Number of UD VBUFs inuse)	0	0	0	0	0	0
mv2_ud_vbuf_max_use (Maximum number of UD VBUFs used)	0	0	0	0	0	0
mv2_vbuf_allocated (Number of VBUFs allocated)	160	160	160	0	1	160
mv2_vbuf_available (Number of VBUFs available)	94	94	94	0	1	94
mv2_vbuf_freed (Number of VBUFs freed)	5,479	5,479	5,479	0	1	5,479
mv2_vbuf_inuse (Number of VBUFs inuse)	66	66	66	0	1	66
mv2_vbuf_max_use (Maximum number of VBUFs used)	66	66	66	0	1	66
num_calloc_calls (Number of MPIT_calloc calls)	89	89	89	0	1	89
num_free_calls (Number of MPIT_free calls)	130	130	130	0	1	130
num_malloc_calls (Number of MPIT_malloc calls)	1,625	1,625	1,625	0	1	1,625
num_memalign_calls (Number of MPIT_memalign calls)	56	56	56	0	1	56
num_memalign_free_calls (Number of MPIT_memalign_free calls)	0	0	0	0	0	0

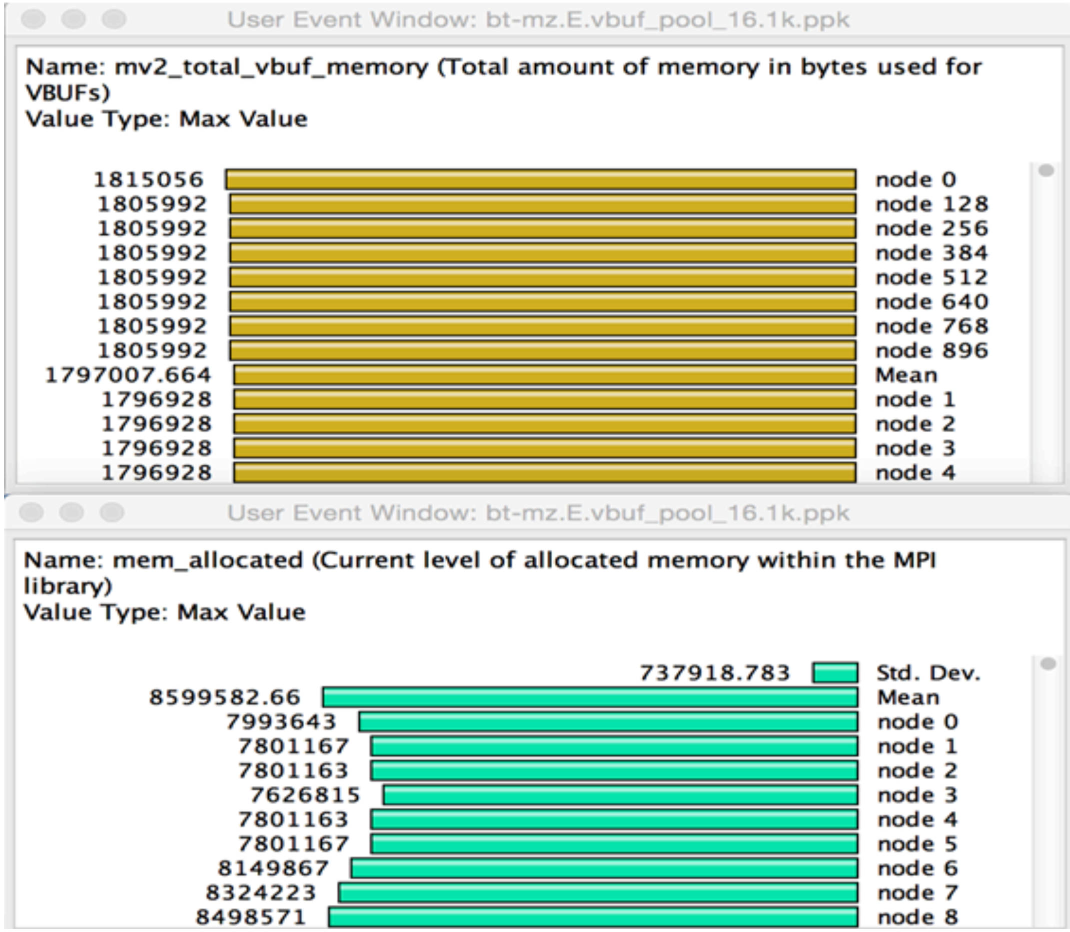
TrialField	Value
MPI Processor Name	c526-502.stampede.tacc.utexas.edu
MPIR_CVAR_VBUF_POOL_SIZE	0 (old) -> 16 (new), This set the size of the VBUF pool

Total memory used by VBUFs is reduced from 3,313,056 to 1,815,056

VBUF Memory Usage Without CVAR



VBUF Memory Usage With CVAR



% export TAU_TRACK_MPI_T_PVARS=1

% export TAU_MPI_T_CVAR_METRICS=MPIR_CVAR_VBUF_POOL_SIZE

% export TAU_MPI_T_CVAR_VALUES=16

% mpirun -np 1024 *tau_exec -T mvapich2* ./a.out

Examples

Simplifying the use of TAU!

Uninstrumented code:

- % mpif90 –g –O3 matmult.f90
- % mpirun –np 16 ./a.out

With TAU:

- % mpirun –np 16 tau_exec ./a.out
- % paraprof
- For more Information at the statement level:
- % mpirun –np 16 tau_exec –ebs ./a.out (or use TAU_SAMPLING=1)
- To rewrite the binary to instrument individual functions (using MAQAO):
- % tau_rewrite a.out a.inst; mpirun –np 16 ./a.inst (beta)
- % pprof -a | more
- % paraprof (GUI)

TAU for Heterogeneous Measurement

Multiple performance perspectives

Integrate Host-GPU support in TAU measurement framework

- Enable use of each measurement approach
- Include use of PAPI and CUPTI
- Provide profiling and tracing support

Tutorial

- Use TAU library wrapping of libraries
- Use `tau_exec` to work with binaries

  % ./a.out (uninstrumented)

  % tau_exec –T <configuration tags> –cupti ./a.out

  % paraprof

TAU Execution Command (tau_exec)

Uninstrumented execution

- % mpirun -np 256 ./a.out

Track GPU operations

- % mpirun –np 256 tau_exec –cupti ./a.out
- % mpirun –np 256 tau_exec –cupti -um ./a.out (for Unified Memory)
- % 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 OpenMP, I/O, and MPI performance (MPI enabled by default)

- % mpirun -np 256 tau_exec –ompt -io ./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 –ebs_source=<PAPI_COUNTER> -ebs_period=<overflow_count>

Using TAU

TAU supports several measurement and thread options

Phase profiling, profiling with hardware counters (papi), MPI library, CUDA, Beacon (backplane for event notification – online monitoring), PDT (automatic source instrumentation) …

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:

% export TAU_MAKEFILE=$TAU/Makefile.tau-papi-mpi-pdt

% 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)

Choosing TAU_MAKEFILE

```
% ls $TAU/Makefile.*
```

Makefile.tau-mpi-pdt

Makefile.tau-papi-mpi-pdt

Makefile.tau-beacon-papi-mpi-pdt-mpit

Makefile.tau-icpc-papi-mpi-pdt

Makefile.tau-icpc-papi-ompt-mpi-pdt-openmp

Makefile.tau-icpc-papi-ompt-pdt-openmp

Makefile.tau-mpi-pdt-openmp-opari

Makefile.tau-mpi-pthread-python-pdt

Makefile.tau-papi-mpi-pdt-openmp-opari-scorep

Makefile.tau-papi-mpi-pdt-scorep

Makefile.tau-papi-mpi-pthread-pdt

Makefile.tau-papi-pthread-pdt

For an MPI+F90 application with MPI, you may choose

Makefile.tau-papi-mpi-pdt

- Supports MPI instrumentation, papi, and PDT for automatic source instrumentation

```
% export TAU_MAKEFILE=$TAU/Makefile.tau-papi-mpi-pdt
% tau_f90.sh matrix.f90 -o matrix
OR with build systems:
% make CC=tau_cc.sh CXX=tau_cxx.sh F90=tau_f90.sh
% cmake -DCMAKE_Fortran_COMPILER=tau_f90.sh
       -DCMAKE_C_COMPILER=tau_cc.sh -DCMAKE_CXX_COMPILER=tau_cxx.sh
% mpirun -np 1024 ./matrix
% paraprof
```

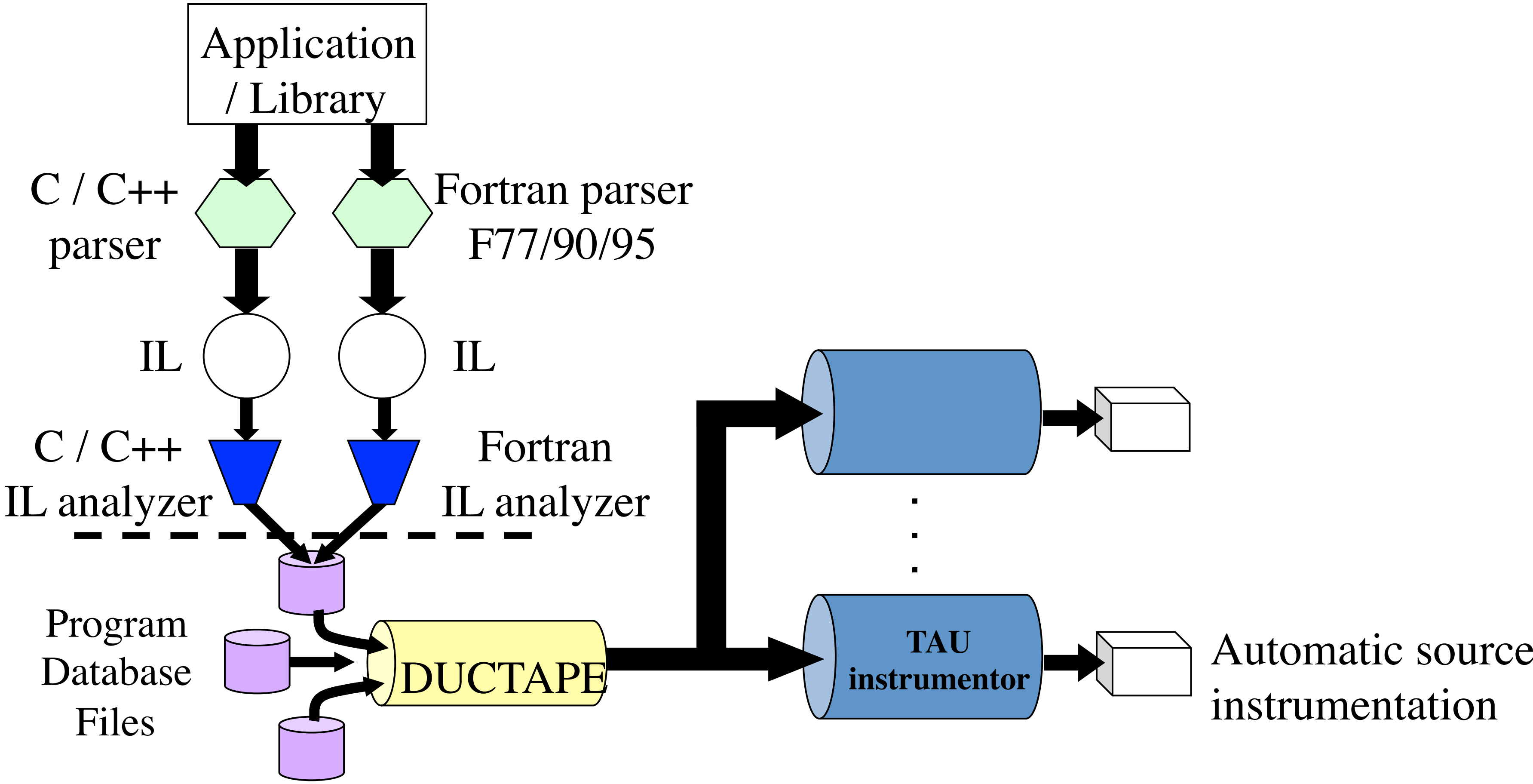
Configuration tags for tau_exec

```
% ./configure -pdt=<dir> -mpi -papi=<dir>; make install
```
Creates in $TAU:
```
Makefile.tau-papi-mpi-pdt(Configuration parameters in stub makefile)
shared-papi-mpi-pdt/libTAU.so

% ./configure -pdt=<dir> -mpi; make install  creates
Makefile.tau-mpi-pdt
shared-mpi-pdt/libTAU.so
```

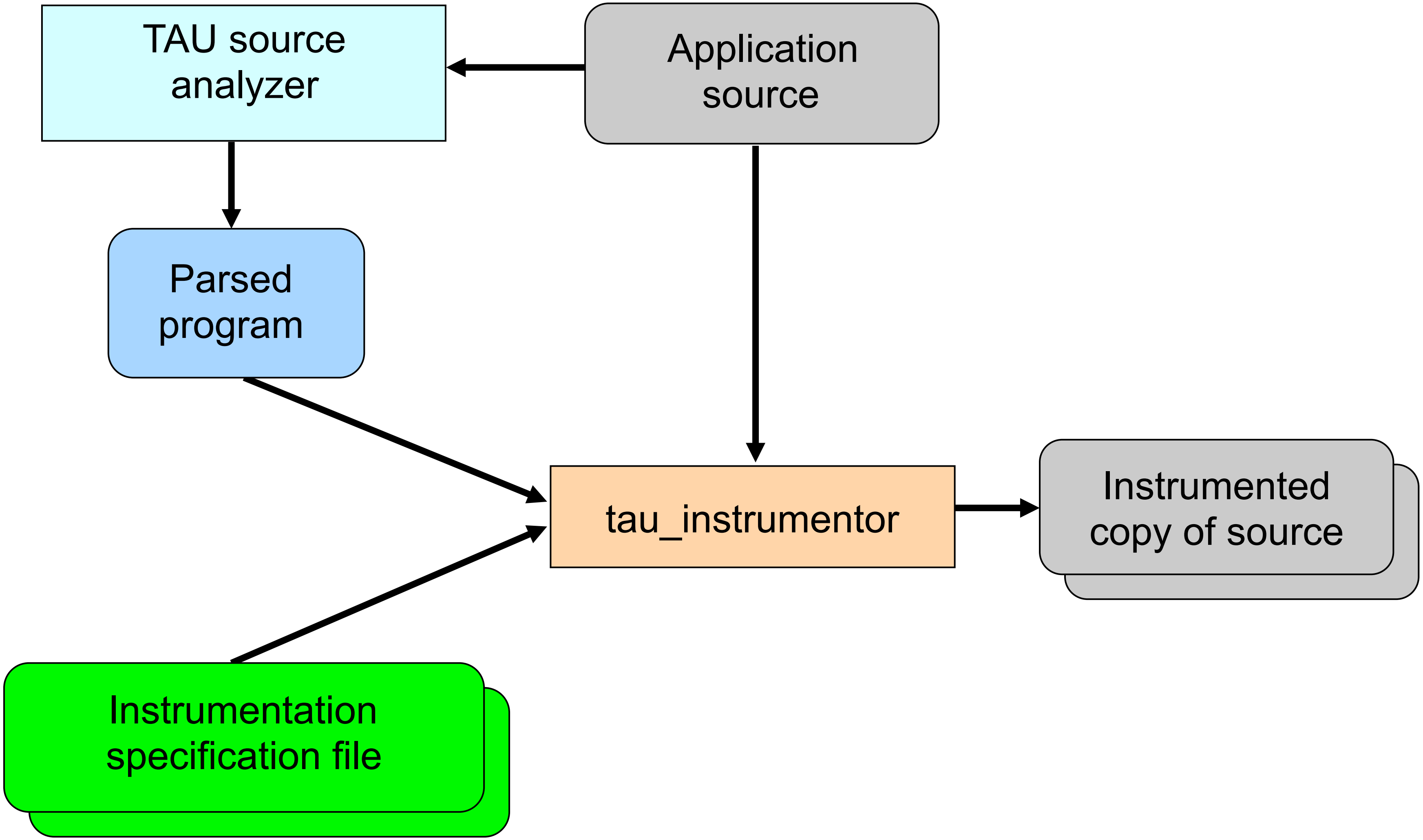
To explicitly choose preloading of shared-<options>/libTAU.so change:
```
% mpirun -np 256 ./a.out     to
% mpirun -np 256  tau_exec -T <comma_separated_options> ./a.out

% mpirun -np 256  tau_exec -T papi,mpi,pdt ./a.out
```
Preloads `$TAU/shared-papi-mpi-pdt/libTAU.so`
```
% mpirun -np 256  tau_exec -T papi ./a.out
```
Preloads `$TAU/shared-papi-mpi-pdt/libTAU.so by matching.`
```
% mpirun -np 256 tau_exec -T papi,mpi,pdt -s ./a.out
```
Does not execute the program. Just displays the library that it will preload if executed without the –s option.

NOTE: -mpi configuration is selected by default. Use –T serial for Sequential programs.

TAU's Static Analysis System: Program Database Toolkit (PDT)



Automatic Source Instrumentation using PDT



Automatic Instrumentation

- **Use TAU's compiler wrappers**
  - Simply replace `CXX` with `tau_cxx.sh, etc.`
  - Automatically instruments source code, links with TAU libraries.
- **Use `tau_cc.sh` for C, `tau_f90.sh` for Fortran, `tau_upc.sh` for UPC, etc.**

Before

```
% cat Makefile
CXX = mpicxx
F90 = mpif90
CXXFLAGS =
LIBS = -lm
OBJS = f1.o f2.o f3.o … fn.o

app: $(OBJS)
      $(CXX) $(LDFLAGS) $(OBJS) -o $@
      $(LIBS)
.cpp.o:
      $(CXX) $(CXXFLAGS) -c $<

% make
```

After

```
% cat Makefile
CXX = tau_cxx.sh
F90 = tau_f90.sh
CXXFLAGS =
LIBS = -lm
OBJS = f1.o f2.o f3.o … fn.o

app: $(OBJS)
      $(CXX) $(LDFLAGS) $(OBJS) -o $@
      $(LIBS)
.cpp.o:
      $(CXX) $(CXXFLAGS) -c $<

% export TAU_MAKEFILE=
      $TAU/Makefile.tau-papi-mpi-pdt
% make
```

Selective Instrumentation File

```
% export TAU_OPTIONS='-optTauSelectFile=select.tau …'
% cat select.tau
BEGIN_INCLUDE_LIST
int main#
int dgemm#
END_INCLUDE_LIST
BEGIN_FILE_INCLUDE_LIST
Main.c
Blas/*.f77
END_FILE_INCLUDE_LIST
# replace include with exclude list

BEGIN_INSTRUMENT_SECTION
loops routine="foo"
loops routine="int main#"
END_INSTRUMENT_SECTION
```

Installing and Configuring TAU

- **Installing PDT:**
  - 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
  - ./configure –mpi -bfd=download -pdt=<dir> -papi=<dir> ...
  - make install
- **Using TAU:**
  - export TAU_MAKEFILE=<taudir>/x86_64/
    lib/Makefile.tau-<TAGS>
  - % export TAU_OPTIONS='-optTauSelectFile=select.tau'
  - 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.)

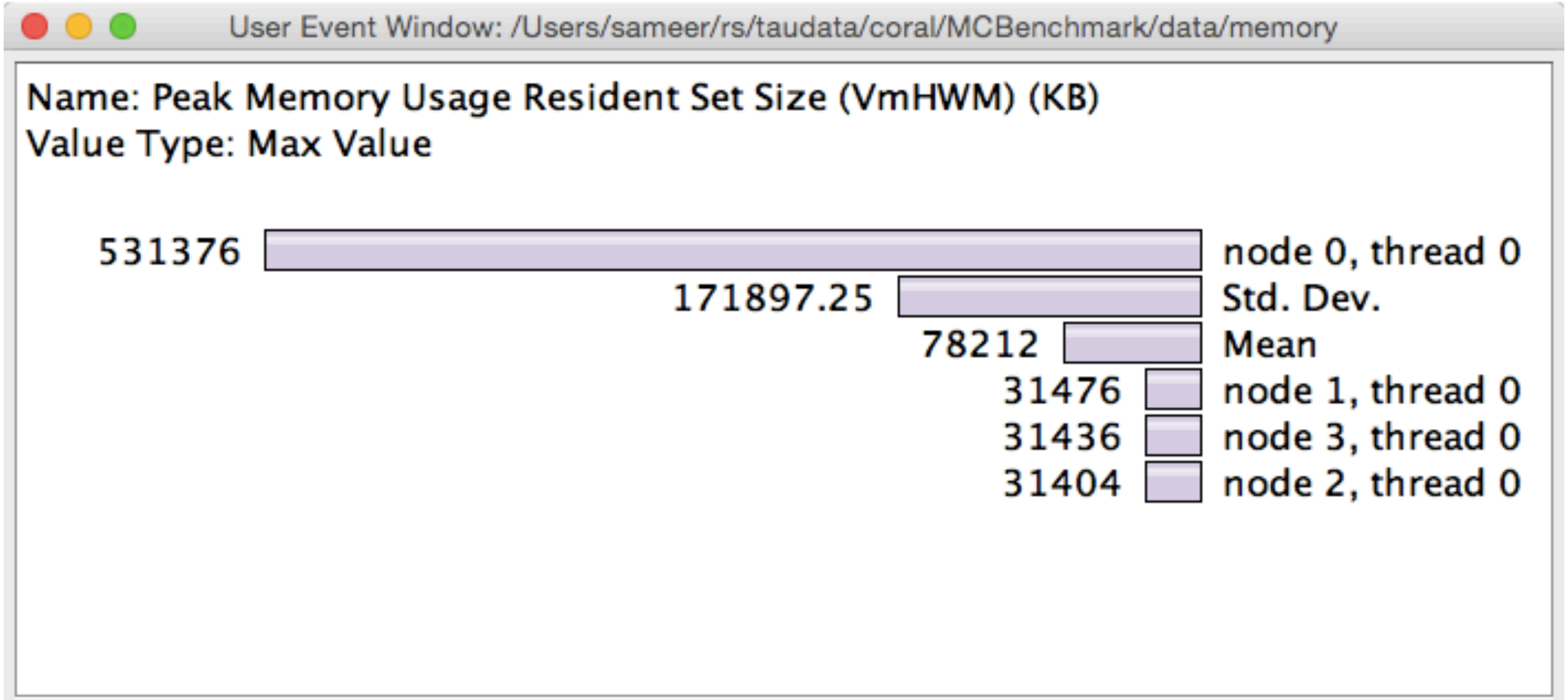
Optional parameters for the TAU_OPTIONS environment variable:
% tau_compiler.sh

-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.

…

Measuring Memory Footprint



% export TAU_TRACK_MEMORY_FOOTPRINT=1
Paraprof:
Right click on a node -> Show Context Event Window -> see memory events

Usage Scenarios with MVAPICH2

- TAU measures the high water mark of total memory usage (TAU_TRACK_MEMORY_FOOTPRINT=1), finds that it is at 98% of available memory, and queries MVAPICH2 to find out how much memory it is using. Based on the number of pools allocated and used, it requests it to reduce the number of VBUF pools and controls the size of the these pools using the MPI-T interface. The total memory memory footprint of the application reduces.
- TAU tracks the message sizes of messages (TAU_COMM_MATRIX=1), detects excessive time spent in MPI_Wait and other synchronization operations. It compares the average message size with the eager threshold and sets the new eager threshold value to match the message size. This could be done offline by re-executing the application with the new CVAR setting for eager threshold or online.
- TAU uses Beacon (backplane for event and control notification) to observe the performance of a running application (for e.g., vbuf pool statistics, high water mark of total and vbuf memory usage, message size statistics).

Other Runtime Environment Variables

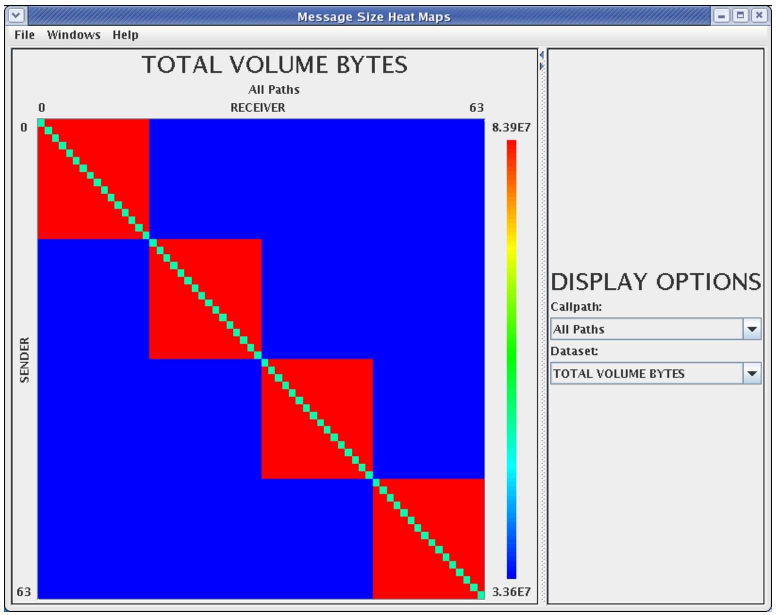
Environment Variable	Default	Description
TAU_TRACE	0	Setting to 1 turns on tracing
TAU_CALLPATH	0	Setting to 1 turns on callpath profiling
TAU_TRACK_MEMORY_FOOTPRINT	0	Setting to 1 turns on tracking memory usage by sampling periodically the resident set size and high water mark of memory usage
TAU_TRACK_POWER	0	Tracks instantaneous 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	0	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. Enabled by default to remove 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_COMPENSATE	0	Setting to 1 enables runtime compensation of instrumentation overhead
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., TIME,ENERGY,PAPI_FP_INS,PAPI_NATIVE_<event>:<subevent>)

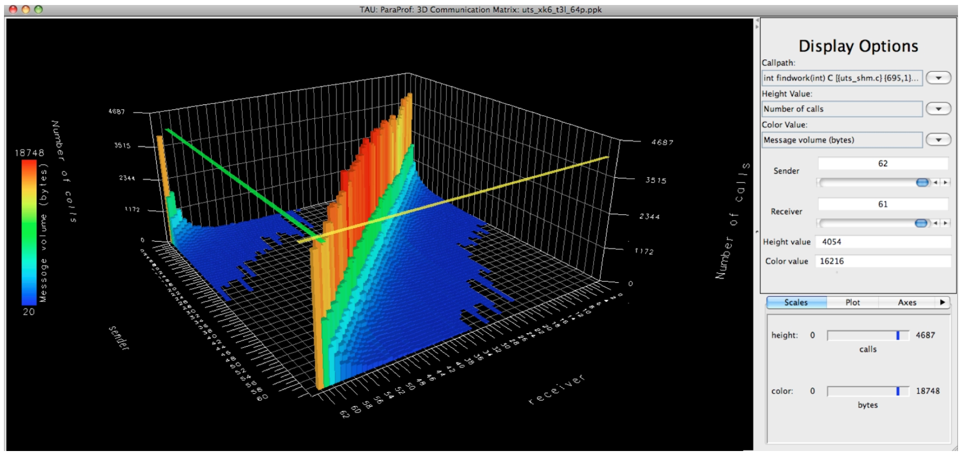
Runtime Environment Variables (contd.

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

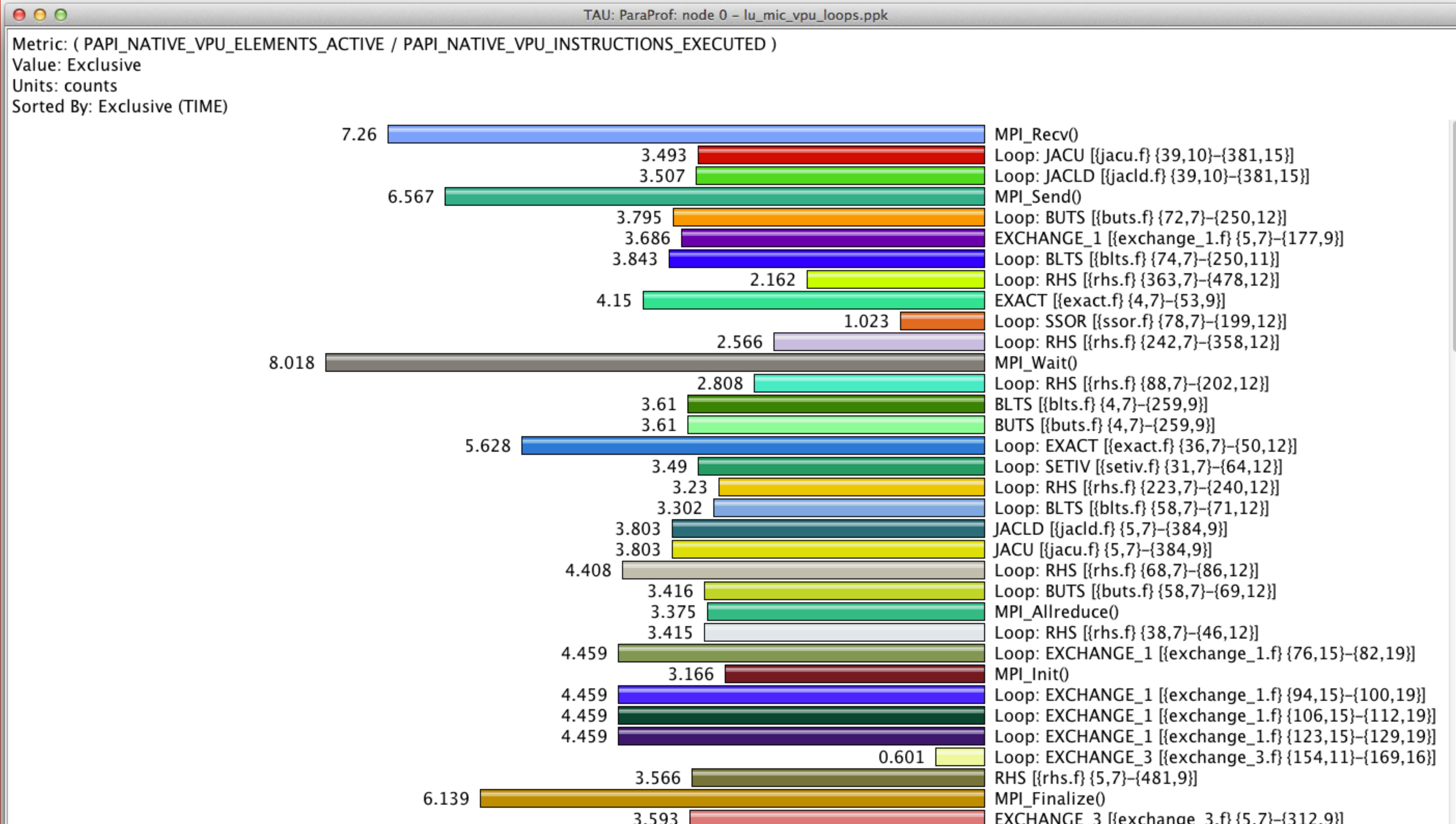
Communication Matrix Display

Goal: What is the volume of inter-process communication? Along which calling path?



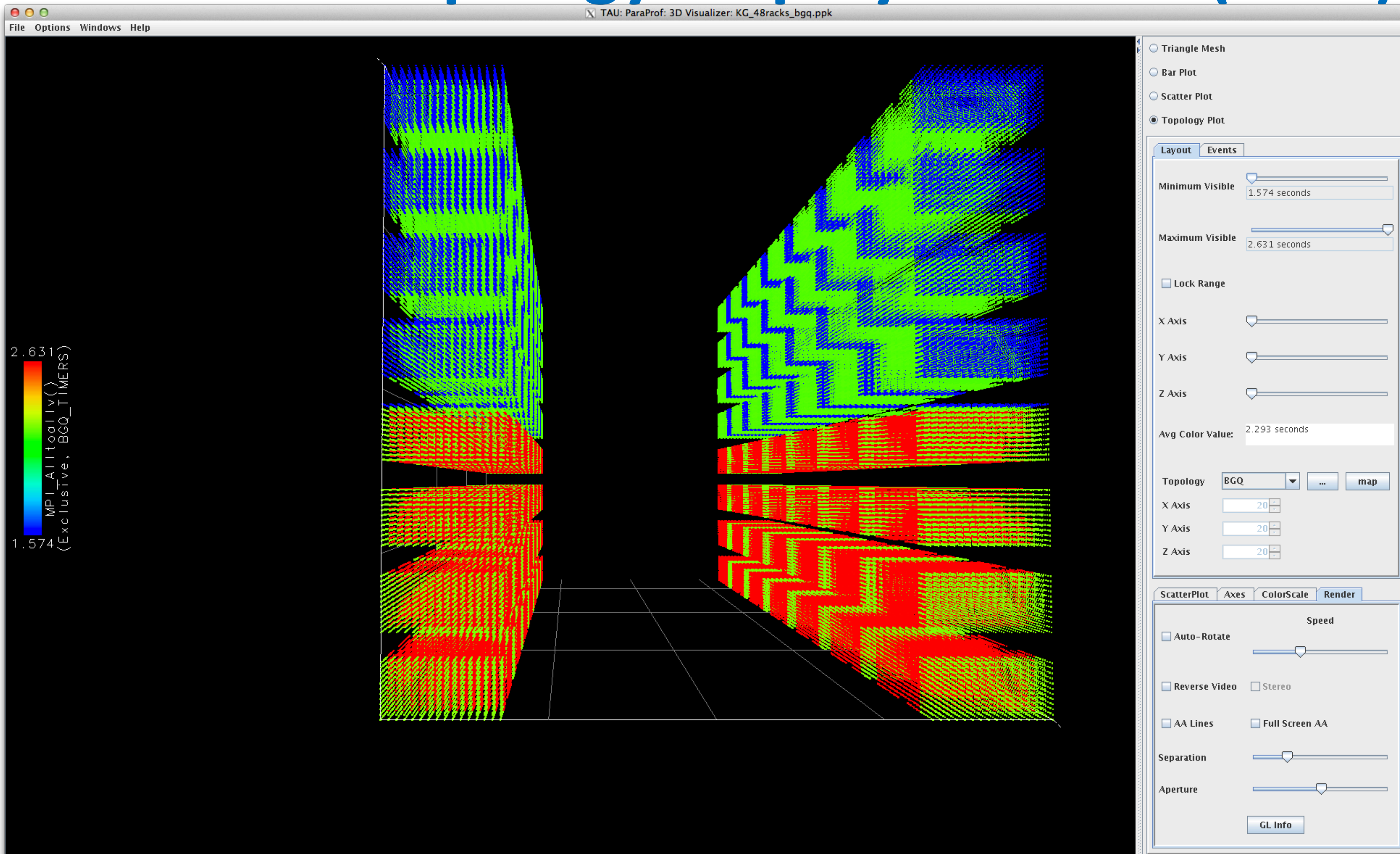


Evaluating Extent of Vectorization on MIC

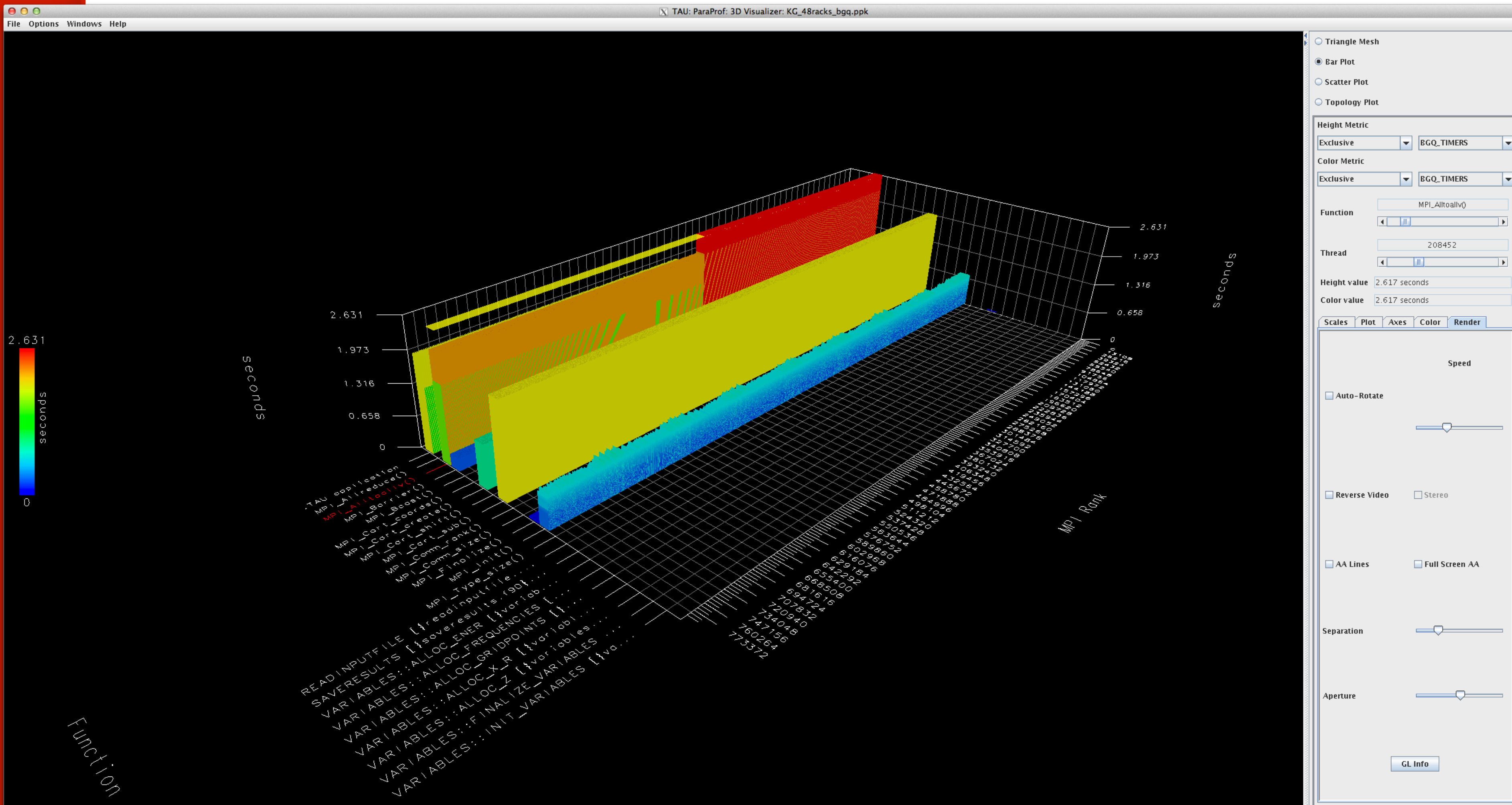


% export TAU_MAKEFILE=$TAUROOT/mic_linux/lib/Makefile.tau-papi-mpi-pdt
% export TAU_METRICS=TIME,
PAPI_NATIVE_VPU_ELEMENTS_ACTIVE,PAPI_NATIVE_VPU_INSTRUCTIONS_EXECUTED

ParaProf’s Topology Display Window (BGQ)

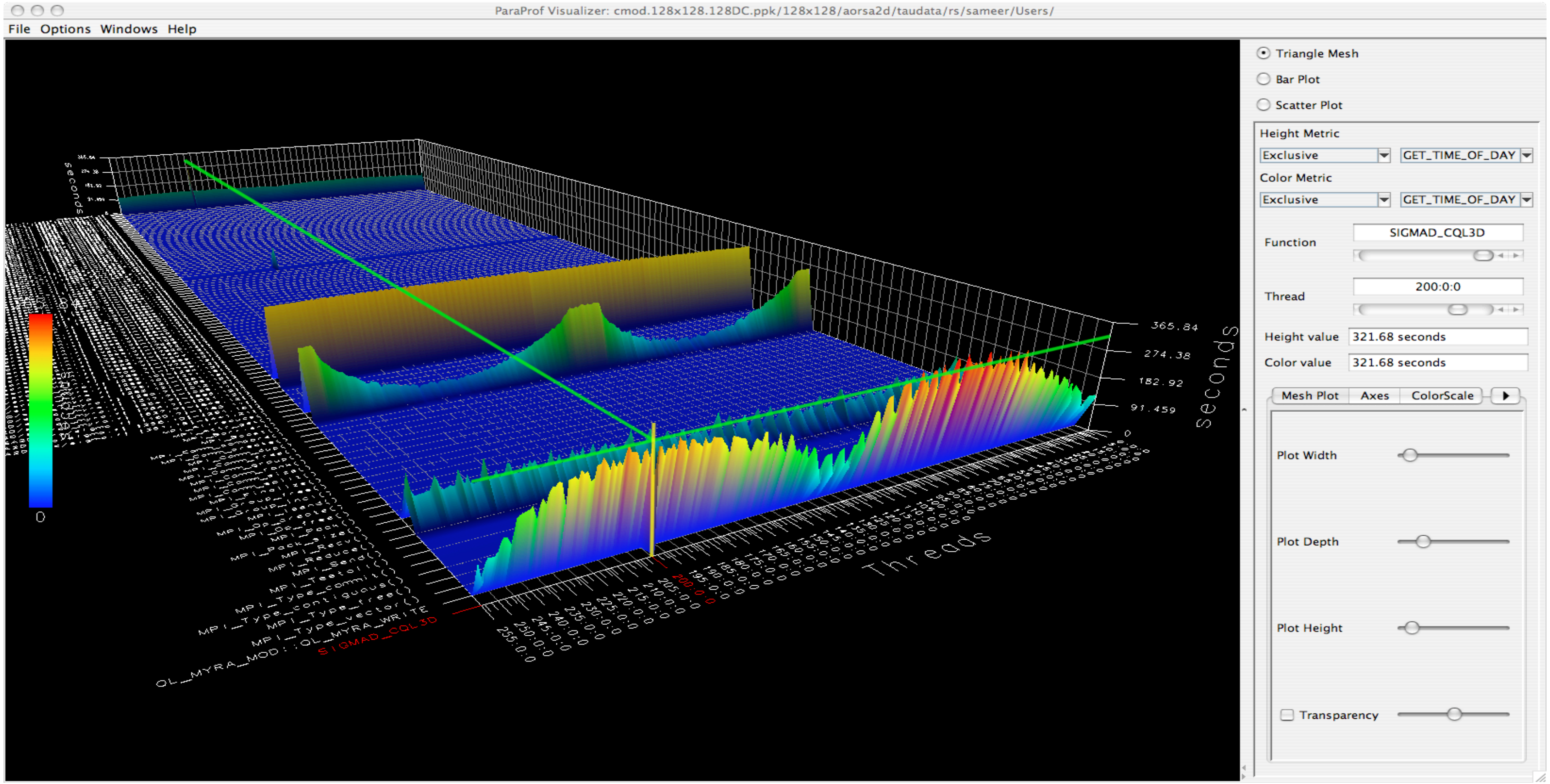


ParaProf's Scalable 3D Visualization (BGQ)



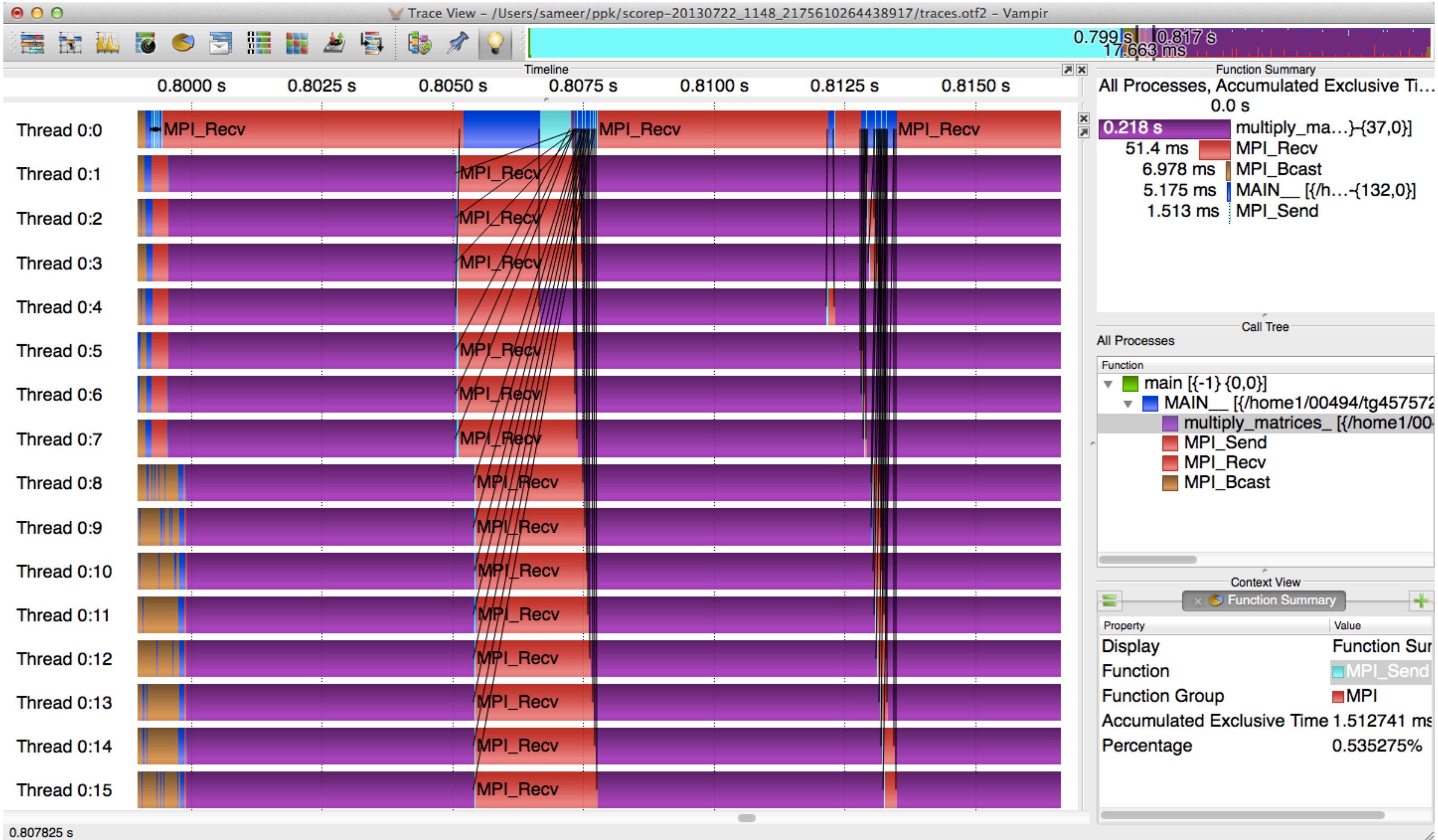
786,432 ranks

ParaProf 3D Profile Browser



Generating a Trace File Using Score-P

- Goal: Identify the temporal aspect of performance. What happens in my code at a given time? When? Configure with –scorep=download (new in TAU v2.25.2)
- Event trace visualized in Vampir [www.vampir.eu]



Download TAU from U. Oregon

http://www.hpclinux.com [OVA file]

http://tau.uoregon.edu/tau.pptx

for more information

Free download, open source, BSD license

PRL, University of Oregon, Eugene

www.uoregon.edu

Support Acknowledgments

National Science Foundation (NSF)

- SI2-SSI, Glassbox

US Department of Energy (DOE)

- Office of Science contracts
- SciDAC, LBL contracts
- LLNL-LANL-SNL ASC/NNSA contract
- Battelle, PNNL contract
- ANL, ORNL contract

Department of Defense (DoD)

- PETTT, HPCMP

NASA

Partners:

University of Oregon

The Ohio State University

ParaTools, Inc.

University of Tennessee, Knoxville

T.U. Dresden, GWT

Juelich Supercomputing Center