TAU PERFORMANCE SYSTEM

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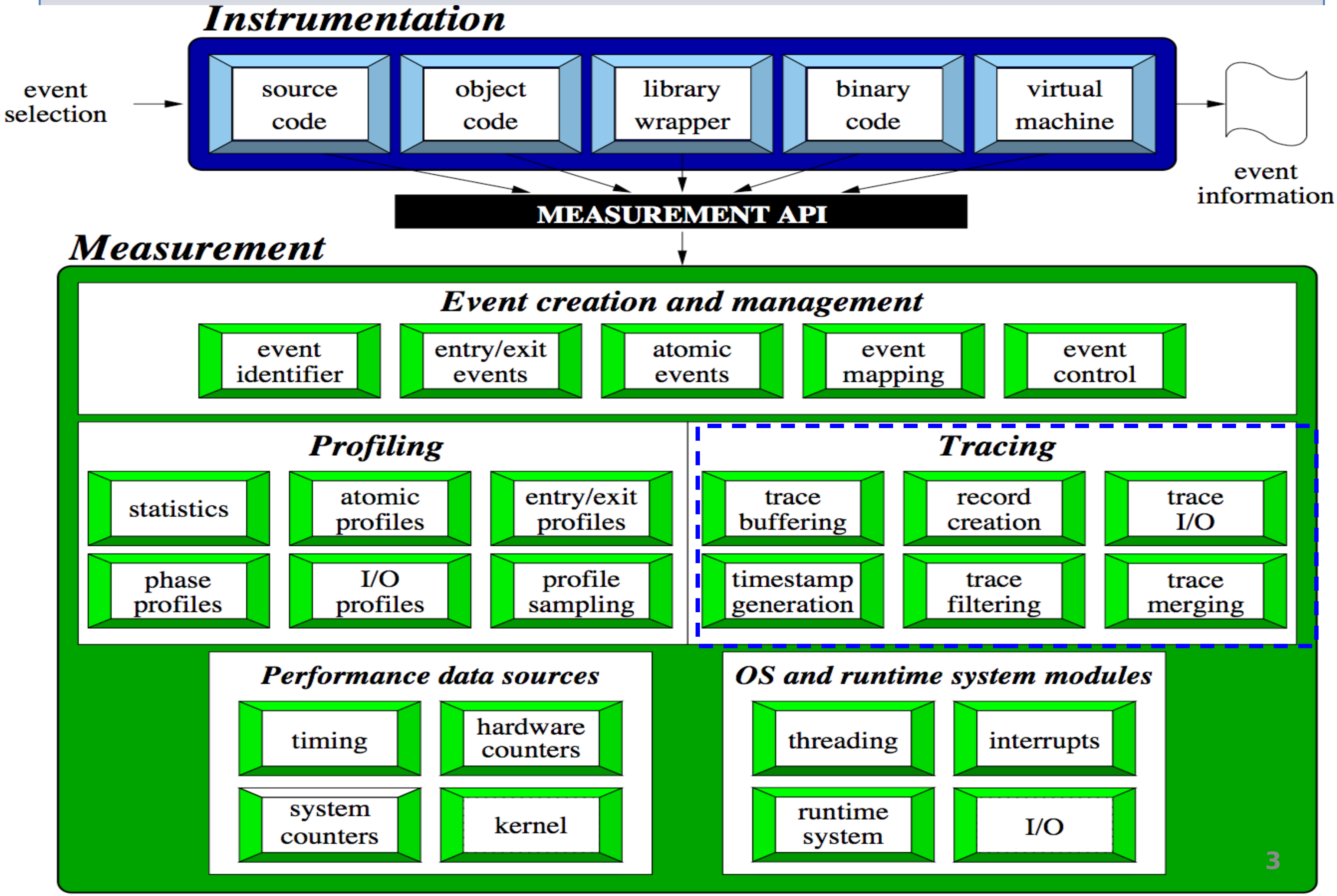
What Is Tau?

- *T*uning and *A*nalysis *U*tilities (15+ year project)
- Performance problem solving framework for HPC
  - Integrated, scalable, flexible, portable
  - Target all parallel programming / execution paradigms
- Integrated performance toolkit (open source)
  - Instrumentation, measurement, analysis, visualization
  - Widely-ported performance profiling / tracing system
  - Performance data management and data mining
- Broad application use (NSF, DOE, DOD, ...)

TAU Instrumentation / Measurement



TAU Measurement Approach

- Portable and scalable parallel profiling solution
  - Multiple profiling types and options
  - Event selection and control (enabling/disabling, throttling)
  - Online profile access and sampling
  - Online performance profile overhead compensation
- Portable and scalable parallel tracing solution
  - Trace translation to OTF, EPILOG, Paraver, and SLOG2
  - Trace streams (OTF) and hierarchical trace merging
- Robust timing and hardware performance support
- Multiple counters (hardware, user-defined, system)
- Performance measurement of I/O and Linux kernel

TAU Measurement Mechanisms

- Parallel profiling
  - Function-level, block-level, statement-level
  - Supports user-defined events and mapping events
  - Support for flat, callgraph/callpath, phase profiling
  - Support for parameter and context profiling
  - Support for tracking I/O and memory (library wrappers)
  - Parallel profile stored (dumped, shapshot) during execution
- Tracing
  - All profile-level events
  - Inter-process communication events
  - Inclusion of multiple counter data in traced events

Types of Parallel Performance Profiling

- Flat profiles
  - Metric (e.g., time) spent in an event (callgraph nodes)
  - Exclusive/inclusive, # of calls, child calls
- Callpath profiles (Calldepth profiles)
  - Time spent along a calling path (edges in callgraph)
  - “main=> f1 => f2 => MPI_Send” (event name)
  - TAU_CALLPATH_DEPTH environment variable
- Phase profiles
  - Flat profiles under a phase (nested phases are allowed)
  - Default “main” phase
  - Supports static or dynamic (per-iteration) phases
  - Phase profiles may be generated from full callpath profiles in paraprof by choosing events as phases

Direct Performance Observation

- Execution actions of interest exposed as events
  - In general, actions reflect some execution state
  - presence at a code location or change in data
  - occurrence in parallelism context (thread of execution)
  - Events encode actions for performance system to observe
- Observation is direct
  - Direct instrumentation of program (system) code (probes)
  - Instrumentation invokes performance measurement
  - Event measurement: performance data, meta-data, context
- Performance experiment
  - Actual events + performance measurements
- Contrast with (indirect) event-based sampling

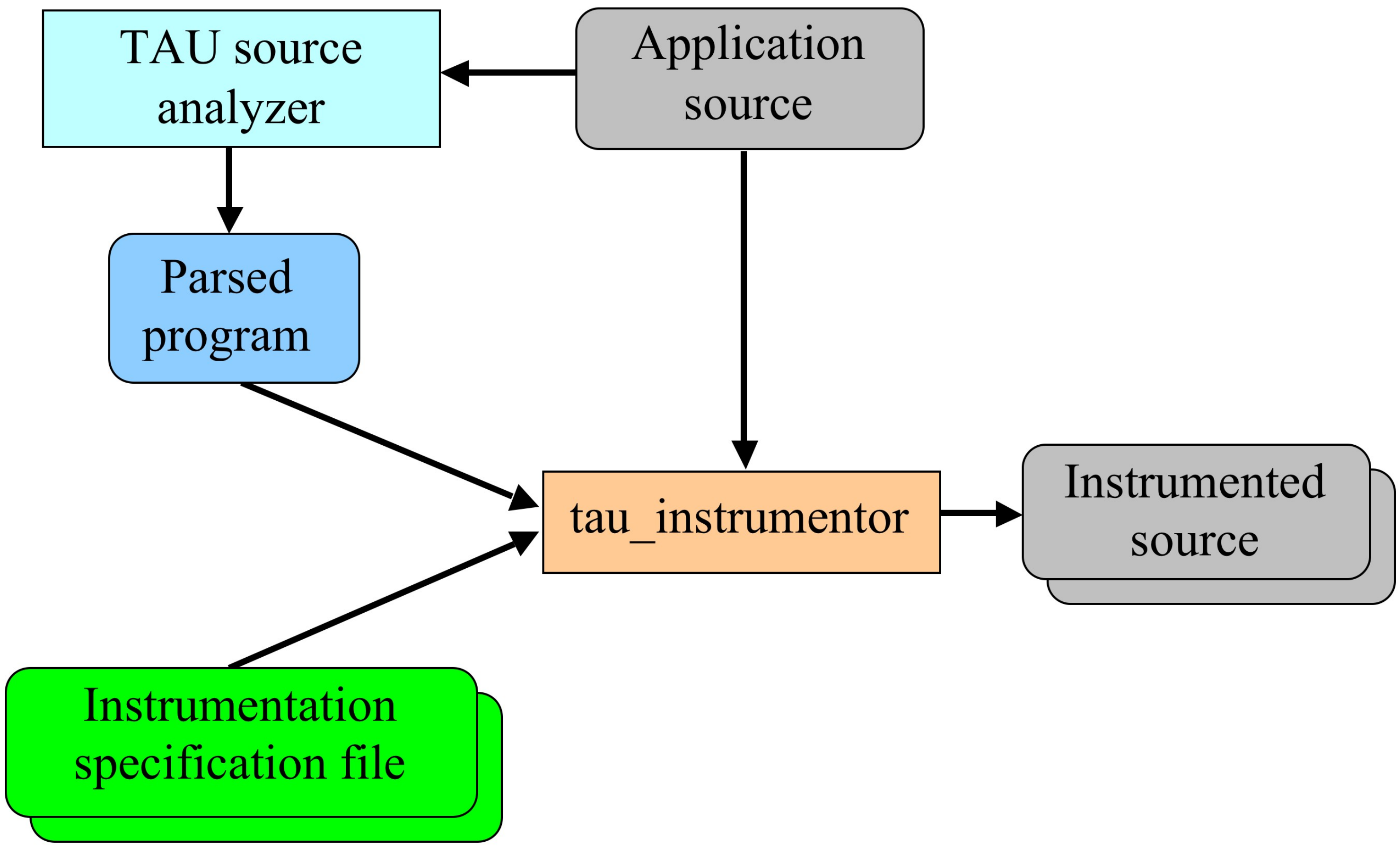
TAU Instrumentation Approach

- Support for standard program events
  - Routines, classes and templates
  - Statement-level blocks
  - Begin/End events (Interval events)
- Support for user-defined events
  - Begin/End events specified by user
  - Atomic events (e.g., size of memory allocated/freed)
  - Flexible selection of event statistics
- Provides static events and dynamic events
- Enables “semantic” mapping
- Specification of event groups (aggregation, selection)
- Instrumentation optimization

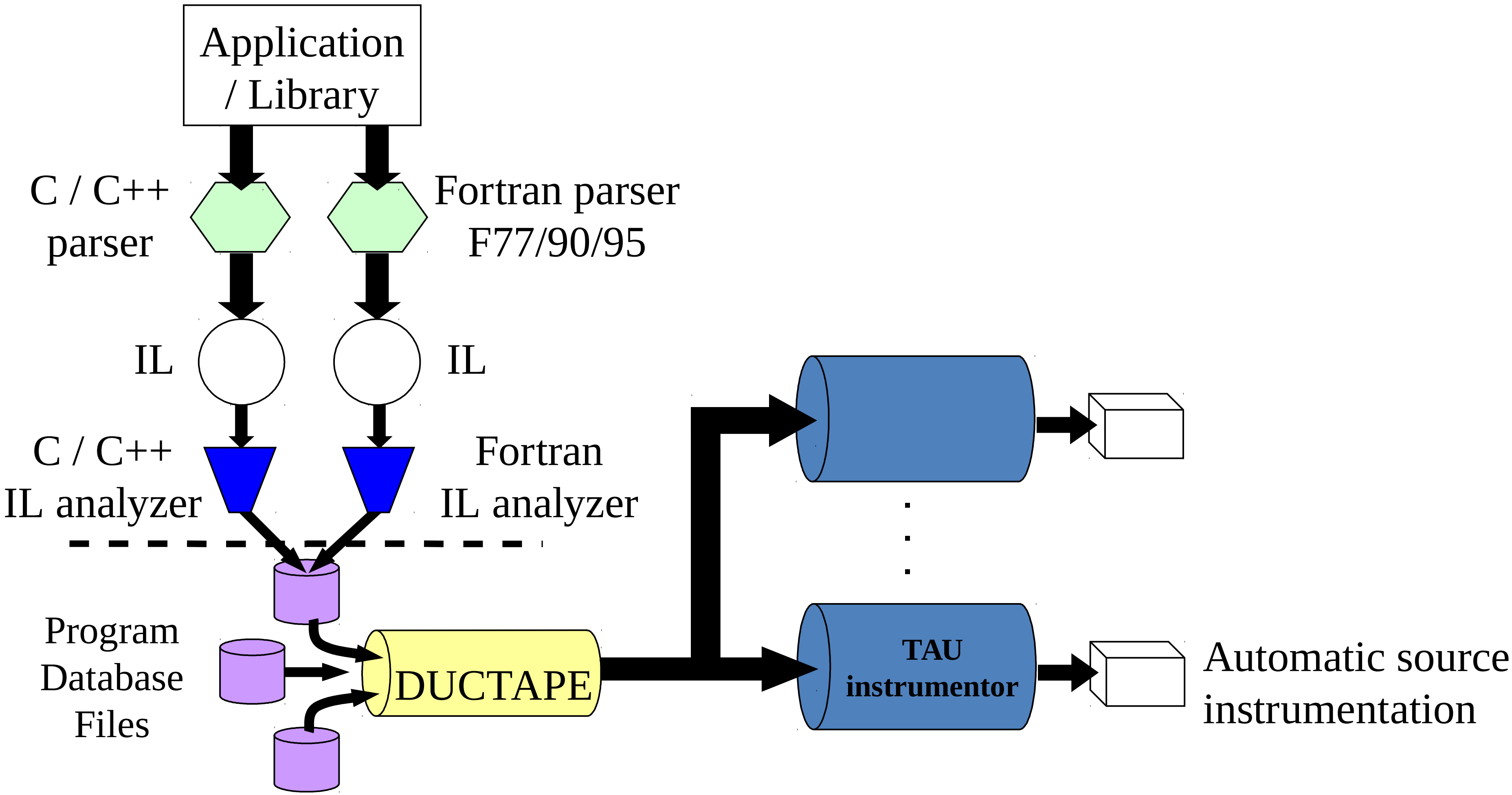
TAU Instrumentation Mechanisms

- Source code
  - Manual (TAU API, TAU component API)
  - Automatic (robust)
  - C, C++, F77/90/95 (Program Database Toolkit (PDT))
  - OpenMP (directive rewriting (Opari), POMP2 spec)
  - Library header wrapping
- Object code
  - Pre-instrumented libraries (e.g., MPI using PMPI)
  - Statically- and dynamically-linked (with LD_PRELOAD)
- Executable code
  - Binary and dynamic instrumentation (Dyninst)
  - Virtual machine instrumentation (e.g., Java using JVMPI)
- TAU_COMPILER to automate instrumentation process

Automatic Source-level Instrumentation



Program Database Toolkit (PDT)



Selective Instrumentation File

- Specify a list of events to exclude or include
- # is a wildcard in a routine name

```
BEGIN_EXCLUDE_LIST
Foo
Bar
D#EMM
END_EXCLUDE_LIST

BEGIN_INCLUDE_LIST
int main(int, char **)
F1
F3
END_INCLUDE_LIST
```

Selective Instrumentation File

- Optionally specify a list of files
- * and ? may be used as wildcard characters

```
BEGIN_FILE_EXCLUDE_LIST
f*.f90
Foo?.cpp
END_FILE_EXCLUDE_LIST
BEGIN_FILE_INCLUDE_LIST
main.cpp
foo.f90
END_FILE_INCLUDE_LIST
```

Selective Instrumentation File

- User instrumentation commands
  - Placed in INSTRUMENT section
  - Routine entry/exit
  - Arbitrary code insertion
  - Outer-loop level instrumentation
  -

```
BEGIN_INSTRUMENT_SECTION
loops file=“foo.f90” routine=“matrix#”
memory file=“foo.f90” routine=“#”
io routine=“matrix#”
[static/dynamic] phase routine=“MULTIPLY”
dynamic [phase/timer] name=“foo” file=“foo.cpp” line=22 to line=35
file=“foo.f90” line = 123 code = "  print *, \" Inside foo\""
exit routine = “int foo()” code = "cout <<\"exiting foo\"<<endl;”
END_INSTRUMENT_SECTION
```

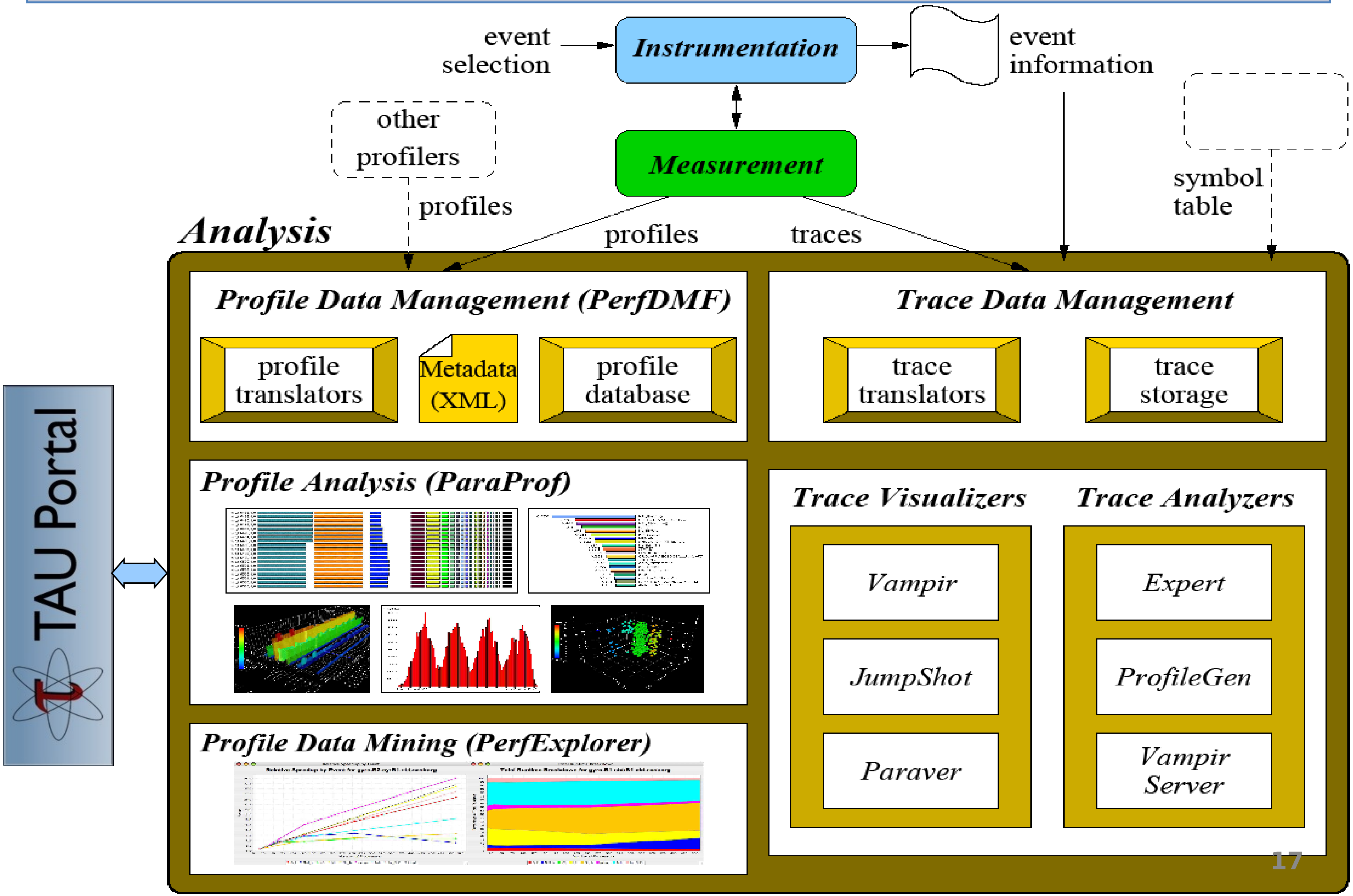
MPI Wrapper Interposition Library

- Uses standard MPI Profiling Interface
  - Provides name shifted interface
  - MPI_Send = PMPI_Send
  - Weak bindings
- Create TAU instrumented MPI library
  - Interpose between MPI and TAU
  - Done during program link
  - -lmpi replaced by –lTauMpi –lpmpi –lmpi
  - No change to the source code!
  - Just re-link application to generate performance data

MPI Shared Library Instrumentation

- Interpose the MPI wrapper library for applications that have already been compiled
  - Avoid re-compilation or re-linking
- Requires shared library MPI
  - Uses LD_PRELOAD for Linux
  - On AIX use MPI_EUILIB / MPI_EUILIBPATH
  - Does not work on XT3
- Approach will work with other shared libraries
- Use TAU tauex
  - % mpirun -np 4 tauex a.out

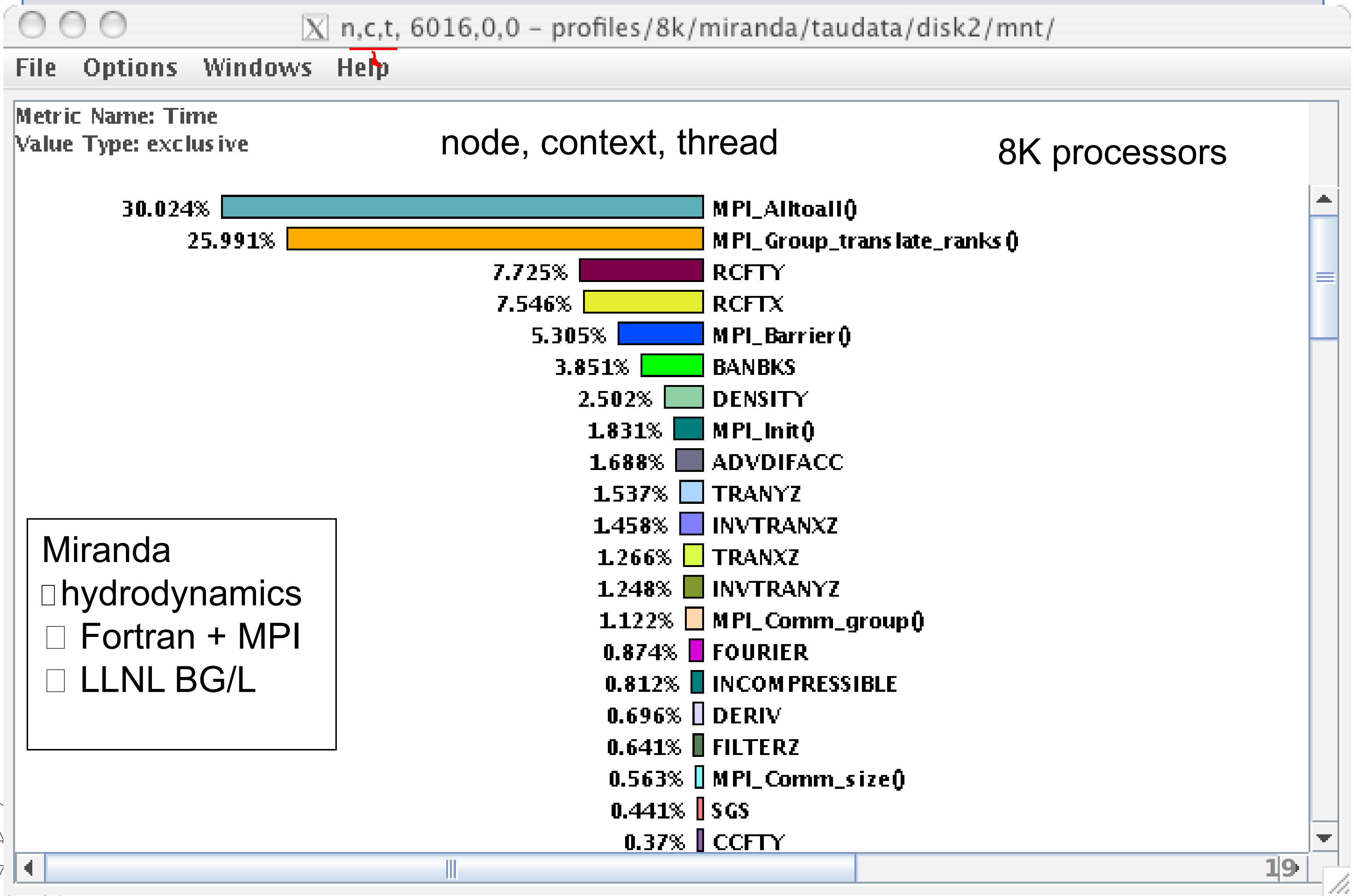
TAU Analysis



Performance Analysis

- Analysis of parallel profile and trace measurement
- Parallel profile analysis (ParaProf)
  - Java-based analysis and visualization tool
  - Support for large-scale parallel profiles
- Performance data management framework (PerfDMF)
- Parallel trace analysis
  - Translation to VTF (V3.0), EPILOG, OTF formats
  - Integration with Vampir / Vampir Server (TU Dresden)
  - Profile generation from trace data
- Online parallel analysis and visualization
- Integration with CUBE browser (Scalasca, UTK / FZJ)

ParaProf – Flat Profile

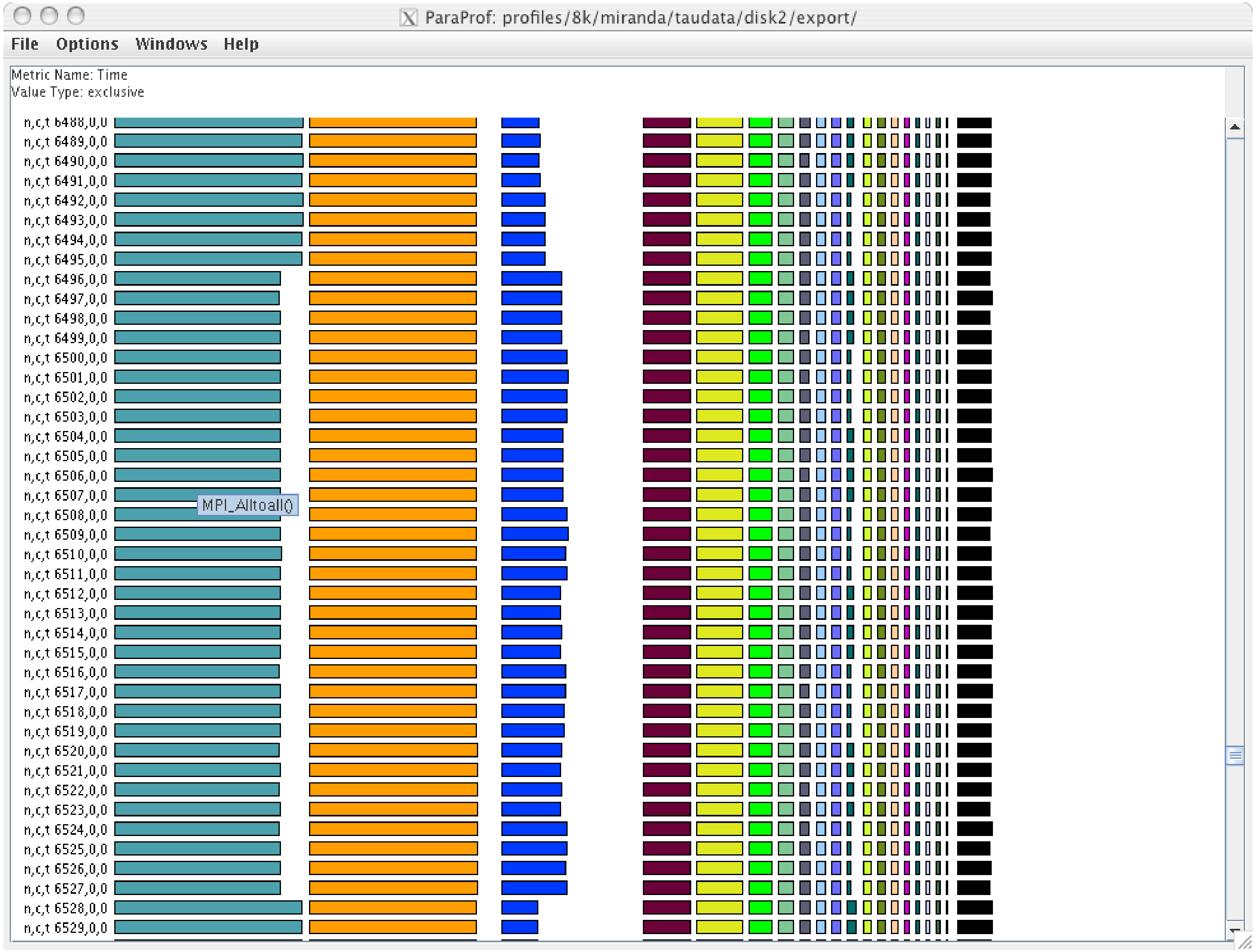


node, context, thread

8K processors

Miranda
- hydrodynamics
- Fortran + MPI
- LLNL BG/L

ParaProf – Stacked View



Interval Events, Atomic Events in TAU

```
xterm
NODE 0;CONTEXT 0;THREAD 0:
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0        0.187        1,105           1          44    1105659 int main(int, char **) C
 93.2        1,030        1,030           1           0    1030654 MPI_Init()
  5.9        0.879           65          40         320       1637 void func(int, int) C
  4.6           51           51          40           0       1277 MPI_Barrier()
  1.2           13           13         120           0        111 MPI_Recv()
  0.8            9            9           1           0       9328 MPI_Finalize()
  0.0        0.137        0.137         120           0          1 MPI_Send()
  0.0        0.086        0.086          40           0          2 MPI_Bcast()
  0.0        0.002        0.002           1           0          2 MPI_Comm_size()
  0.0        0.001        0.001           1           0          1 MPI_Comm_rank()
---------------------------------------------------------------------------------------

USER EVENTS Profile :NODE 0, CONTEXT 0, THREAD 0
---------------------------------------------------------------------------------------
NumSamples   MaxValue   MinValue  MeanValue  Std. Dev.  Event Name
---------------------------------------------------------------------------------------
       365  5.138E+04      44.39   3.09E+04  1.234E+04  Heap Memory Used (KB) : Entry
       365  5.138E+04       2064  3.115E+04   1.21E+04  Heap Memory Used (KB) : Exit
        40         40         40         40          0  Message size for broadcast
---------------------------------------------------------------------------------------
                                                                   27,1          1%
```

Interval event e.g., routines (start/stop)

Atomic events (trigger with value)

% setenv TAU_CALLPATH_DEPTH 0
% setenv TAU_TRACK_HEAP 1

Atomic Events, Context Events

```
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0        0.253        1,106           1         44     1106701 int main(int, char **) C
 93.2        1,031        1,031           1          0     1031311 MPI_Init()
  6.0            1           66          40        320        1650 void func(int, int) C
  5.7           63           63          40          0        1588 MPI_Barrier()
  0.8            9            9           1          0        9119 MPI_Finalize()
  0.1            1            1         120          0          10 MPI_Recv()
  0.0        0.141        0.141         120          0           1 MPI_Send()
  0.0        0.085        0.085          40          0           2 MPI_Bcast()
  0.0        0.001        0.001           1          0           1 MPI_Comm_size()
  0.0            0            0           1          0           0 MPI_Comm_rank()
---------------------------------------------------------------------------------------

USER EVENTS Profile :NODE 0, CONTEXT 0, THREAD 0
---------------------------------------------------------------------------------------
NumSamples   MaxValue   MinValue  MeanValue  Std. Dev.  Event Name
---------------------------------------------------------------------------------------
        40         40         40         40          0  Message size for broadcast
       365  5.139E+04      44.39  3.091E+04  1.234E+04  Heap Memory Used (KB) : Entry
        40  5.139E+04       3097  3.114E+04  1.227E+04  Heap Memory Used (KB) : Entry : MPI_Barrier()
        40  5.139E+04   1.13E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : MPI_Bcast()
         1       2067       2067       2067          0  Heap Memory Used (KB) : Entry : MPI_Comm_rank()
         1       2066       2066       2066          0  Heap Memory Used (KB) : Entry : MPI_Comm_size()
         1  5.139E+04  5.139E+04  5.139E+04  0.0006905  Heap Memory Used (KB) : Entry : MPI_Finalize()
         1      57.56      57.56      57.56          0  Heap Memory Used (KB) : Entry : MPI_Init()
       120  5.139E+04   1.13E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : MPI_Recv()
       120  5.139E+04  1.129E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : MPI_Send()
         1      44.39      44.39      44.39          0  Heap Memory Used (KB) : Entry : int main(int, char **) C
        40  5.036E+04       2068  3.011E+04  1.227E+04  Heap Memory Used (KB) : Entry : void func(int, int) C
                                                                                  4,9          1%
```

Atomic event

Context event = atomic event + executing context

```
% setenv TAU_CALLPATH_DEPTH  1
% setenv TAU_TRACK_HEAP      1
```

Configuring TAU

- TAU can measure several metrics with profiling and tracing approaches
- Different tools can also be invoked to instrument programs for TAU measurement
- Each configuration of TAU produces a measurement library for an architecture
- Each measurement configuration of TAU also creates a corresponding stub makefile that can be used to compile programs
- Typically configure multiple measurement libraries

TAU Measurement Configuration

cd /soft/apps/tau/tau_latest/bgp/lib/; ls Makefile.tau-*

- - Makefile.tau-bgptimers-gnu-mpi-python-pdt
- - Makefile.tau-bgptimers-gnu-papi-mpi-pdt
- - Makefile.tau-bgptimers-gnu-papi-mpi-pdt-openmp-opari
- - Makefile.tau-bgptimers-mpi-pdt...
- For an MPI+F90 application, you may want to start with:
  - Makefile.tau-bgptimers-mpi-pdt
  - Supports MPI instrumentation & PDT for automatic source instrumentation
- export TAU_MAKEFILE=/soft/apps/tau/tau_latest/bgp/lib/Makefile.tau-bgptimers-mpi-pdt

Using TAU: A brief Introduction

- To instrument source code using PDT
  - Choose an appropriate TAU stub makefile in <arch>/lib:

% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64/lib/Makefile.tau-mpi-pdt

% setenv TAU_OPTIONS '-optVerbose …' (see tau_compiler.sh)

And use tau_f90.sh, tau_cxx.sh or tau_cc.sh as Fortran, C++ or C compilers:

% mpif90 foo.f90

changes to

% tau_f90.sh foo.f90

- Execute application and analyze performance data:

% pprof (for text based profile display)

% paraprof (for GUI)

Application Build Environment

- Minimize impact on user's application build procedures
- Handle parsing, instrumentation, compilation, linking
- Dealing with Makefiles
  - Minimal change to application Makefile
  - Avoid changing compilation rules in application Makefile
  - No explicit inclusion of rules for process stages
- Some applications do not use Makefiles
  - Facilitate integration in whatever procedures used
- Two techniques:
  - TAU shell scripts (tau_<compiler>.sh)
  - Invokes all PDT parser, TAU instrumenter, and compiler
  - TAU_COMPILER

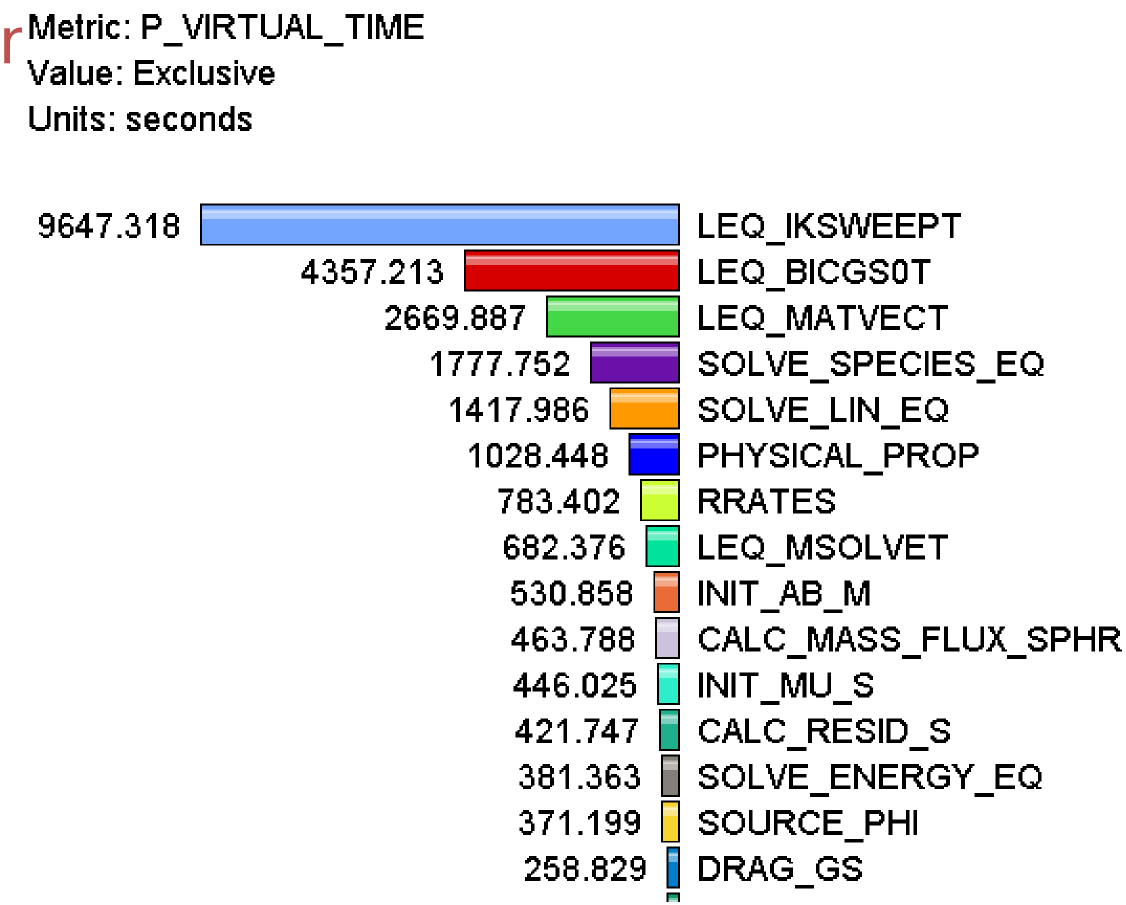
Compile-Time Environment Variables

- Optional parameters for TAU_OPTIONS: [tau_compiler.sh –help]

-optVerbose	Turn on verbose debugging messages
-optCompInst	Use compiler based instrumentation
-optDetectMemoryLeaks	Turn on debugging memory allocations/de-allocations to track leaks
-optKeepFiles	Does not remove intermediate .pdb and .inst.* files
-optPreProcess	Preprocess Fortran sources before instrumentation
-optTauSelectFile=""	Specify selective instrumentation file for tau_instrumentor
-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)
-optTauSelectFile=""	Specify selective instrumentation file for tau_instrumentor
-optNoCompInst	Do not revert to compiler-based instrumentation if source instrumentation fails
-optPdtF95Opts=""	Add options for Fortran parser in PDT (f95parse/gfparse)
-optPdtF95Reset=""	Reset options for Fortran parser in PDT (f95parse/gfparse)
-optPdtCOpts=""	Options for C parser in PDT (cparse). Typically $(TAU_MPI_INCLUDE) $(TAU_INCLUDE) $(TAU_DEFS)
-optPdtCxxOpts=""	Options for C++ parser in PDT (cxxparse). Typically $(TAU_MPI_INCLUDE) $(TAU_INCLUDE) $(TAU_DEFS)

Usage Scenarios: Routine Level Profile

- Goal: What routines account for the most time? How r

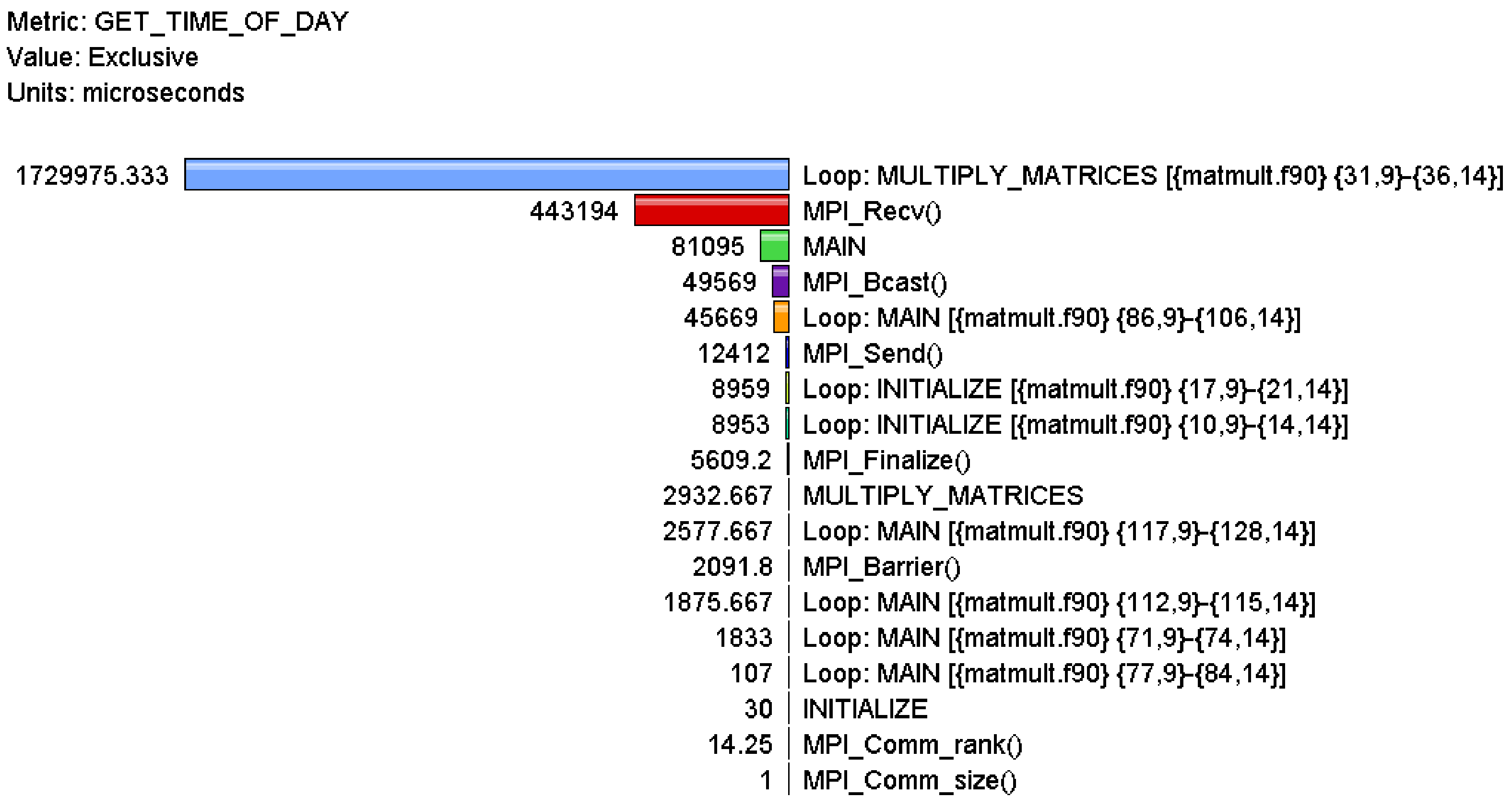


Solution: Generating a flat profile with MPI

```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
                    /lib/Makefile.tau-mpi-pdt
% set path=(/opt/tau-2.19.1/x86_64/bin $path)
Or
% module load tau
% make F90=tau_f90.sh
Or
% tau_f90.sh matmult.f90 -o matmult
(Or edit Makefile and change F90=tau_f90.sh)
% qsub run.job
% paraprof
To view. To view the data locally on the workstation,
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.

% paraprof app.ppk
```

Usage Scenarios: Loop Level Instrumentation

- Goal: What loops account for the most time? How much?
- Flat profile with wallclock time with loop instrumentation:



Solution: Generating a loop level profile

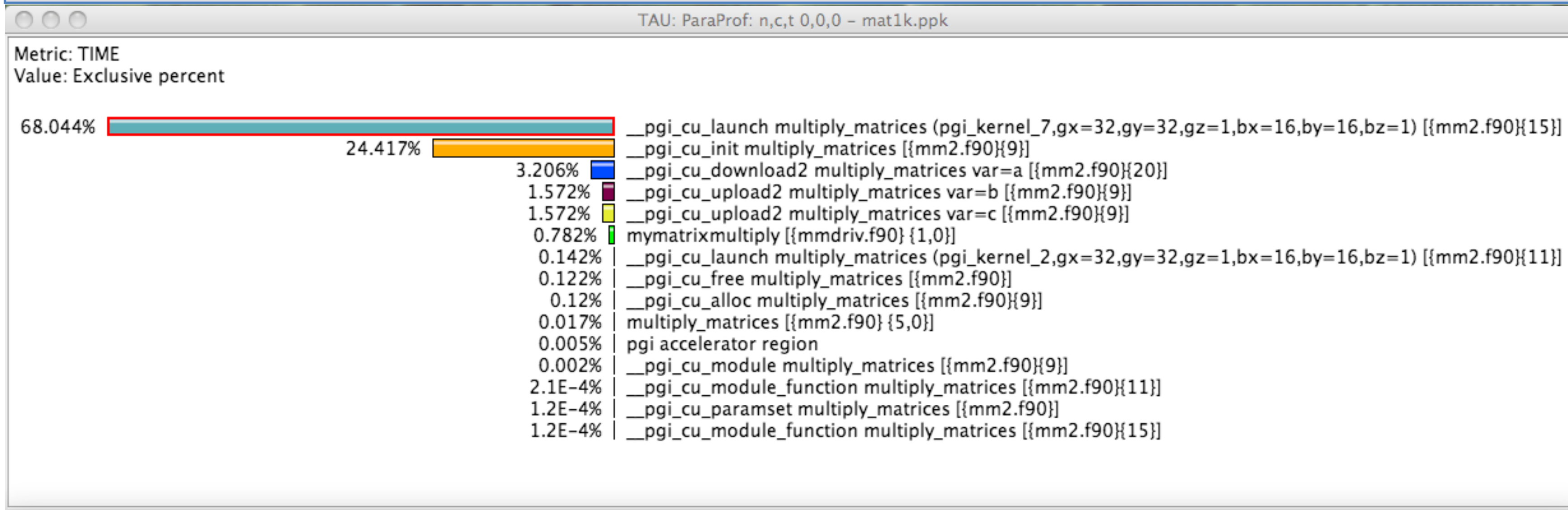
```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
                  /lib/Makefile.tau-mpi-pdt
% setenv TAU_OPTIONS '-optTauSelectFile=select.tau -optVerbose'
% cat select.tau
  BEGIN_INSTRUMENT_SECTION
  loops routine="#"
  END_INSTRUMENT_SECTION

% module load tau
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% qsub  run.job
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.

% paraprof app.ppk
```

Using tau_exec

xterm

```
> cd ~/workshop-point/matmult
> mpif90 matmult.f90 -o matmult
> mpirun -np 4 ./matmult
>
> # To use tau_exec to measure the I/O and memory usage:
> mpirun -np 4 tau_exec -io -memory ./matmult
>
> # To measure memory leaks and get complete callpaths
> setenv TAU_TRACK_MEMORY_LEAKS 1
> setenv TAU_CALLPATH_DEPTH 100
> mpirun -np 4 tau_exec -io -memory ./matmult
> paraprof
> # Right click on a given rank (e.g. "node 2") and choose "Show Context Event
> # Window" and expand the ".TAU Application" node to see the callpath
> # To use a different configuration (e.g., Makefile.tau-papi-mpi-pdt)
> setenv TAU_METRICS TIME:PAPI_FP_INS:PAPI_L1_DCM
> mpirun -np 4 tau_exec -io -memory -T papi,mpi,pdt ./matmult
> # Using tau_exec with DyninstAPI:
> tau_run matmult -o matmult.i
> mpirun -np 4 tau_exec -io -memory ./matmult.i
>
> tau_run -XrunTAUsh-papi-mpi-pdt matmult -o matmult.i
> mpirun -np 4 tau_exec -io -memory -T papi,mpi,pdt ./matmult.i
> paraprof
```

Measuring Performance of PGI Accelerator Code



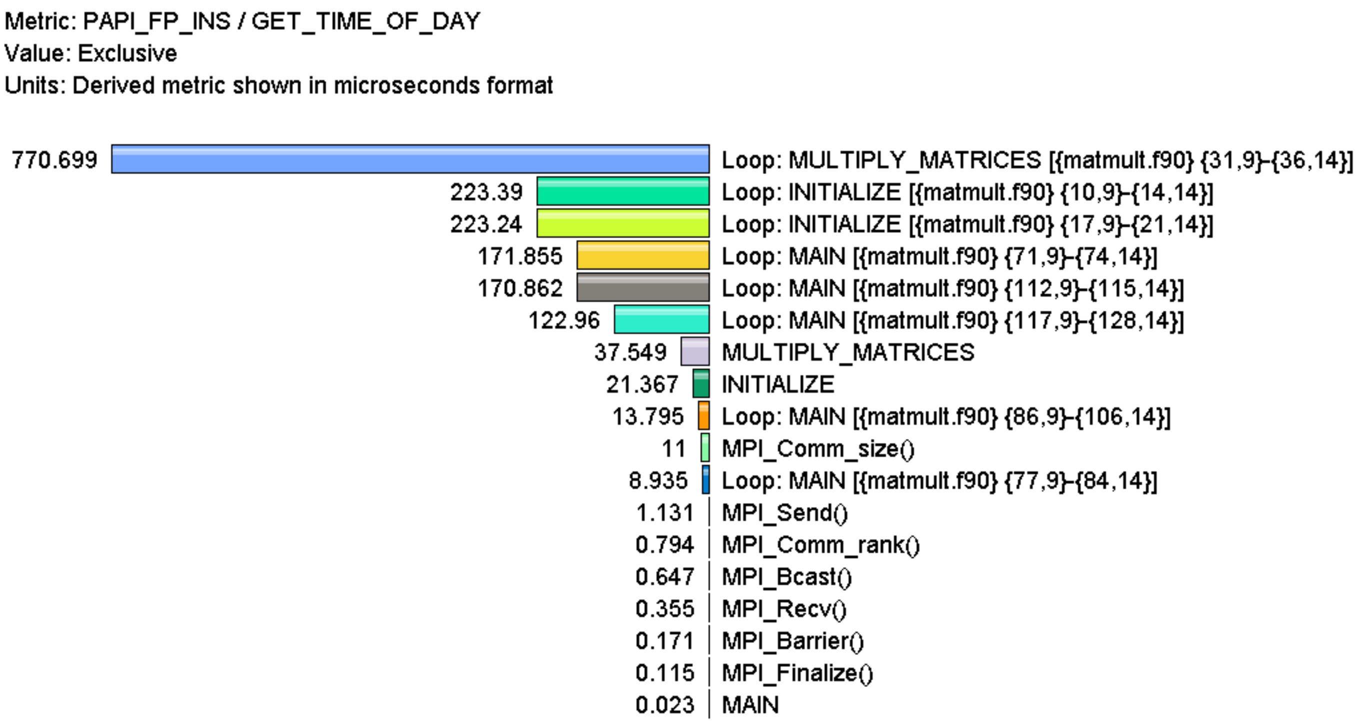
TAU: ParaProf: Thread Statistics: n,c,t, 0,0,0 – mat1k.ppk

Name	Exclusive TIME ▽	Inclusive TIME	Calls	Child Calls
__pgi_cu_launch multiply_matrices (pgi_kernel_7,gx=32,gy=32,gz=1,bx=16,by=16,bz=1) [{mm2.f90}{15}]	10.901	10.901	5	0
__pgi_cu_init multiply_matrices [{mm2.f90}{9}]	3.912	3.912	5	0
__pgi_cu_download2 multiply_matrices var=a [{mm2.f90}{20}]	0.514	0.514	5	0
__pgi_cu_upload2 multiply_matrices var=b [{mm2.f90}{9}]	0.252	0.252	5	0
__pgi_cu_upload2 multiply_matrices var=c [{mm2.f90}{9}]	0.252	0.252	5	0
mymatrixmultiply [{mmdriv.f90} {1,0}]	0.125	16.021	1	1
__pgi_cu_launch multiply_matrices (pgi_kernel_2,gx=32,gy=32,gz=1,bx=16,by=16,bz=1) [{mm2.f90}{11}]	0.023	0.023	5	0
__pgi_cu_free multiply_matrices [{mm2.f90}]	0.02	0.02	15	0
__pgi_cu_alloc multiply_matrices [{mm2.f90}{9}]	0.019	0.019	15	0
multiply_matrices [{mm2.f90} {5,0}]	0.003	15.895	5	9
pgi accelerator region	0.001	15.893	5	85
__pgi_cu_module multiply_matrices [{mm2.f90}{9}]	0	0	5	0
__pgi_cu_module_function multiply_matrices [{mm2.f90}{11}]	0	0	5	0
__pgi_cu_paramset multiply_matrices [{mm2.f90}]	0	0	10	0

Show Source Code
Show Function Bar Chart
Show Function Histogram
Assign Function Color
Reset to Default Color

Usage Scenarios: MFlops in Loops

- Goal: What execution rate do my application loops get in mflops?
- Flat profile with PAPI_FP_INS/OPS and time (-papi) with

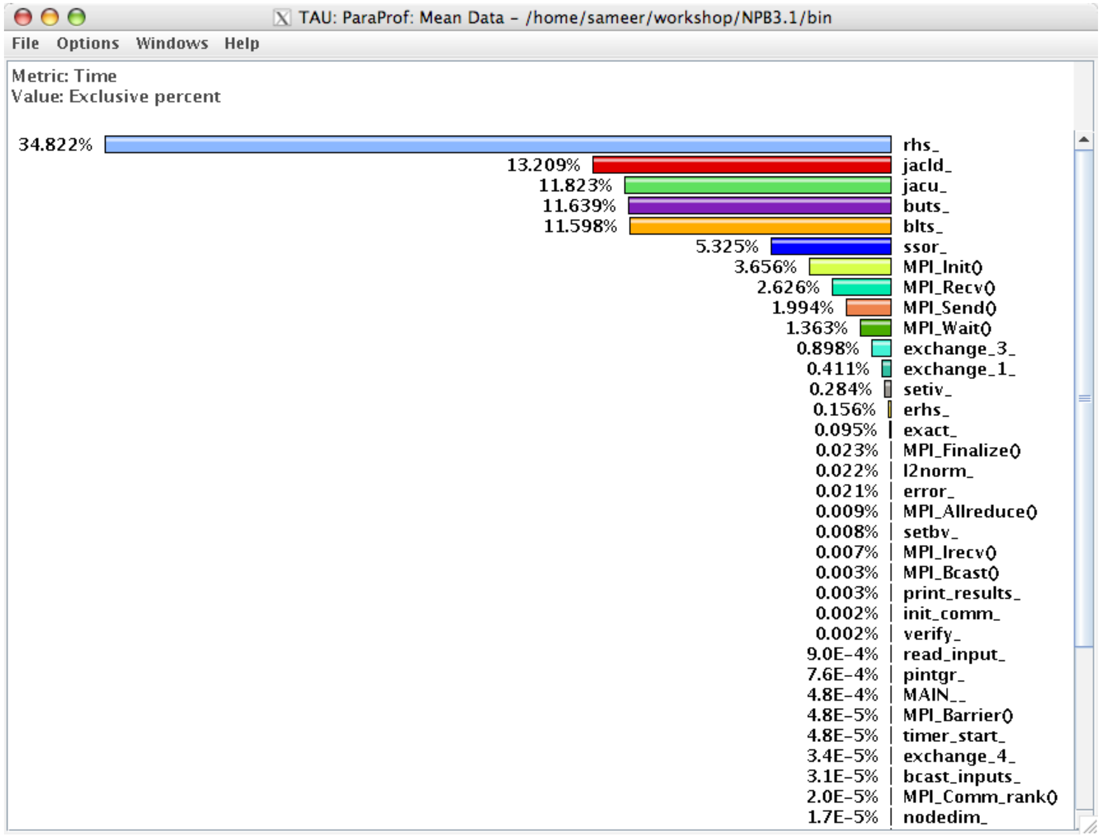


Generate a PAPI profile with 2 or more counters

```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
          /lib/Makefile.tau-papi-mpi-pdt
% setenv TAU_OPTIONS '-optTauSelectFile=select.tau –optVerbose'
% cat select.tau
  BEGIN_INSTRUMENT_SECTION
  loops routine="#"
  END_INSTRUMENT_SECTION

% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% setenv TAU_METRICS TIME:PAPI_FP_INS
% qsub  run.job
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
  Choose Options -> Show Derived Panel -> Arg 1 = PAPI_FP_INS,
 Arg 2 = GET_TIME_OF_DAY, Operation = Divide -> Apply, choose.
```

Usage Scenarios: Compiler-based Instrumentation

- Goal: Easily generate routine level performance data using the compiler instead of PDT for parsing the source code



Use Compiler-Based Instrumentation

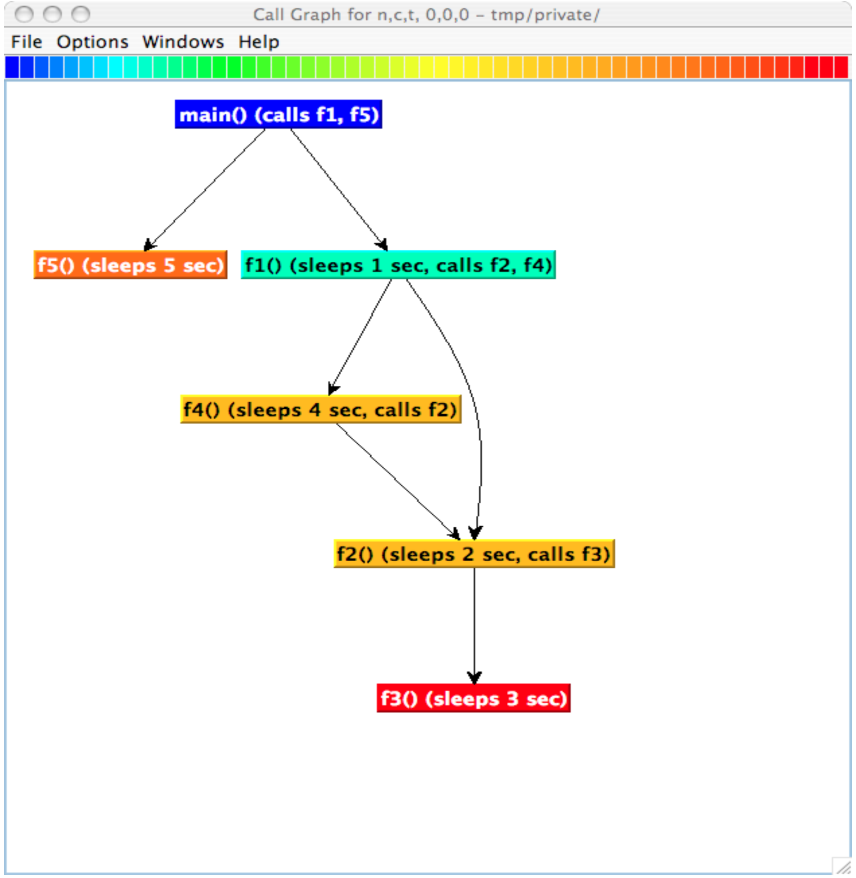
```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
  /lib/Makefile.tau-mpi-pdt
% setenv TAU_OPTIONS '-optCompInst -optVerbose'
% module load tau
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)


% qsub  run.job
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
```

-PROFILECALLPATH Option

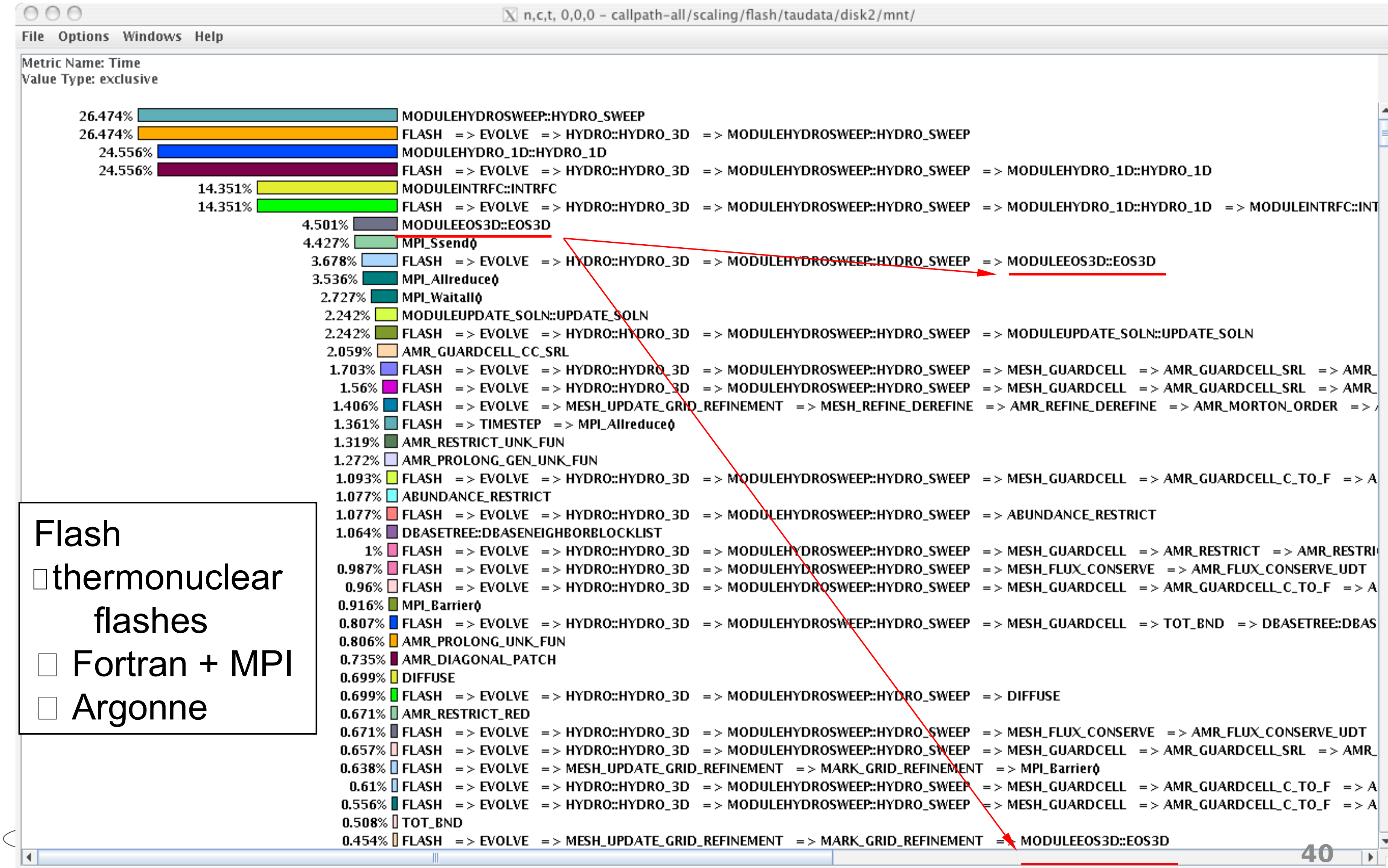
- Generates profiles that show the calling order (edges and nodes in callgraph)
  - A=>B=>C shows the time spent in C when it was called by B and B was called by A
  - Control the depth of callpath using TAU_CALLPATH_DEPTH environment variable
  - -callpath in the name of the stub Makefile name or setting TAU_CALLPATH= 1 at runtime (TAU v2.18.1+)

Callpath Profile

- Generates program callgraph



ParaProf – Callpath Profile



Flash
- thermonuclear flashes
- Fortran + MPI
- Argonne

Generate a Callpath Profile

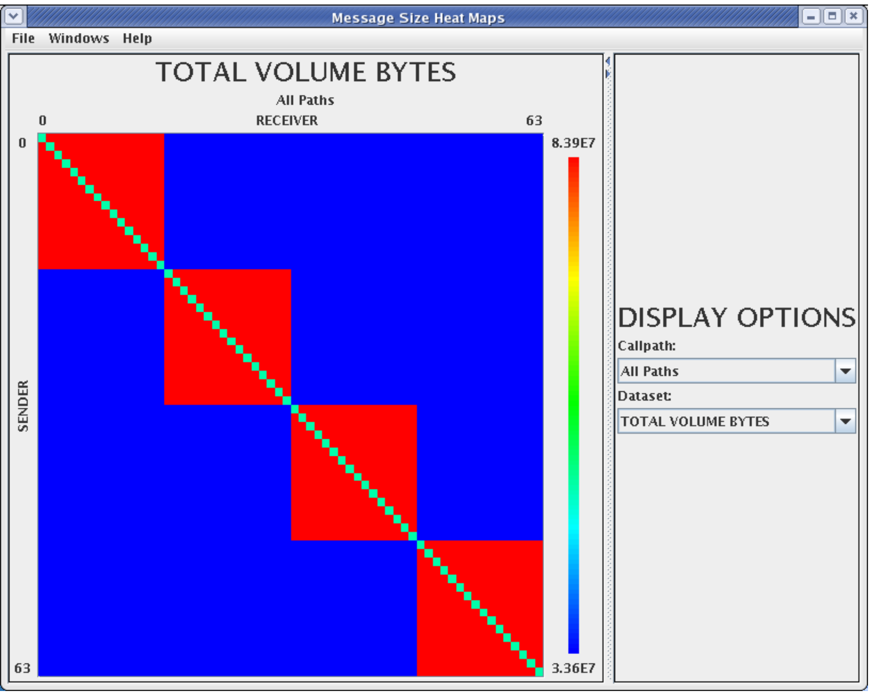
```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
           /lib/Makefile.tau-mpi-pdt
% set path=(/opt/tau-2.19.1/x86_64/bin $path)
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% setenv TAU_CALLPATH 1
% setenv TAU_CALLPATH_DEPTH 100


to generate the callpath profiles without any recompilation.
% qsub  run.job
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
(Windows -> Thread -> Call Graph)
```

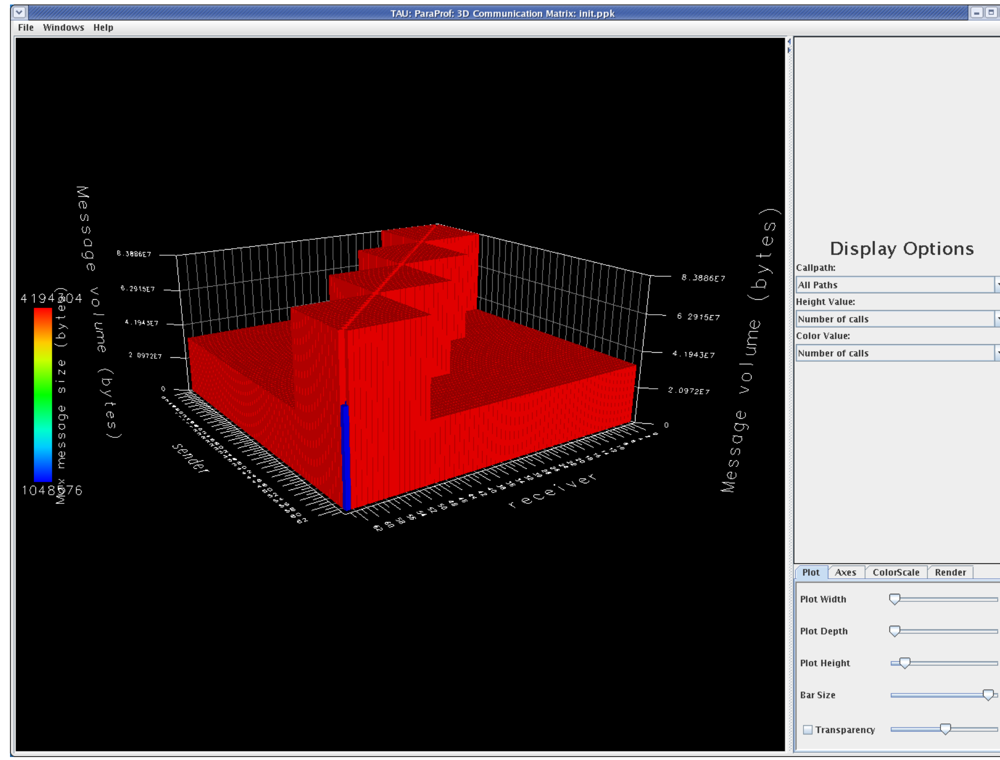
-DEPTHLIMIT Option

- Allows users to enable instrumentation at runtime based on the depth of a calling routine on a callstack
  - Disables instrumentation in all routines a certain depth away from the root in a callgraph
- TAU_DEPTH_LIMIT environment variable specifies depth
  - % setenv TAU_DEPTH_LIMIT 1
  - enables instrumentation in only “main”
  - % setenv TAU_DEPTH_LIMIT 2
  - enables instrumentation in main and routines that are directly called by main
- Stub makefile has -depthlimit in its name:
  - setenv TAU_MAKEFILE <taudir>/<arch>/lib/Makefile.tau-mpi-depthlimit-pdt

Communication Matrix Display

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

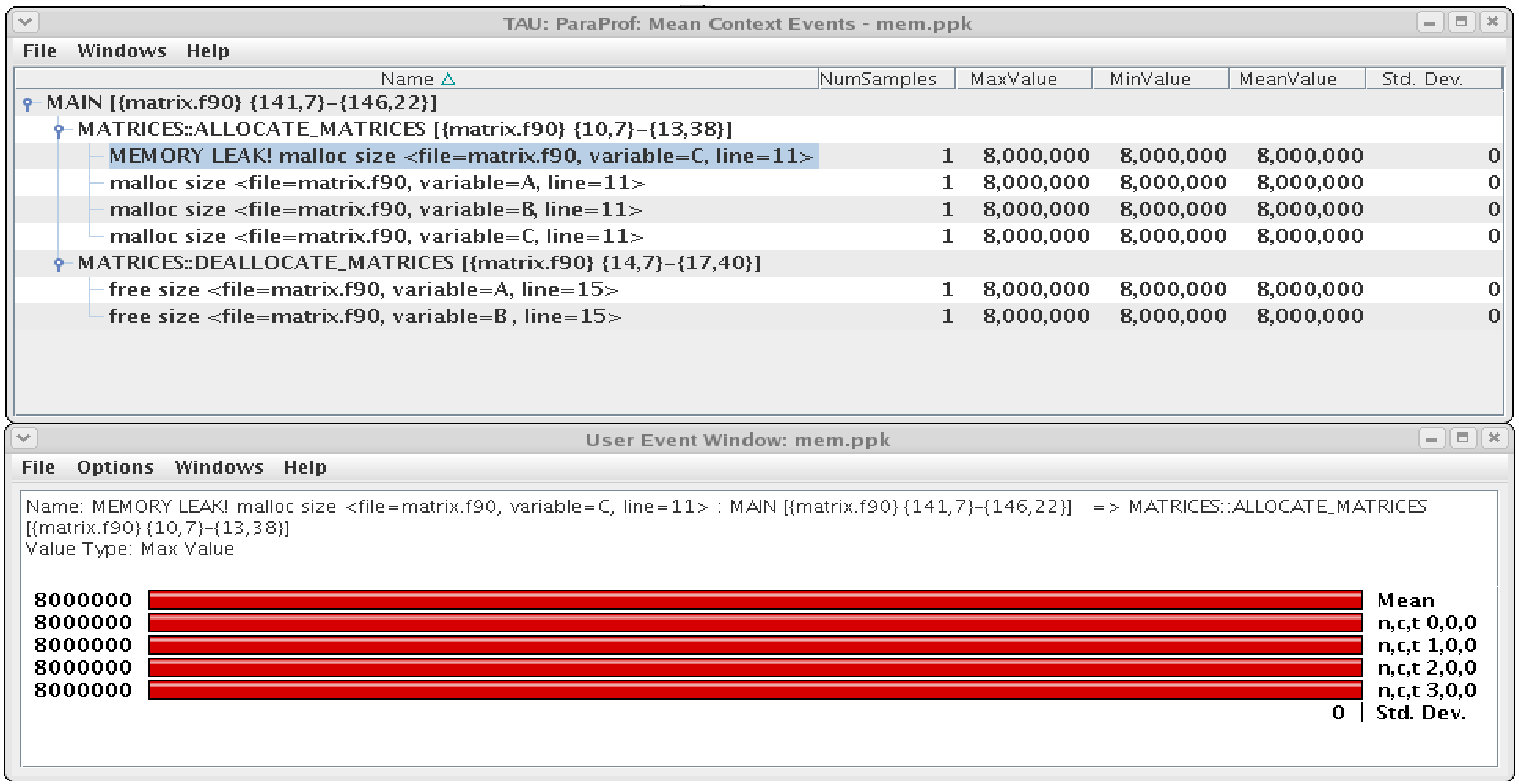




Communication Matrix Profiles

```
% export TAU_MAKEFILE    =    $TAU/Makefile.tau-mpi-pdt
% export PATH=/usr/local/packages/tau-2.19.1/x86_64/bin=$PATH
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% export TAU_COMM_MATRIX = 1

% qsub run.job (setting the environment variables)

% paraprof
(Windows -> Communication Matrix)
(Windows -> 3D Communication Matrix)
```

Usage Scenario: Detect Memory Leaks

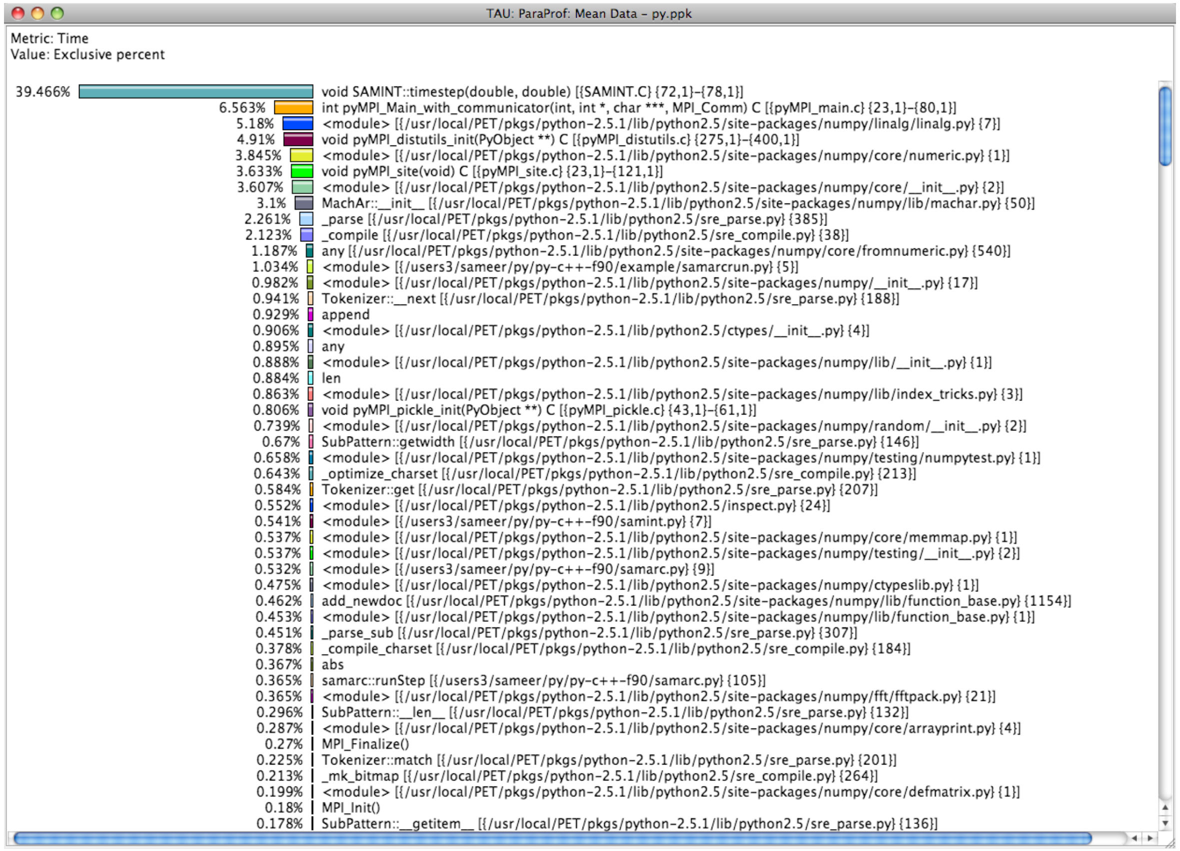


Detect Memory Leaks

```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64   /lib/Makefile.tau-mpi-pdt
% setenv TAU_OPTIONS '-optDetectMemoryLeaks -optVerbose'
% module load tau
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% setenv TAU_CALLPATH_DEPTH 100


% qsub  run.job
% paraprof --pack app.ppk
      Move the app.ppk file to your desktop.
% paraprof app.ppk
(Windows -> Thread -> Context Event Window -> Select thread -> select...
    expand tree)
(Windows -> Thread -> User Event Bar Chart -> right click LEAK
-> Show User Event Bar Chart)
NOTE: setenv TAU_TRACK_HEAP 1 and setenv TAU_TRACK_HEADROOM 1 may be used to track
heap and headroom utilization at the entry and exit of each routine.
TAU_CALLPATH_DEPTH=1 shows just the routine name, and 0 shows just one event for the
entire program.
```

Usage Scenarios: Mixed Python+F90+C+pyMPI

- Goal: Generate multi-level instrumentation for Python+MPI+C+F90+C++ ...



Generate a Multi-Language Profile w/ Python

```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
              /lib/Makefile.tau-python-mpi-pdt
% set path=(/opt/tau-2.19.1/x86_64/bin $path)
% setenv TAU_OPTIONS '-optShared -optVerbose…'
(Python needs shared object based TAU library)
% make F90=tau_f90.sh CXX=tau_cxx.sh CC=tau_cc.sh  (build pyMPI w/TAU)
% cat wrapper.py
  import tau
  def OurMain():
      import App
  tau.run('OurMain()')
Uninstrumented:
% poe <dir>/pyMPI-2.4b4/bin/pyMPI ./App.py -procs 4
Instrumented:
% setenv PYTHONPATH <taudir>/x86_64/lib/bindings-python-mpi-pdt-pgi
(same options string as TAU_MAKEFILE)
setenv LD_LIBRARY_PATH <taudir>/x86_64/lib/bindings-icpc-python-mpi-pdt-pgi\:
$LD_LIBRARY_PATH
% poe <dir>/pyMPI-2.5b0-TAU/bin/pyMPI ./wrapper.py -procs 4
(Instrumented pyMPI with wrapper.py)
```

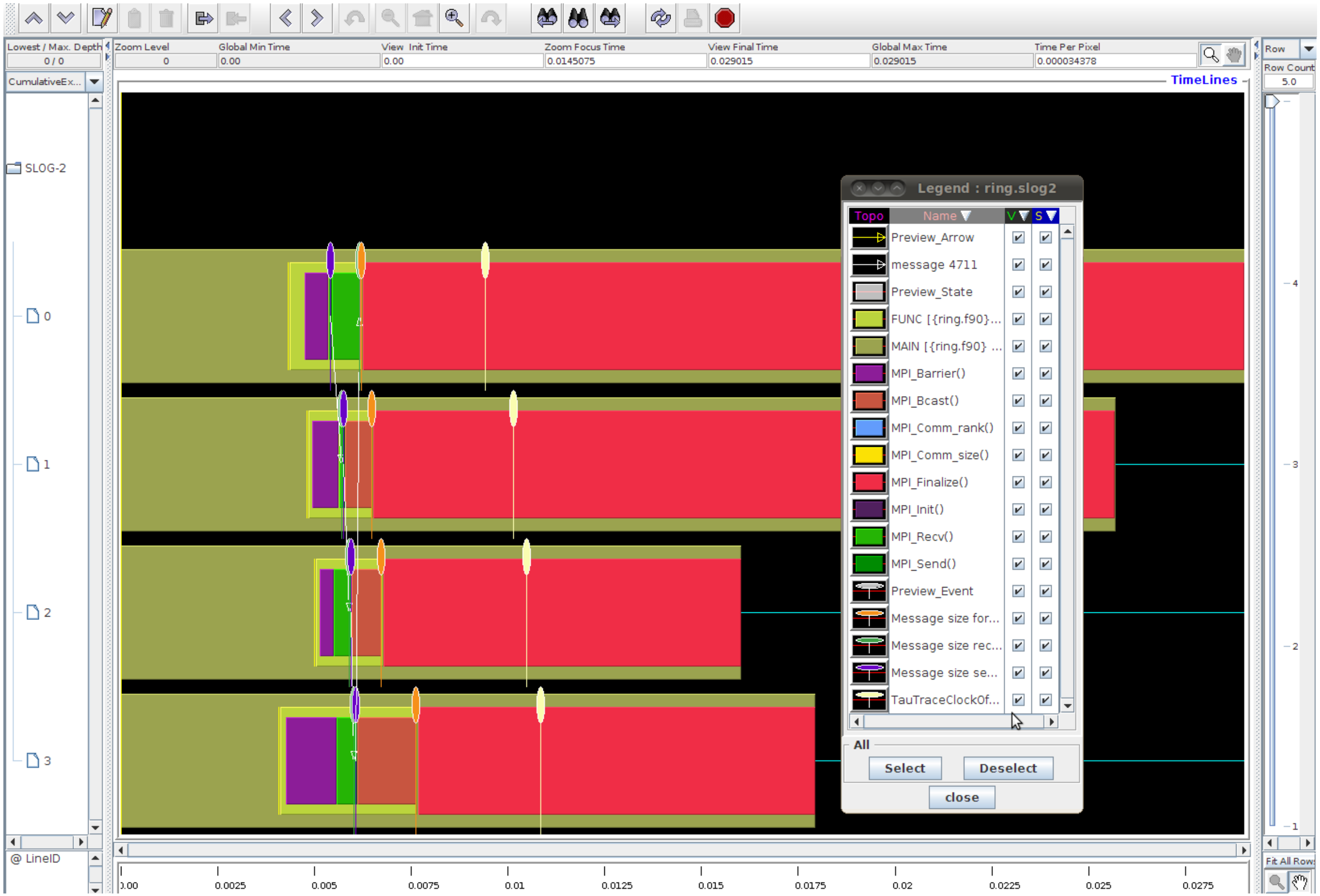
Tracing in TAU

- Generates event-trace logs, rather than summary profiles
  - setenv TAU_TRACE 1
- Traces show when and where an event occurred in terms of location and the process that executed it
- Traces from multiple processes are merged:
  - % tau_treemerge.pl
  - generates tau.trc and tau.edf as merged trace and event definition file
- TAU traces can be converted to Vampir's OTF/VTF3, Jumpshot SLOG2, Paraver trace formats:
  - % tau2otf tau.trc tau.edf app.otf
  - % tau2vtf tau.trc tau.edf app.vpt.gz
  - % tau2slog2 tau.trc tau.edf -o app.slog2
  - % tau_convert -paraver tau.trc tau.edf app.prv

Generate a Trace File

```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
           /lib/Makefile.tau-mpi-pdt
% set path=(/opt/tau-2.19.1/x86_64/bin $path)
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% setenv TAU_TRACE 1
% qsub  run.job
% tau_treemerge.pl
(merges binary traces to create tau.trc and tau.edf files)
JUMPSHOT:
% tau2slog2 tau.trc tau.edf -o app.slog2
% jumpshot app.slog2
   OR
VAMPIR:
% tau2otf tau.trc tau.edf app.otf -n 4 -z
(4 streams, compressed output trace)
% vampir app.otf
(or vng client with vngd server)
```

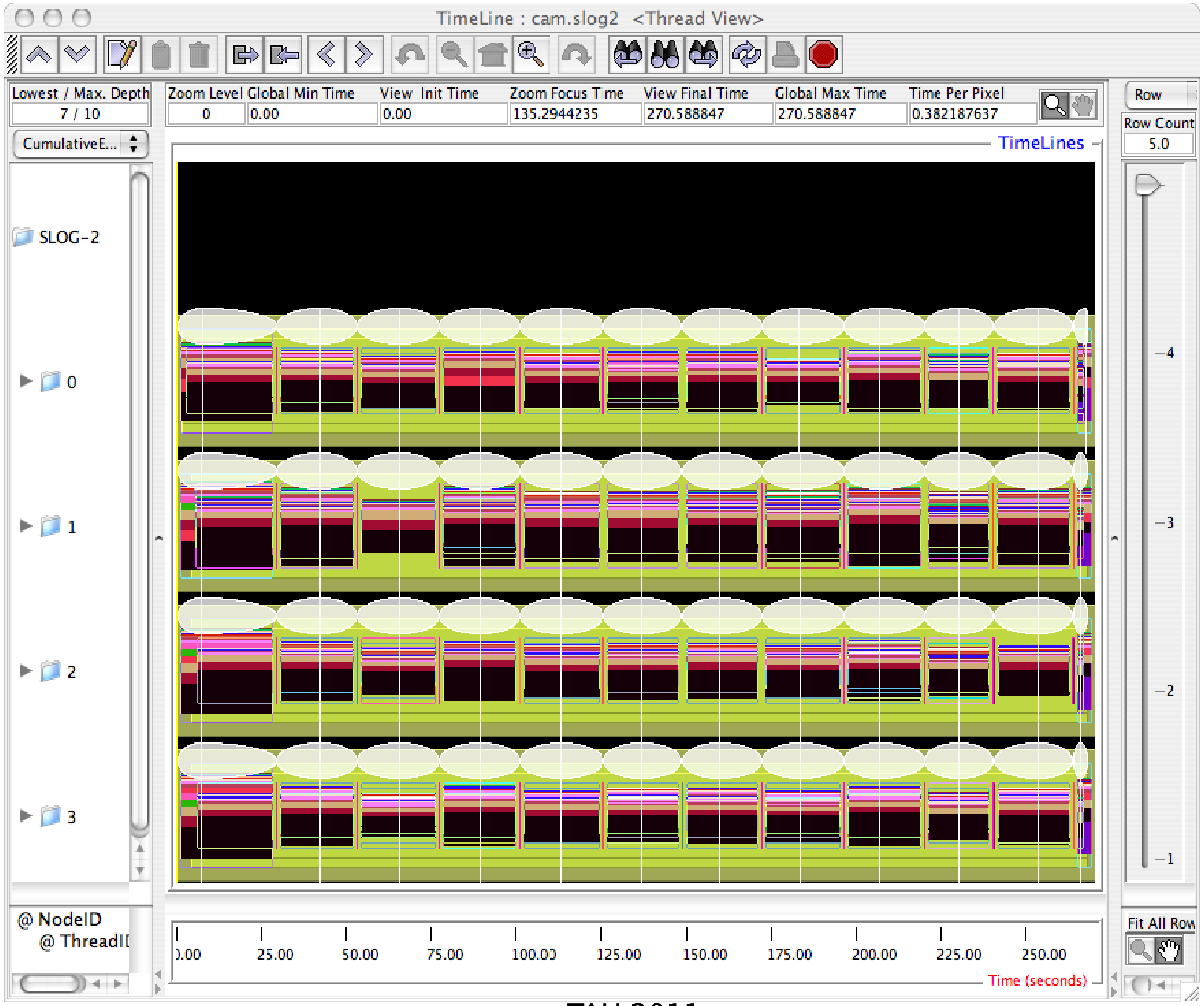
Trace Visualization



Jumpshot

- http://www-unix.mcs.anl.gov/perfvis/software/viewers/index.htm
- Developed at Argonne National Laboratory as part of the MPICH project
  - Also works with other MPI implementations
  - Installed on IBM BG/P
  - Jumpshot is bundled with the TAU package
- Java-based tracefile visualization tool for postmortem performance analysis of MPI programs
- Latest version is Jumpshot-4 for SLOG-2 format
  - Scalable level of detail support
  - Timeline and histogram views
  - Scrolling and zooming
  - Search/scan facility

Jumpshot


TimeLine : cam.slog2 <Thread View>
Lowest / Max. Depth
7 / 10
Zoom Level
0
Global Min Time
0.00
View Init Time
0.00
Zoom Focus Time
135.2944235
View Final Time
270.588847
Global Max Time
270.588847
Time Per Pixel
0.382187637
Row
Row Count
5.0
CumulativeE...
TimeLines
SLOG-2
0
1
2
3
@ NodeID
@ ThreadID
4
3
2
1
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
250.00
Time (seconds)
Fit All Row

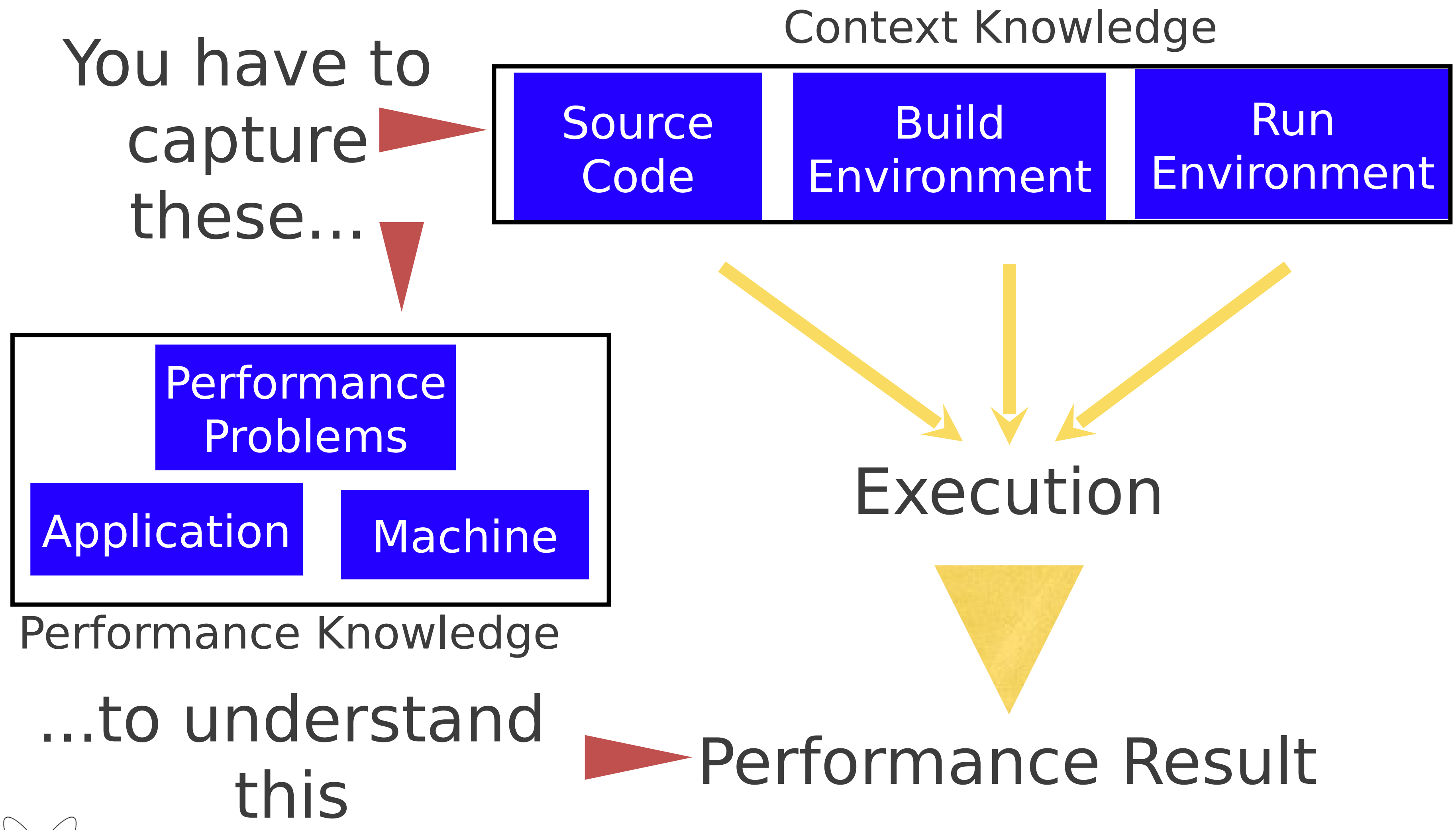
Environment Variables in TAU

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_HEAP or TAU_TRACK_HEADROOM	0	Setting to 1 turns on tracking heap memory/headroom at routine entry & exit using context events (e.g., Heap at Entry: main=>foo=>bar)
TAU_CALLPATH_DEPTH	2	Specifies depth of callpath.
TAU_SYNCHRONIZE_CLOCKS	1	Synchronize clocks across nodes to correct timestamps in traces
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 separted list generates other metrics. (e.g., TIME:linuxtimers:PAPI_FP_OPS:PAPI_NATIVE_<event>)

How to explain performance?

- Should not just redescribe the performance results
- Should explain performance phenomena
  - What are the causes for performance observed?
  - What are the factors and how do they interrelate?
  - Performance analytics, forensics, and decision support
- Need to add knowledge to do more intelligent things
  - Automated analysis needs good informed feedback
  - iterative tuning, performance regression testing
  - Performance model generation requires interpretation
- We need better methods and tools for
  - Integrating meta-information
  - Knowledge-based performance problem solving

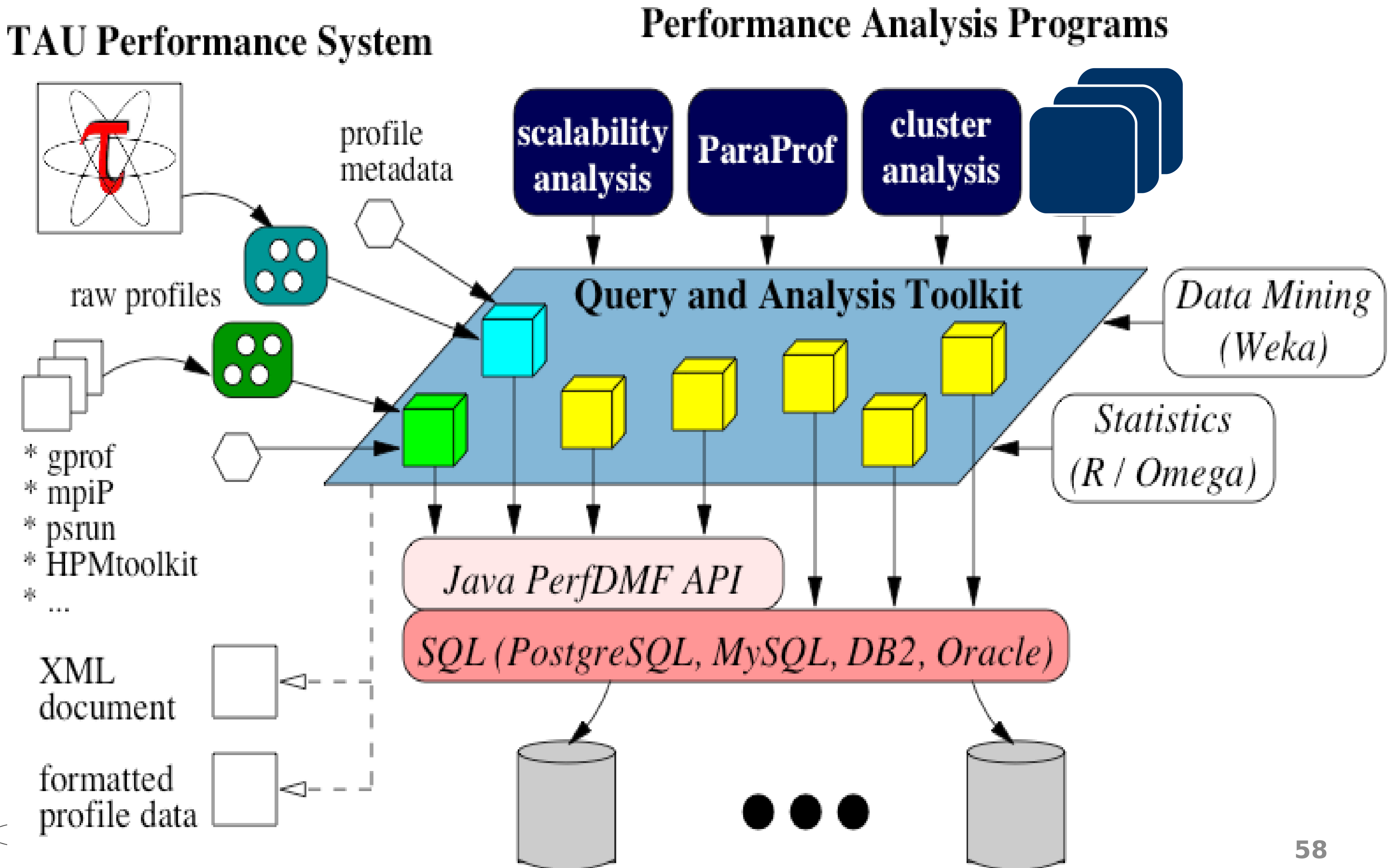
Role of Metadata and Knowledge Role



Performance Data Management

- Provide an open, flexible framework to support common data management tasks
  - Foster multi-experiment performance evaluation
- Extensible toolkit to promote integration and reuse across available performance tools (PerfDMF)
  - Originally designed to address critical TAU requirements
  - Supported profile formats:
    TAU, CUBE (Scalasca), HPC Toolkit (Rice), HPM Toolkit (IBM), gprof, mpiP, psrun (PerfSuite), Open|SpeedShop, ...
  - Supported DBMS:
    PostgreSQL, MySQL, Oracle, DB2, Derby/Cloudscape
  - Profile query and analysis API
- Reference implementation for PERI-DB project

PerfDMF Architecture



Metadata Collection

- Integration of XML metadata for each parallel profile
- Three ways to incorporate metadata
  - Measured hardware/system information (TAU, PERI-DB)
  - CPU speed, memory in GB, MPI node IDs, …
  - Application instrumentation (application-specific)
  - TAU_METADATA() used to insert any name/value pair
  - Application parameters, input data, domain decomposition
  - PerfDMF data management tools can incorporate an XML file of additional metadata
  - Compiler flags, submission scripts, input files, …
- Metadata can be imported from / exported to PERI-DB

Parallel Profile Analysis – pprof

emacs@neutron.cs.uoregon.edu

Buffers Files Tools Edit Search Mule Help

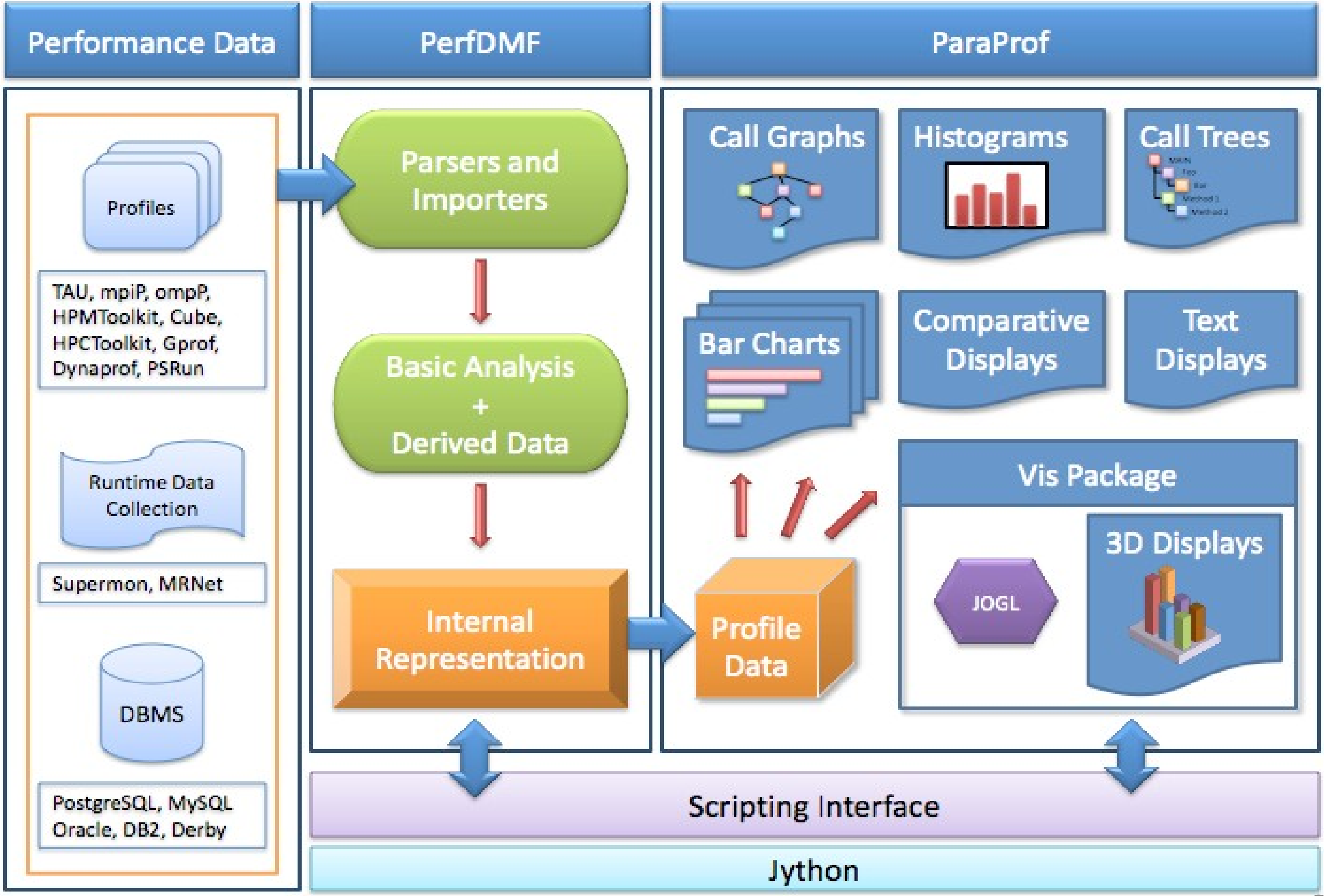
Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:

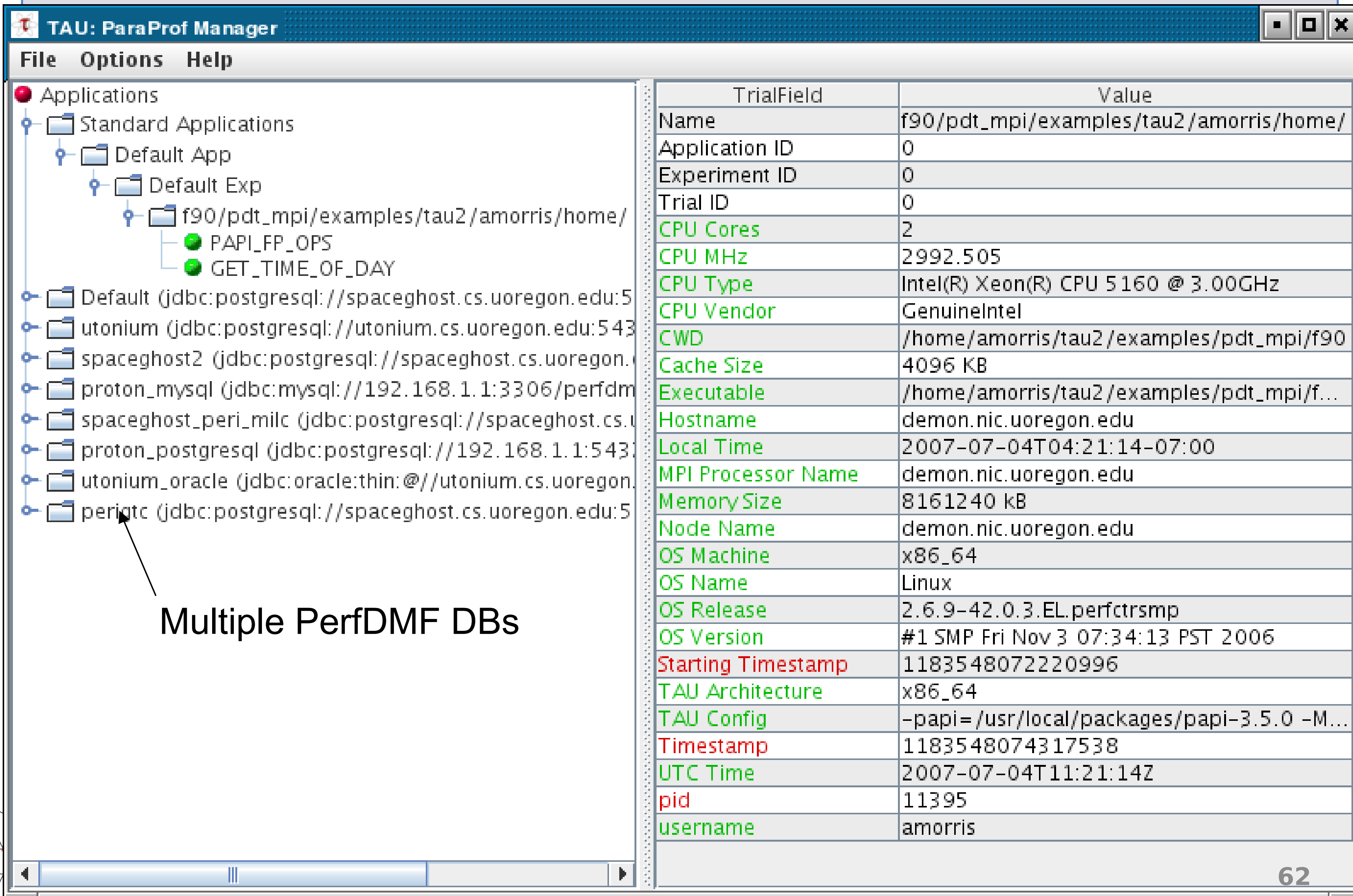
%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	1	3:11.293	1	15	191293269	applu
99.6	3,667	3:10.463	3	37517	63487925	bcast_inputs
67.1	491	2:08.326	37200	37200	3450	exchange_1
44.5	6,461	1:25.159	9300	18600	9157	buts
41.0	1:18.436	1:18.436	18600	0	4217	MPI_Recv()
29.5	6,778	56,407	9300	18600	6065	blts
26.2	50,142	50,142	19204	0	2611	MPI_Send()
16.2	24,451	31,031	301	602	103096	rhs
3.9	7,501	7,501	9300	0	807	jacld
3.4	838	6,594	604	1812	10918	exchange_3
3.4	6,590	6,590	9300	0	709	jacu
2.6	4,989	4,989	608	0	8206	MPI_Wait()
0.2	0.44	400	1	4	400081	init_comm
0.2	398	399	1	39	399634	MPI_Init()
0.1	140	247	1	47616	247086	setiv
0.1	131	131	57252	0	2	exact
0.1	89	103	1	2	103168	erhs
0.1	0.966	96	1	2	96458	read_input
0.0	95	95	9	0	10603	MPI_Bcast()
0.0	26	44	1	7937	44878	error
0.0	24	24	608	0	40	MPI_Irecv()
0.0	15	15	1	5	15630	MPI_Finalize()
0.0	4	12	1	1700	12335	setbv
0.0	7	8	3	3	2893	l2norm
0.0	3	3	8	0	491	MPI_Allreduce()
0.0	1	3	1	6	3874	pintgr
0.0	1	1	1	0	1007	MPI_Barrier()
0.0	0.116	0.837	1	4	837	exchange_4
0.0	0.512	0.512	1	0	512	MPI_Keyval_create()
0.0	0.121	0.353	1	2	353	exchange_5
0.0	0.024	0.191	1	2	191	exchange_6
0.0	0.103	0.103	6	0	17	MPI_Type_contiguous()

--:-- NPB_LU.out (Fundamental)--L8--Top--

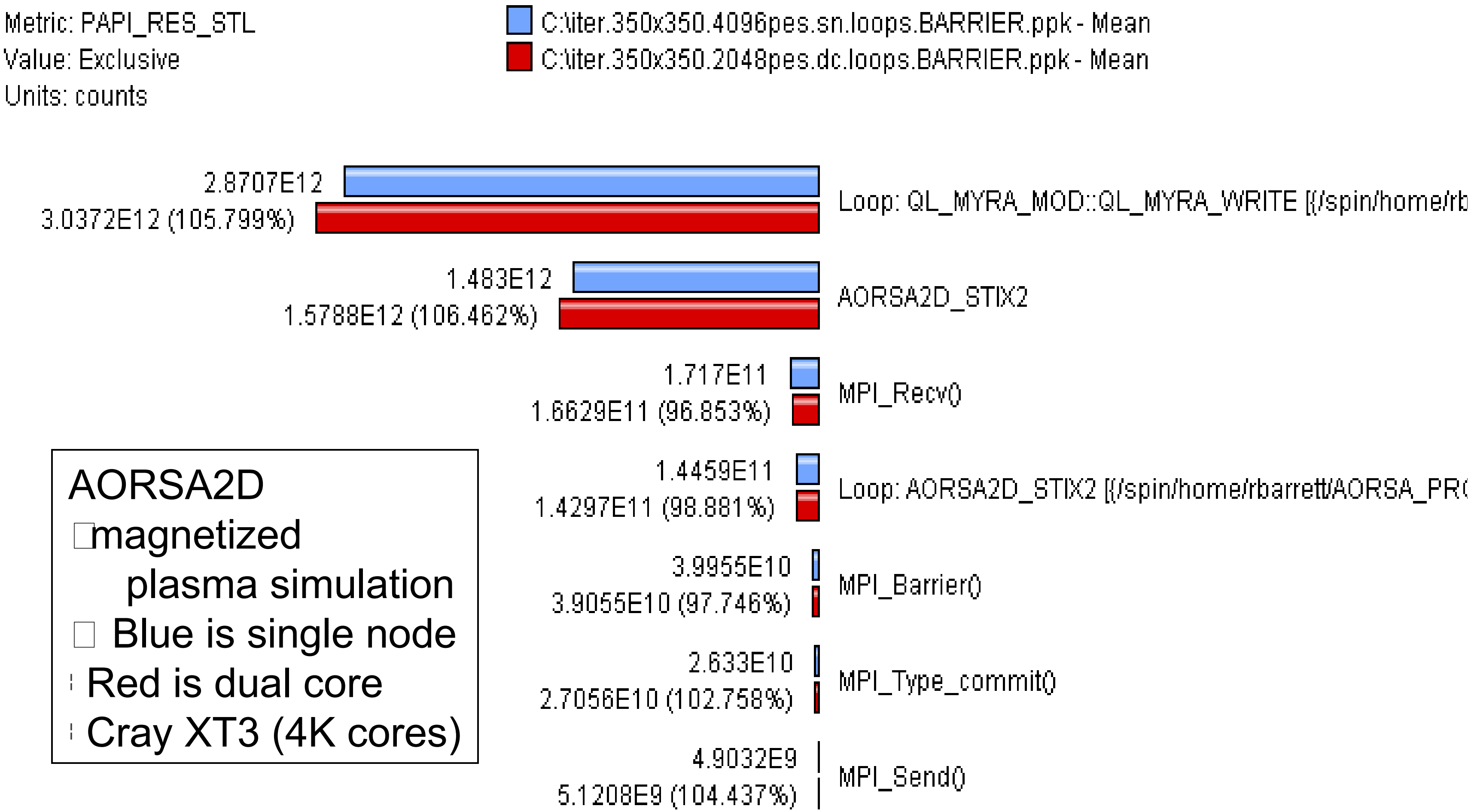
ParaProf Profile Analysis Framework



Metadata for Each Experiment

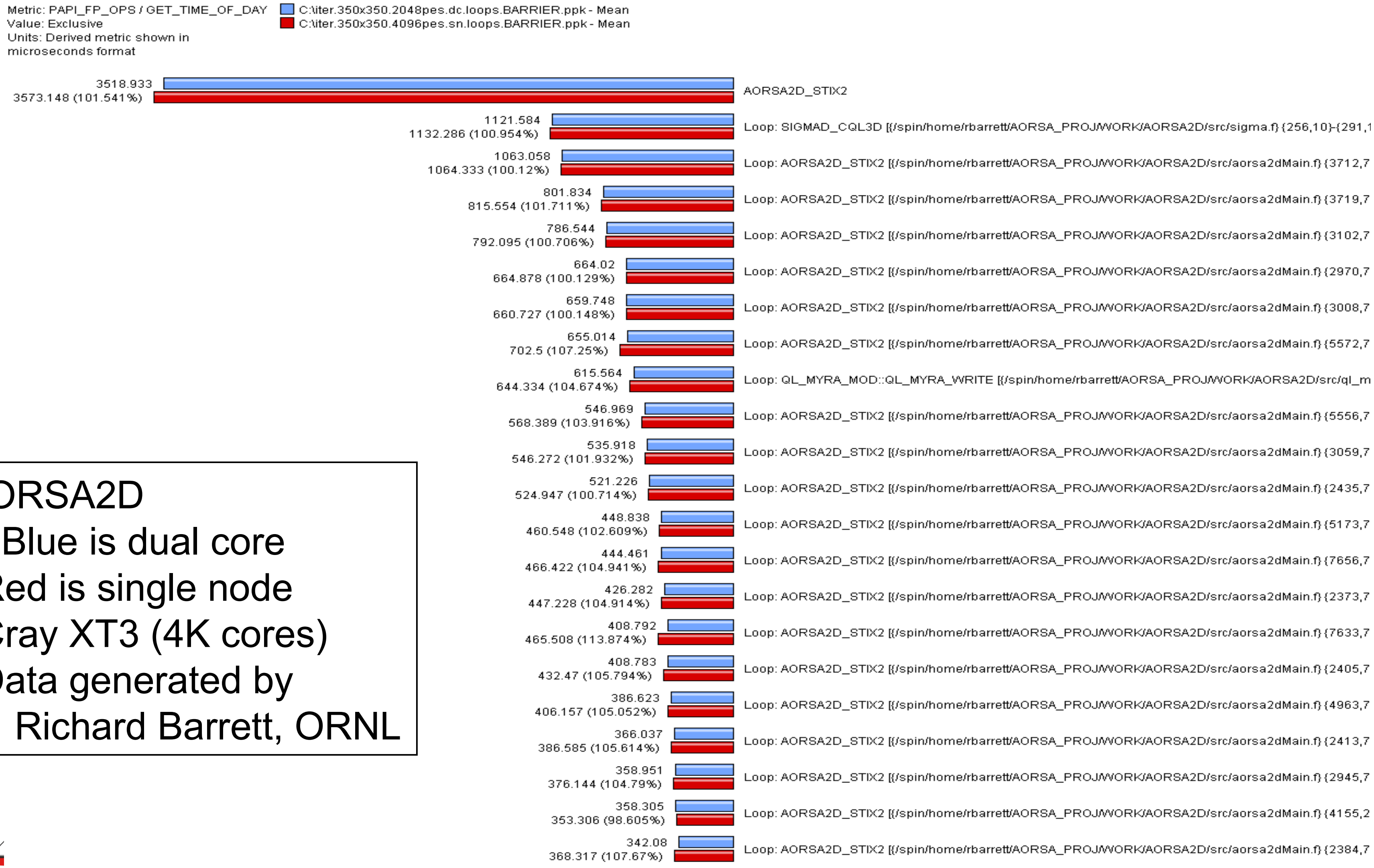


Comparing Effects of Multi-Core Processors



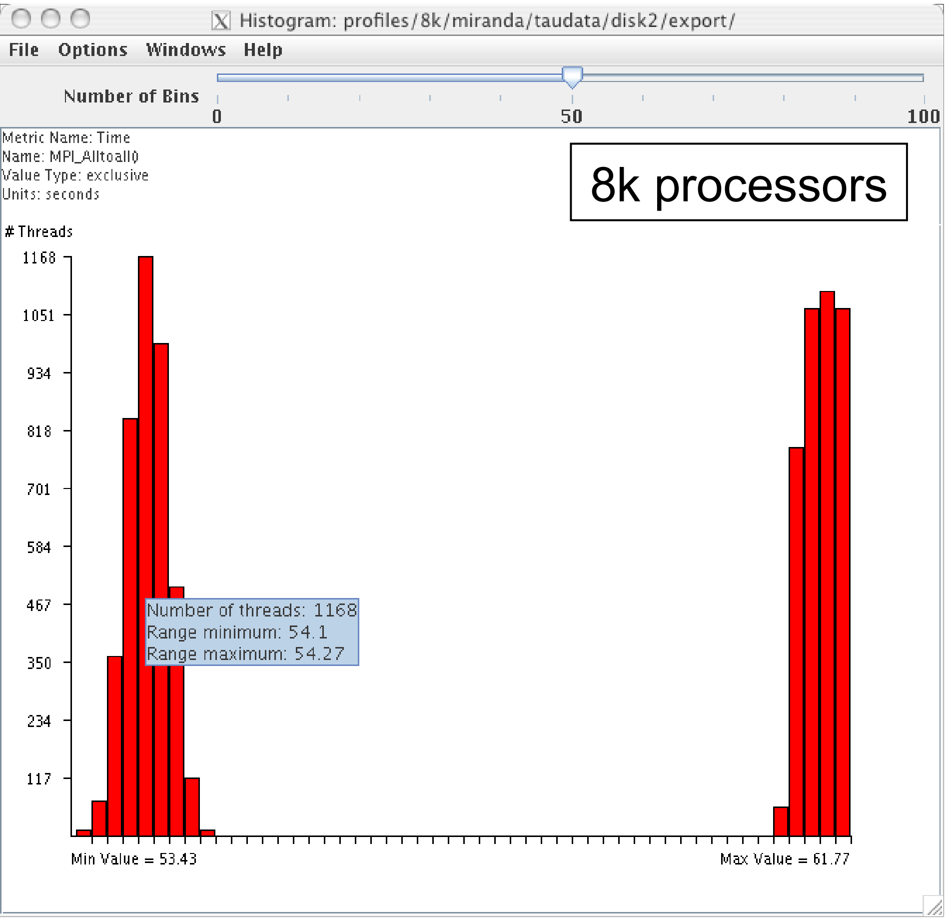
- AORSA2D
  - magnetized plasma simulation
  - Blue is single node
  - Red is dual core
  - Cray XT3 (4K cores)

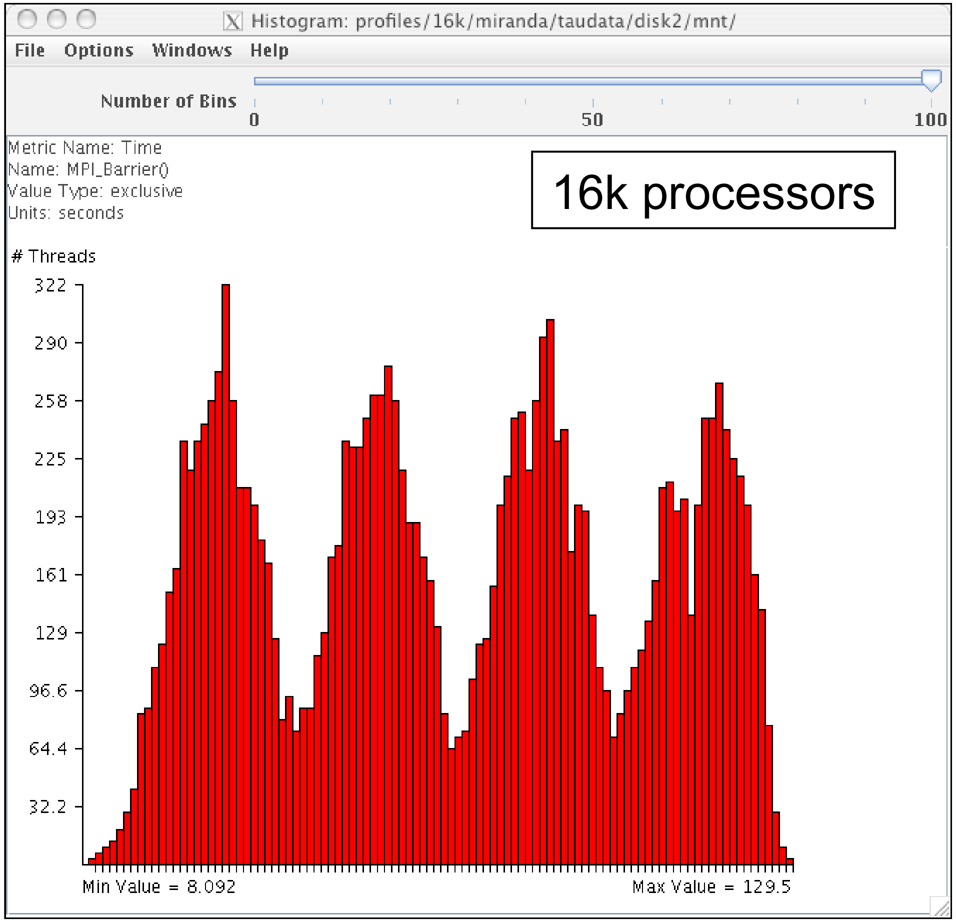
Comparing FLOPS (AORSA2D, Cray XT3)



AORSA2D
- Blue is dual core
- Red is single node
- Cray XT3 (4K cores)
- Data generated by Richard Barrett, ORNL

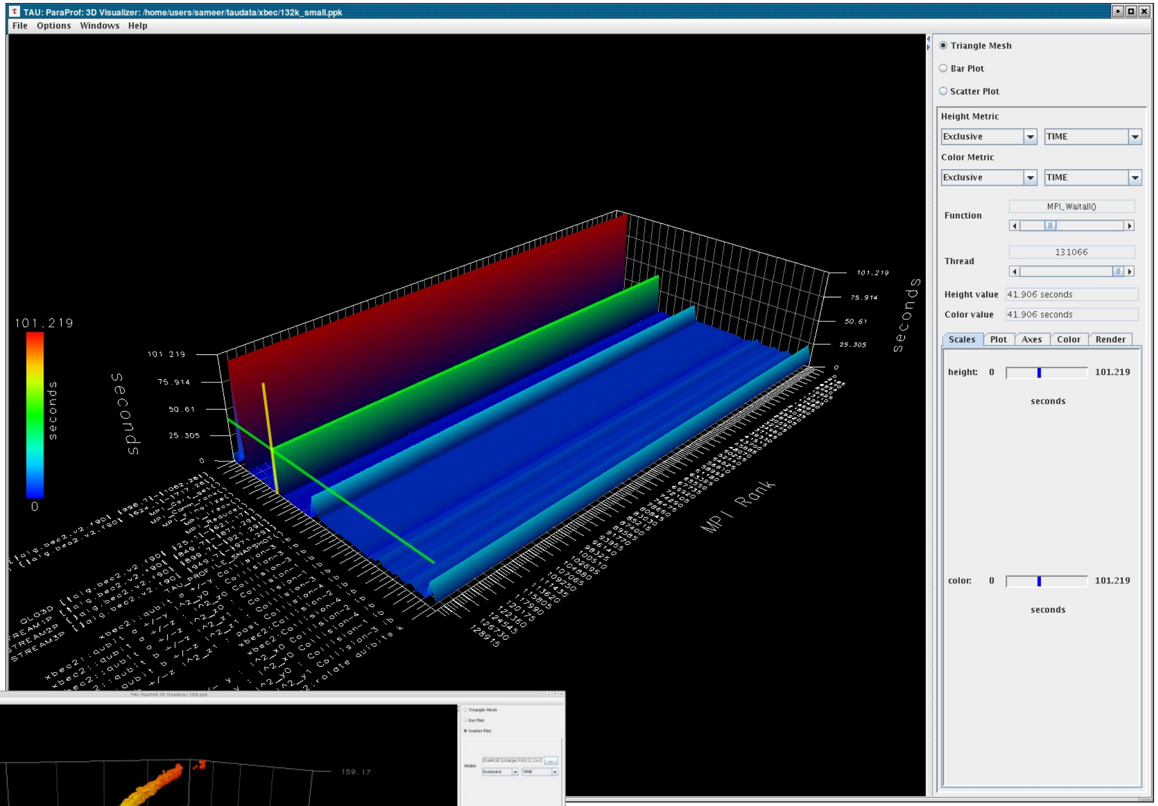
ParaProf – Scalable Histogram

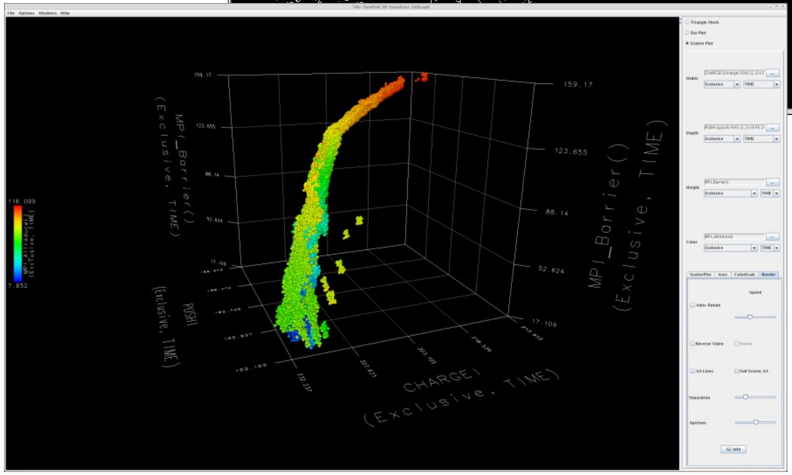




ParaProf – 3D View (Full Profile)

xbec

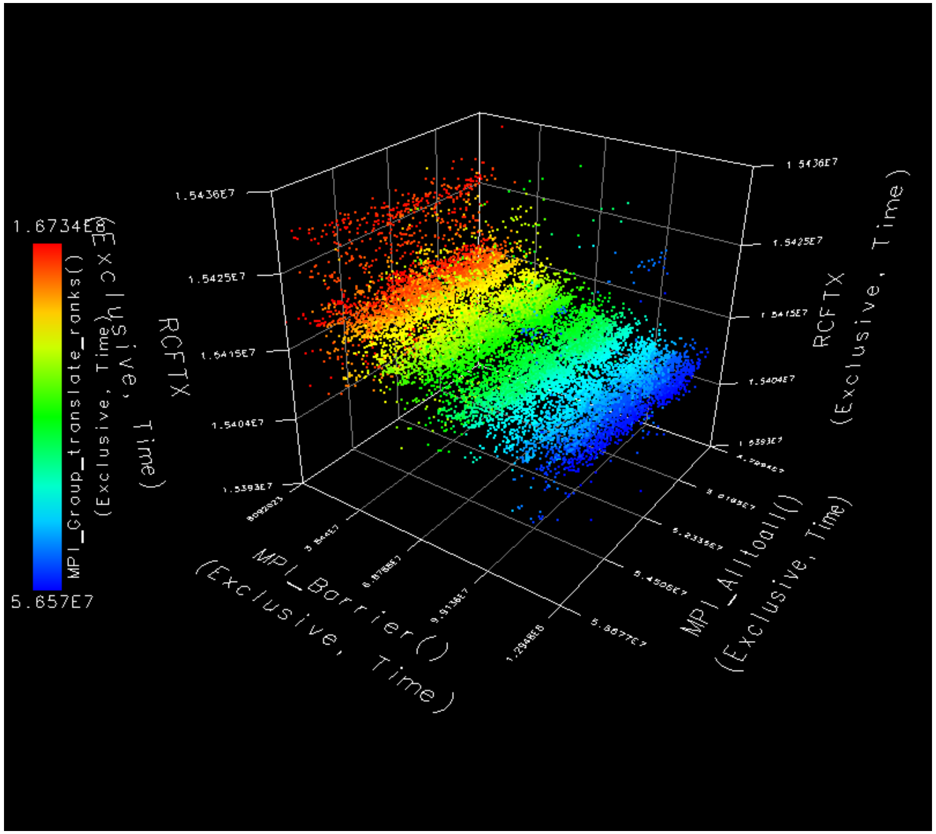




128k processors

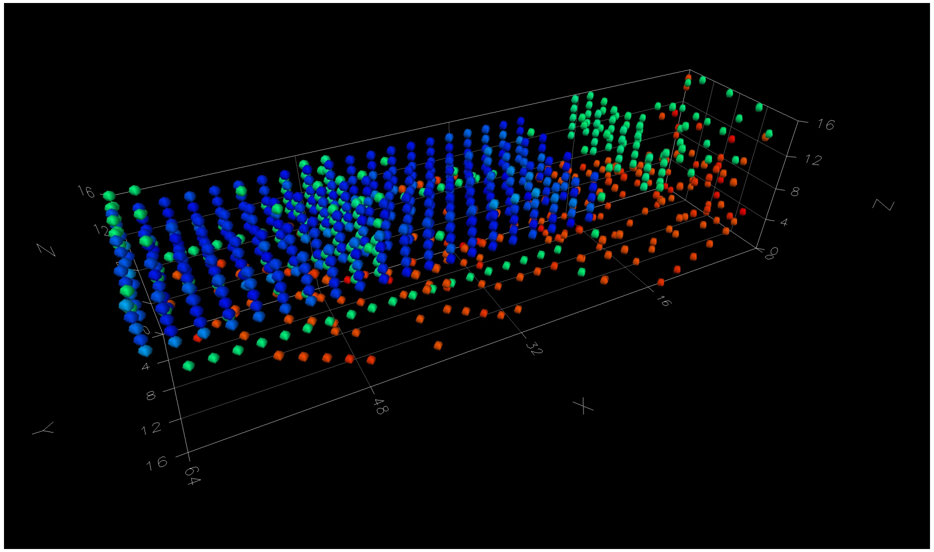
ParaProf – 3D Scatterplot

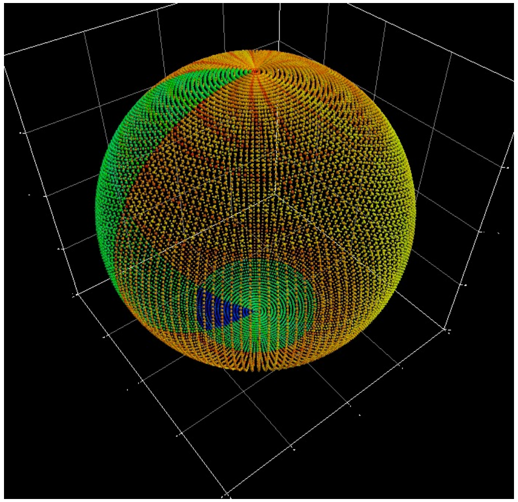
- Each point is a “thread” of execution
- A total of four metrics shown in relation
- ParaProf’s visualization library
  - JOGL
- Miranda, 32k cores



ParaProf – 3D Topology View

- Thread/Node points from metidata or user defined
- Visibility selection by value and position



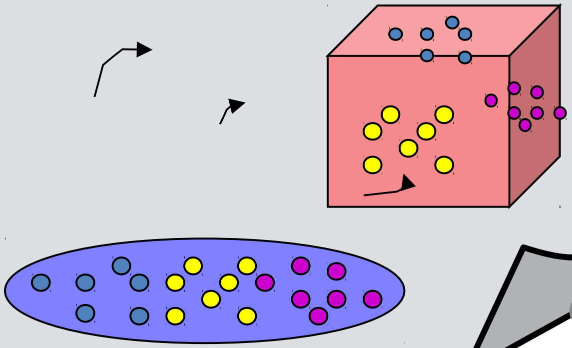


- Sweep3D 16k BGL Run
- Default Cartesian and User Defined Sphere Mappings

Performance Mapping

- Example: Particles distributed on

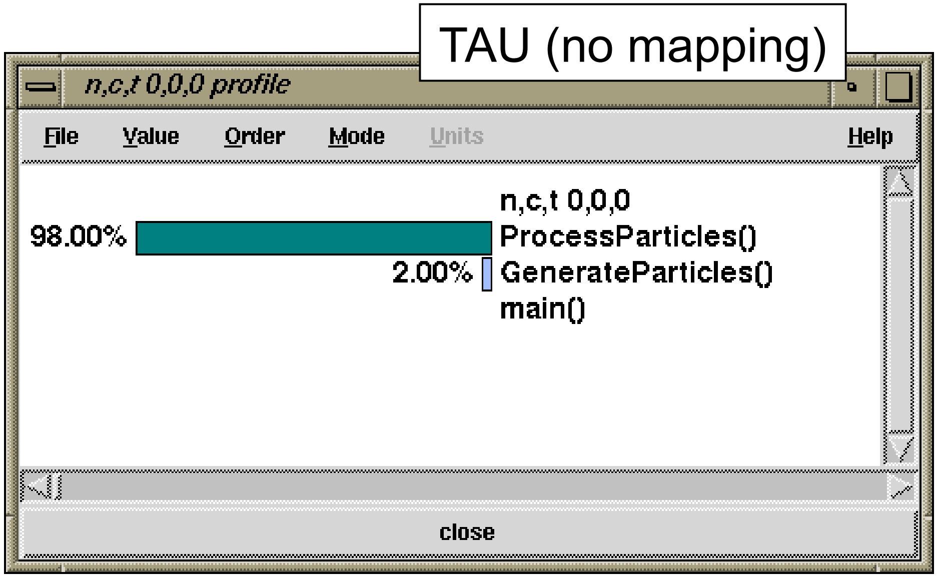
```
Particle* P[MAX]; /* Array of particles */
int GenerateParticles() {
  /* distribute particles over all faces of the cube */
  for (int face=0, last=0; face < 6; face++){
    /* particles on this face */
    int particles_on_this_face = num(face);
    for (int i=last; i < particles_on_this_face; i++) {
      /* particle properties are a function of face */
  P[i] = ... f(face);
      ...
    }
    last+= particles_on_this_face;
  }
}
```

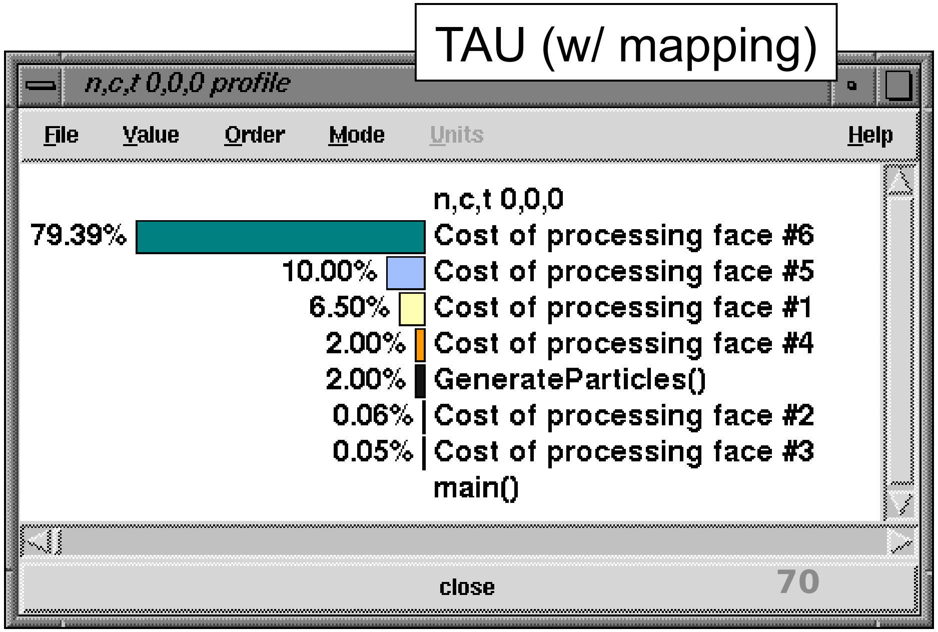


No Mapping versus Mapping

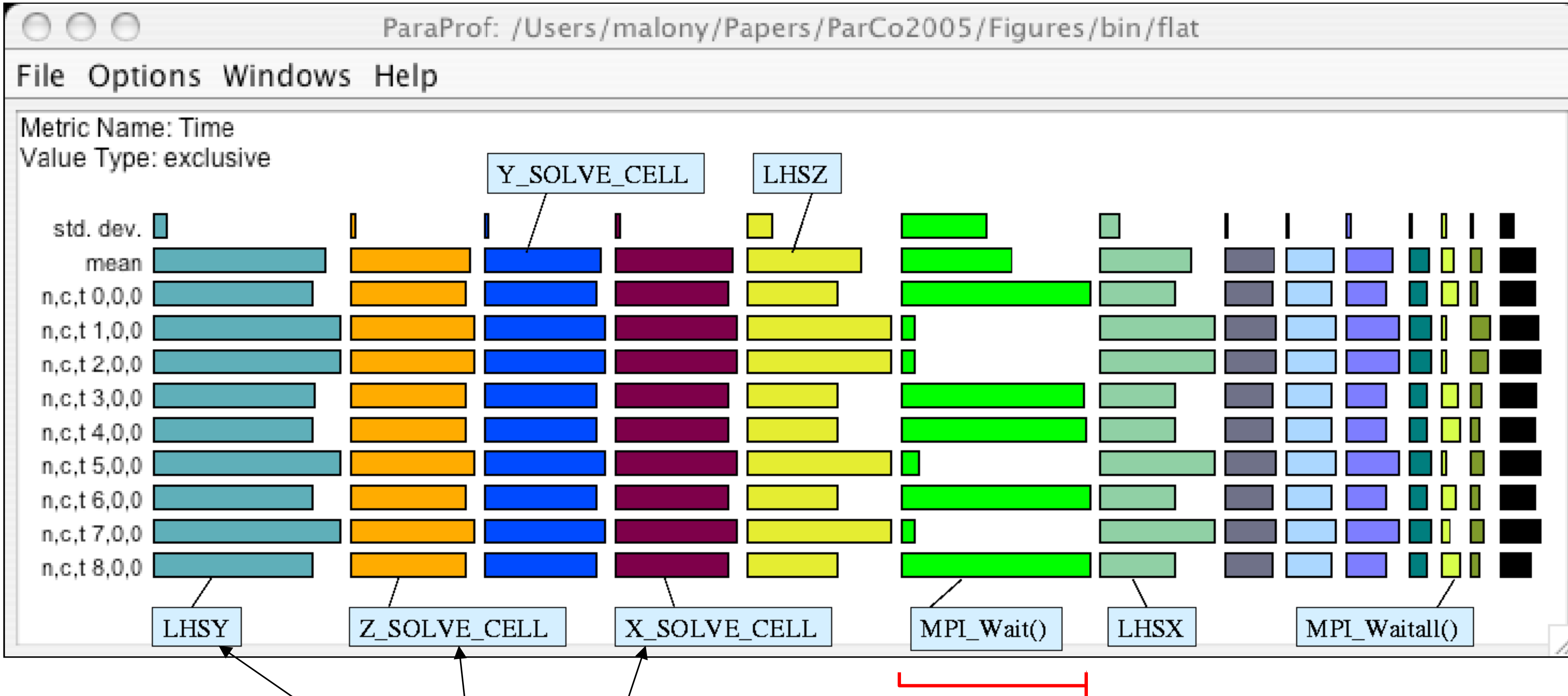
- Typical performance tools report performance with respect to routines
- Does not provide support for mapping

- TAU's performance mapping can observe performance with respect to scientist's programming and problem abstractions





NAS BT – Flat Profile

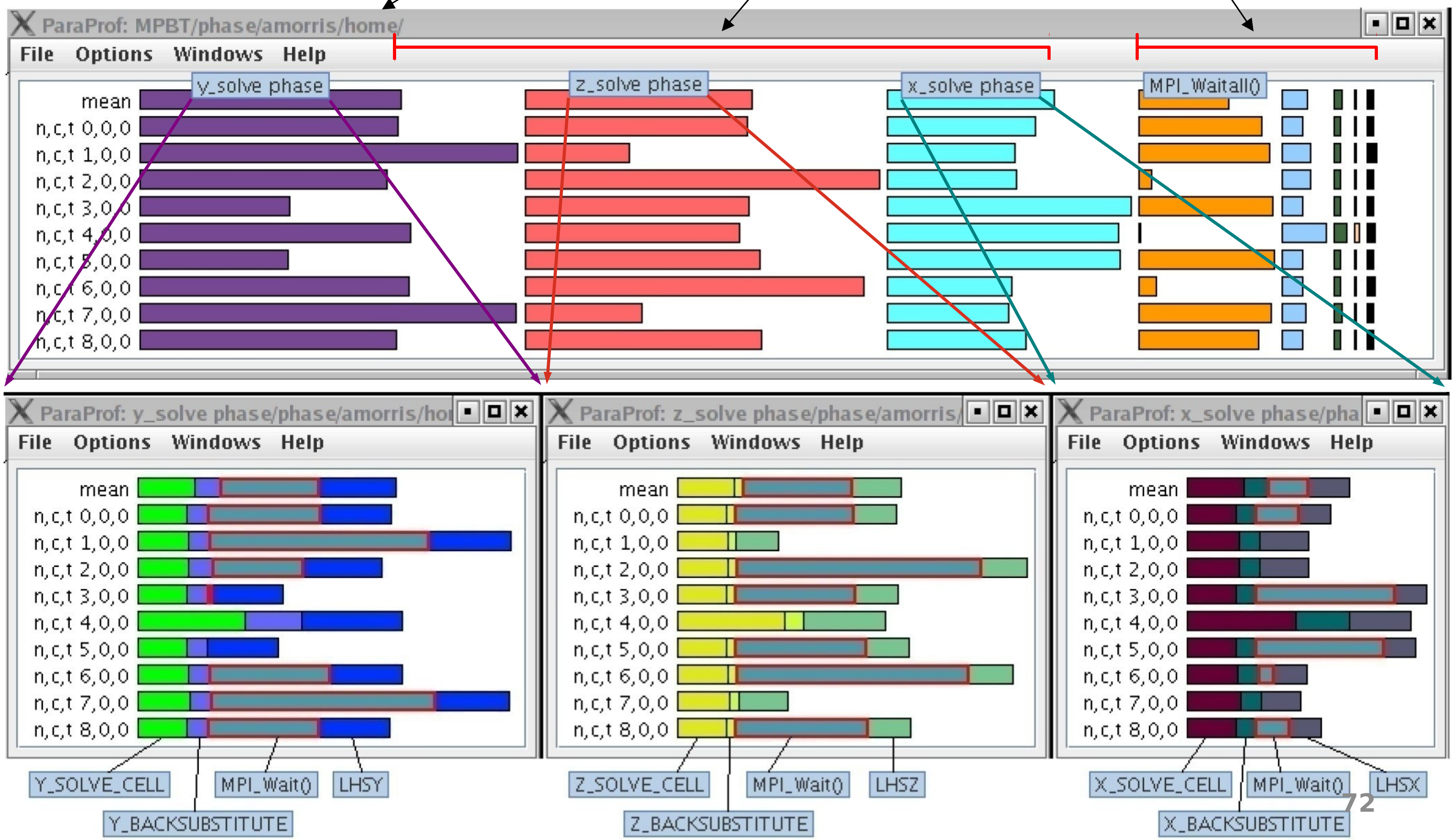


Application routine names reflect phase semantics

How is MPI_Wait() distributed relative to solver direction?

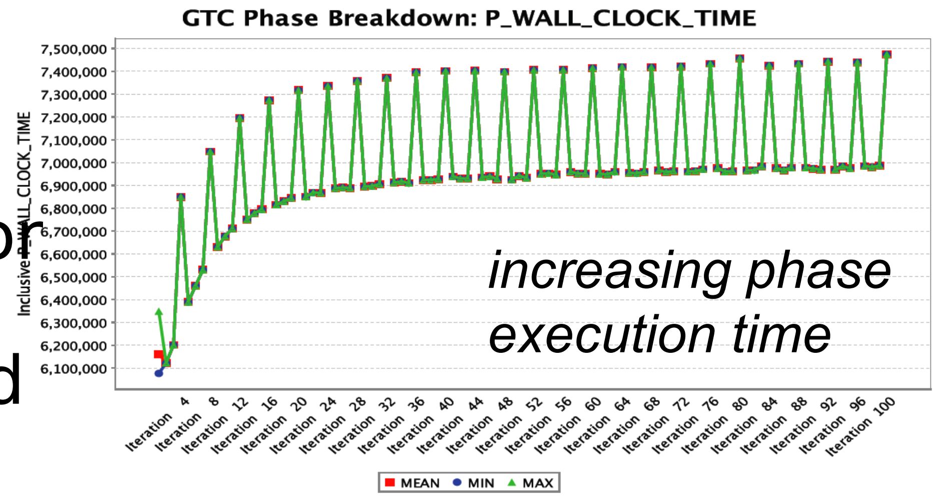
NAS BT – Phase Profile

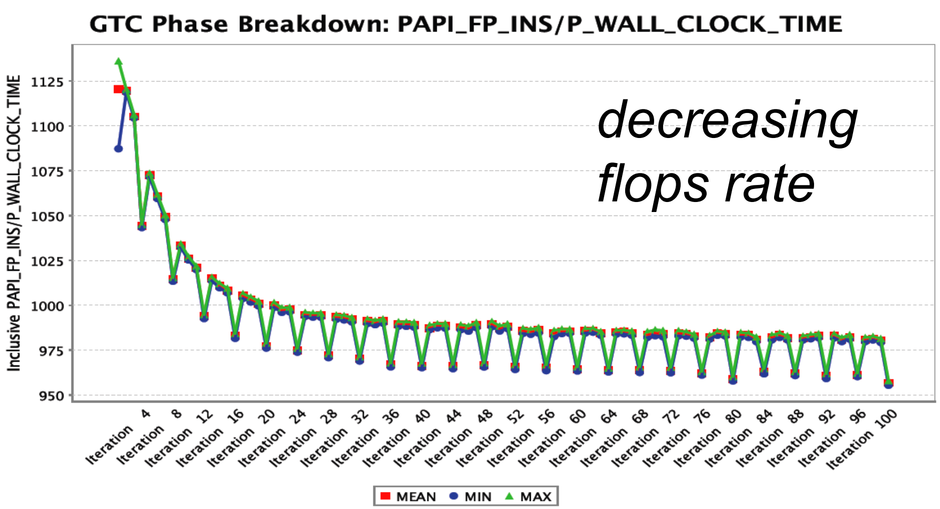
Main phase shows nested phases and immediate events

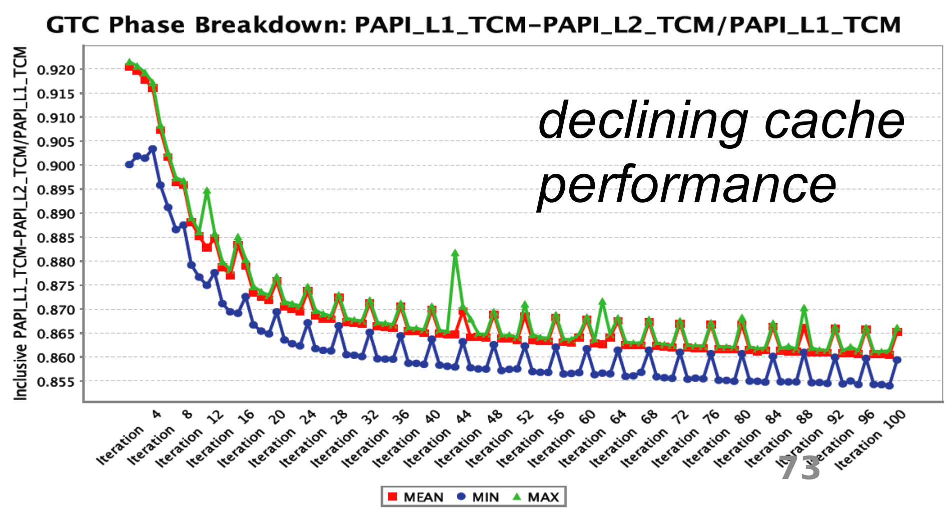


Phase Profiling of HW Counters

- GTC particle-in-cell simulation of fusion turbulence
- Phases assigned to iterations
- Poor temporal locality for one important data
- Automatically generated by PE2 python script

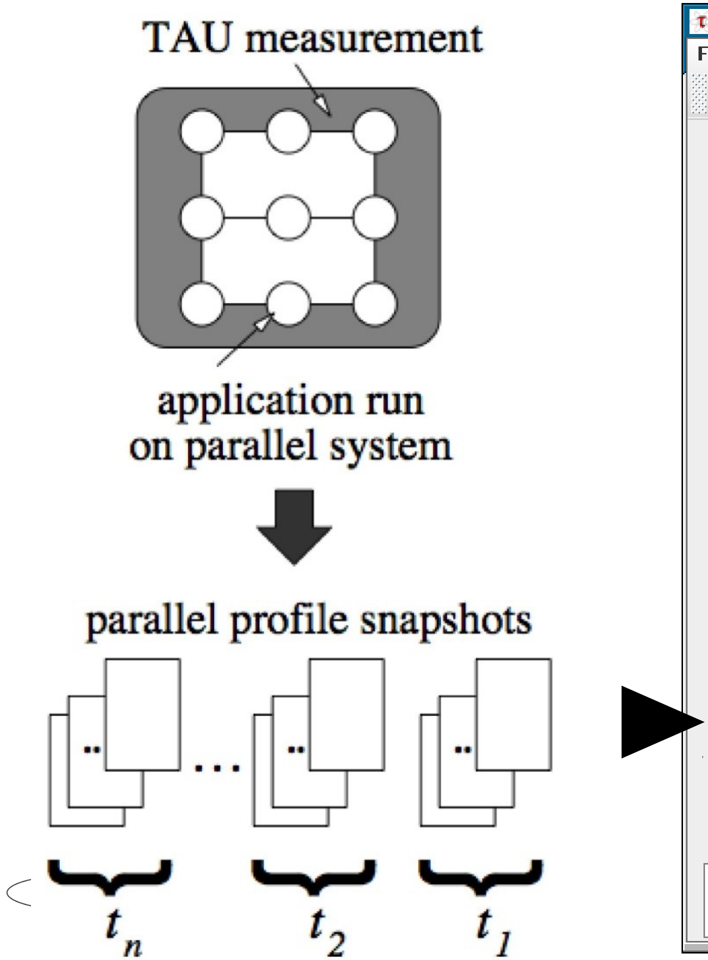


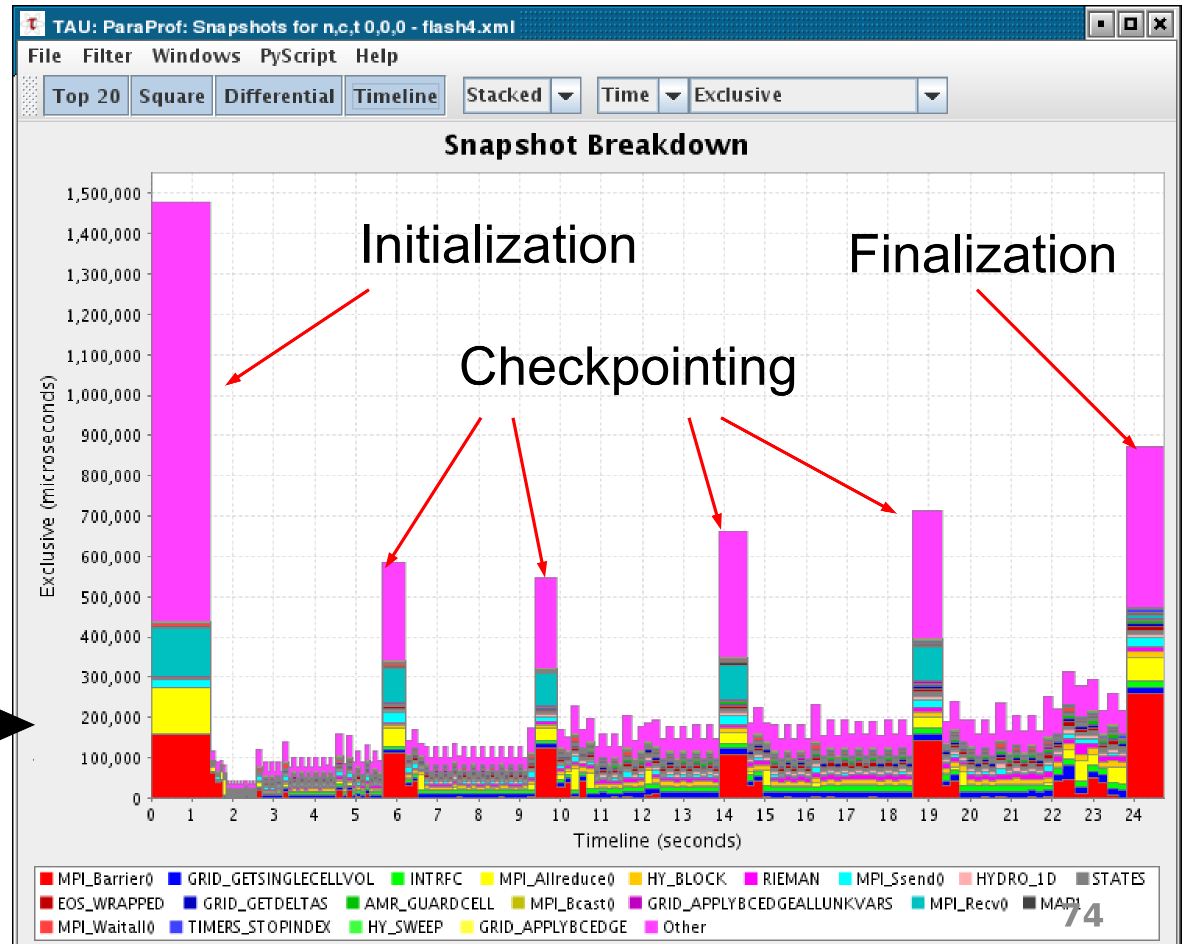




Profile Snapshots in ParaProf

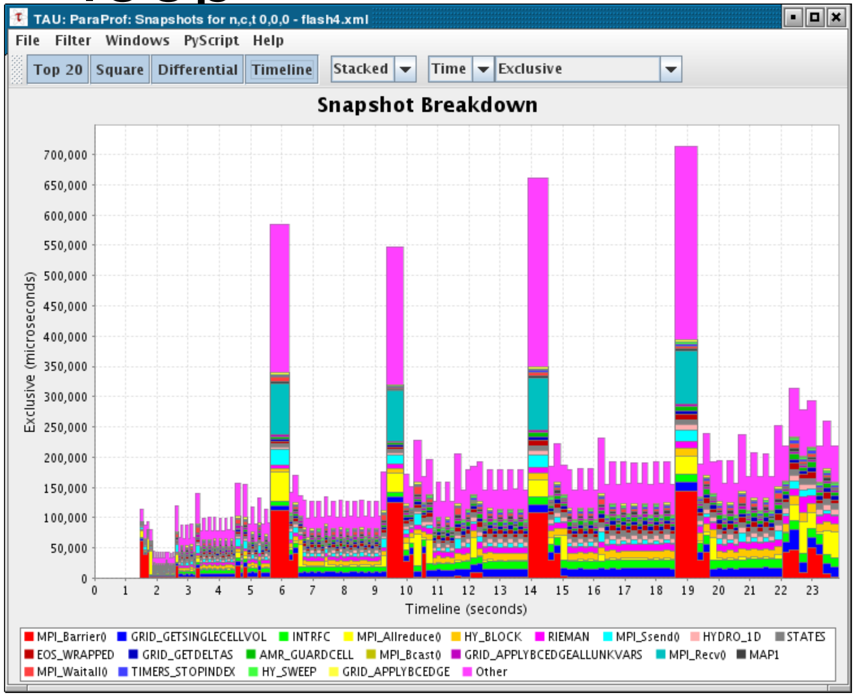
- Profile snapshots are parallel profiles recorded at runtime
- Shows performance profile dynamics (all types allowed)

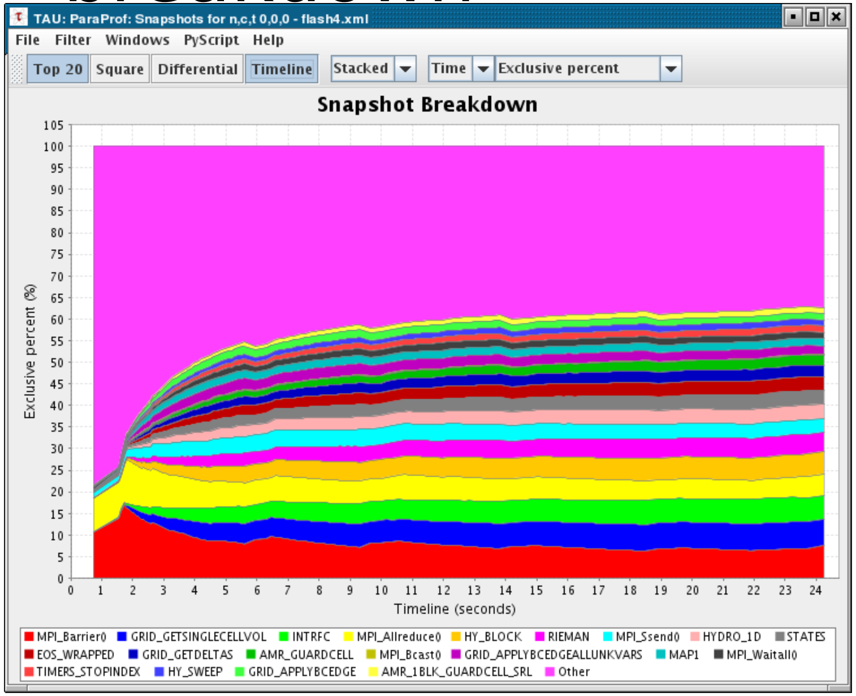




Profile Snapshot Views

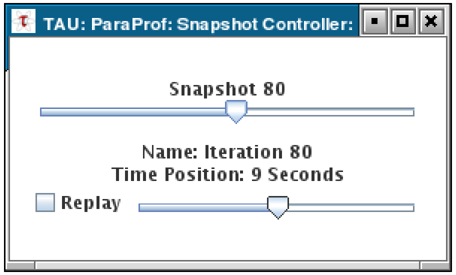
- Only show main loop
- Percentage breakdown

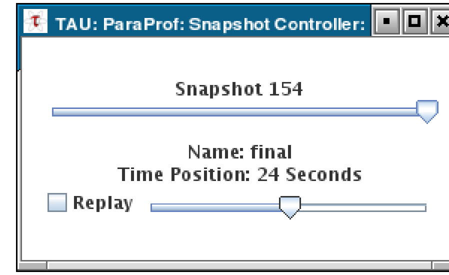


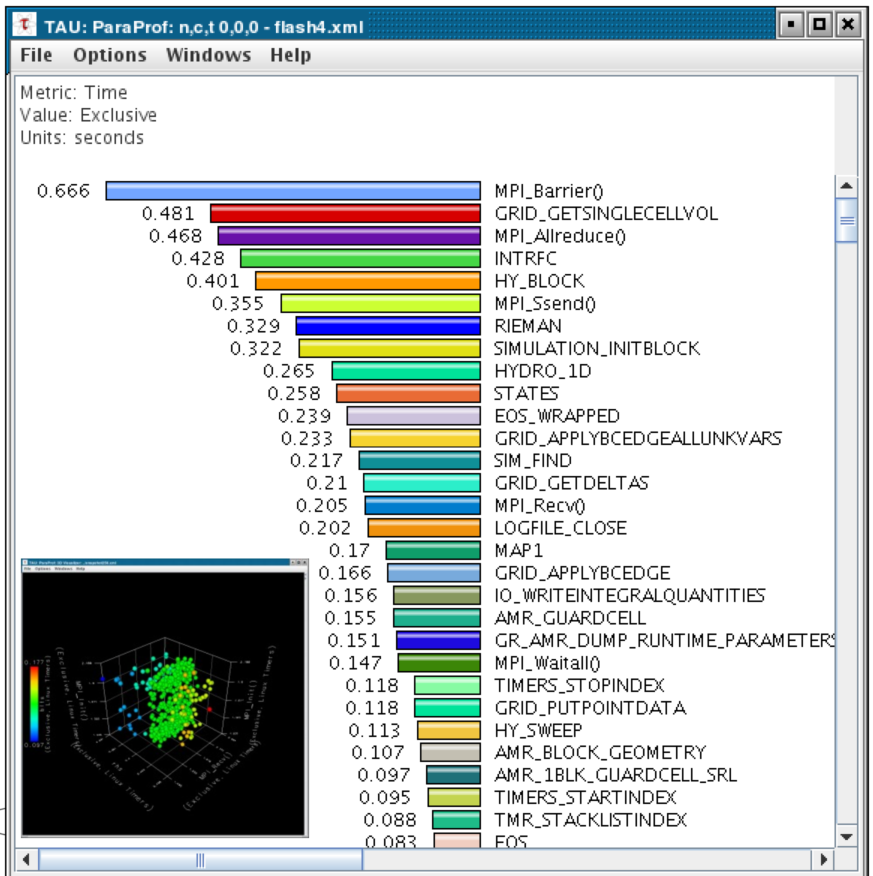


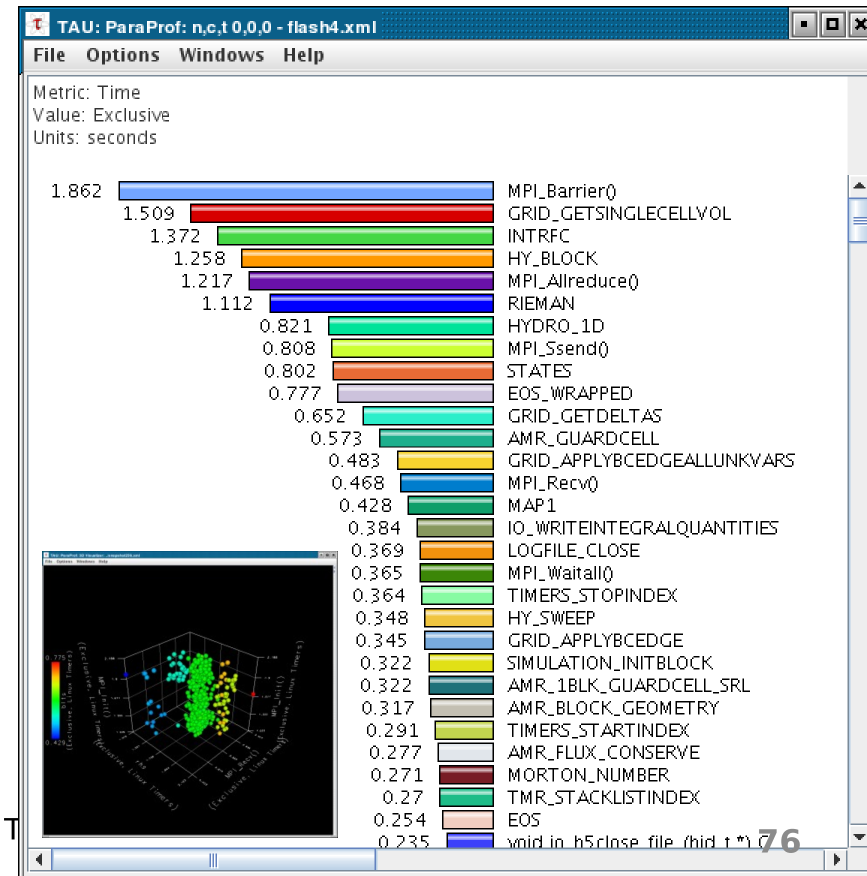
Snapshot Replay in ParaProf

All windows dynamically update









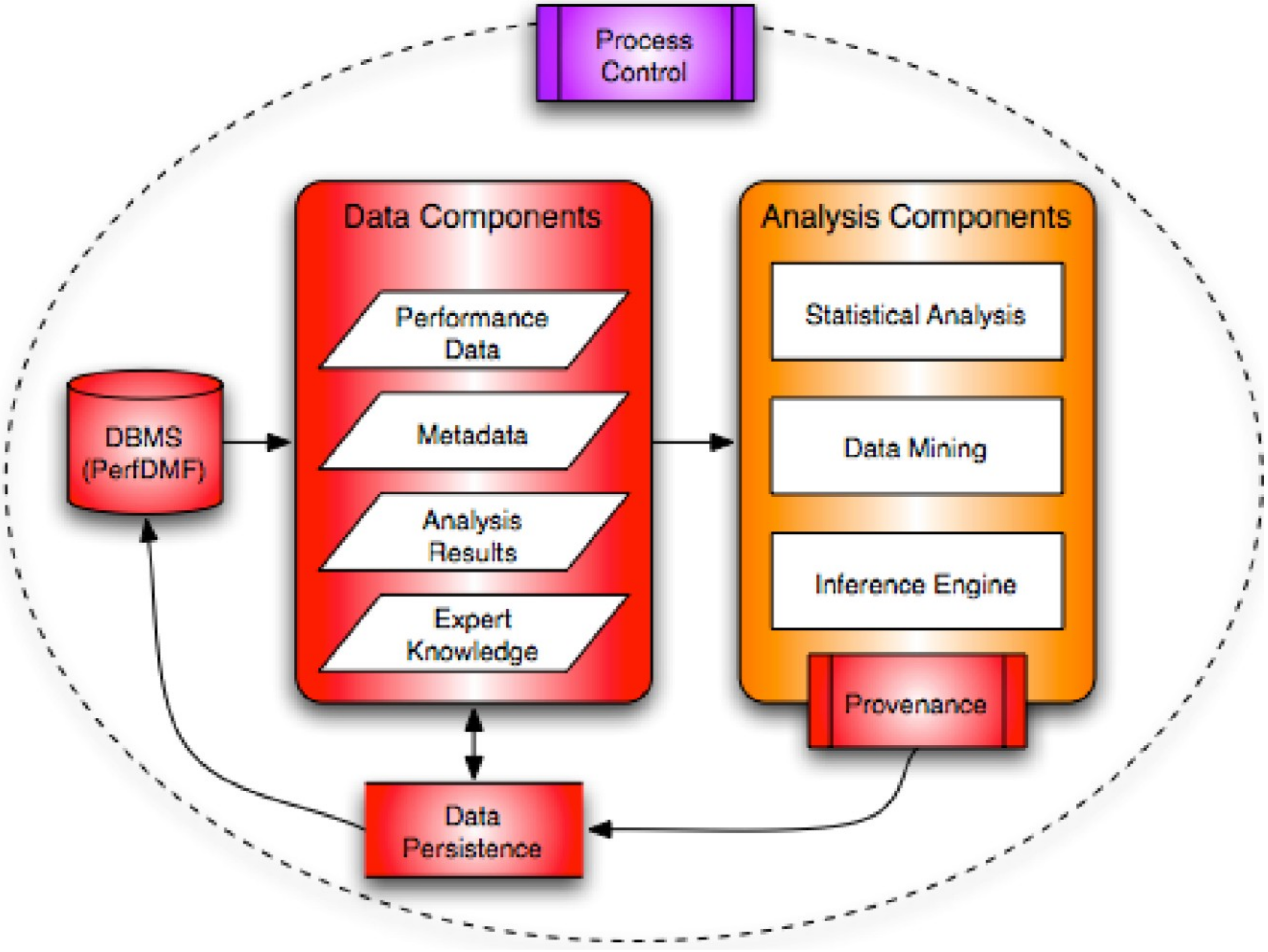
Performance Data Mining / Analytics

- Conduct systematic and scalable analysis process
  - Multi-experiment performance analysis
  - Support automation, collaboration, and reuse
- Performance knowledge discovery framework
  - Data mining analysis applied to parallel performance data
  - comparative, clustering, correlation, dimension reduction, …
  - Use the existing TAU infrastructure
- PerfExplorer v1 performance data mining framework
  - Multiple experiments and parametric studies
  - Integrate available statistics and data mining packages
  - Weka, R, Matlab / Octave
  - Apply data mining operations in interactive enviroment

PerfExplorer v2 – Requirements

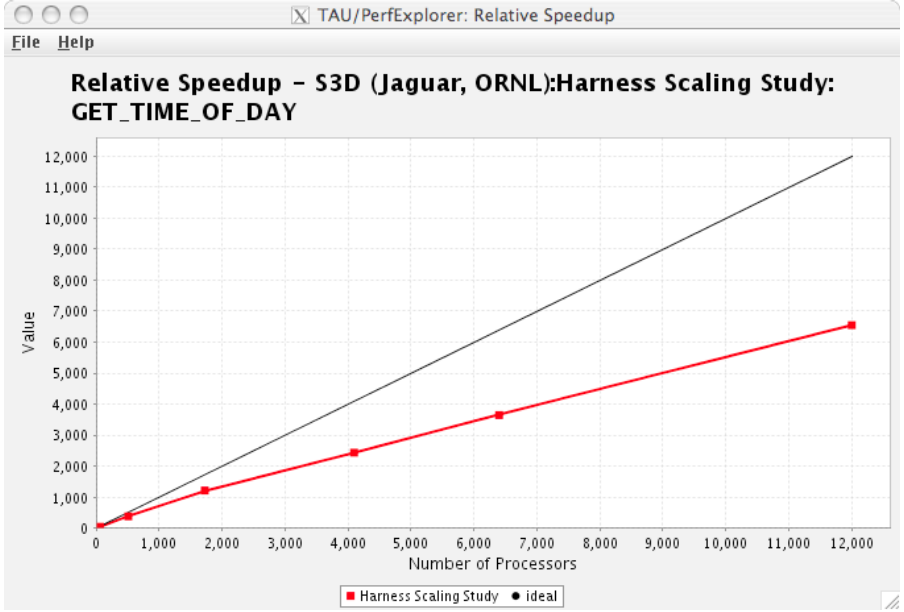
- Component-based analysis process
  - Analysis operations implemented as modules
  - Linked together in analysis process and workflow
- Scripting
  - Provides process/workflow development and automation
- Metadata input, management, and access
- Inference engine
  - Reasoning about causes of performance phenomena
  - Analysis knowledge captured in expert rules
- Persistence of intermediate analysis results
- Provenance
  - Provides historical record of analysis results

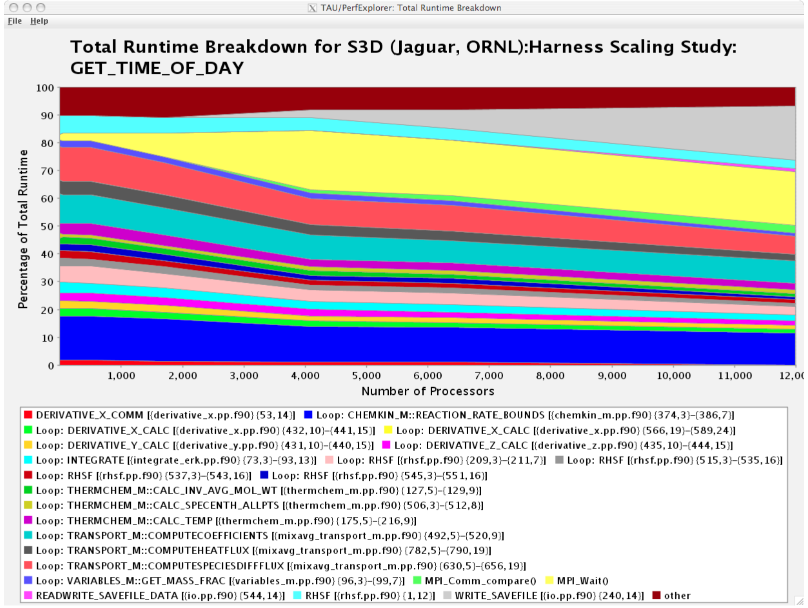
PerfExplorer v2 Architecture



Usage Scenarios: Evaluate Scalability

- Goal: How does my application scale? What bottlenecks at what cpu counts?
- Load profiles in PerfDMF database and examine with PerfExplorer

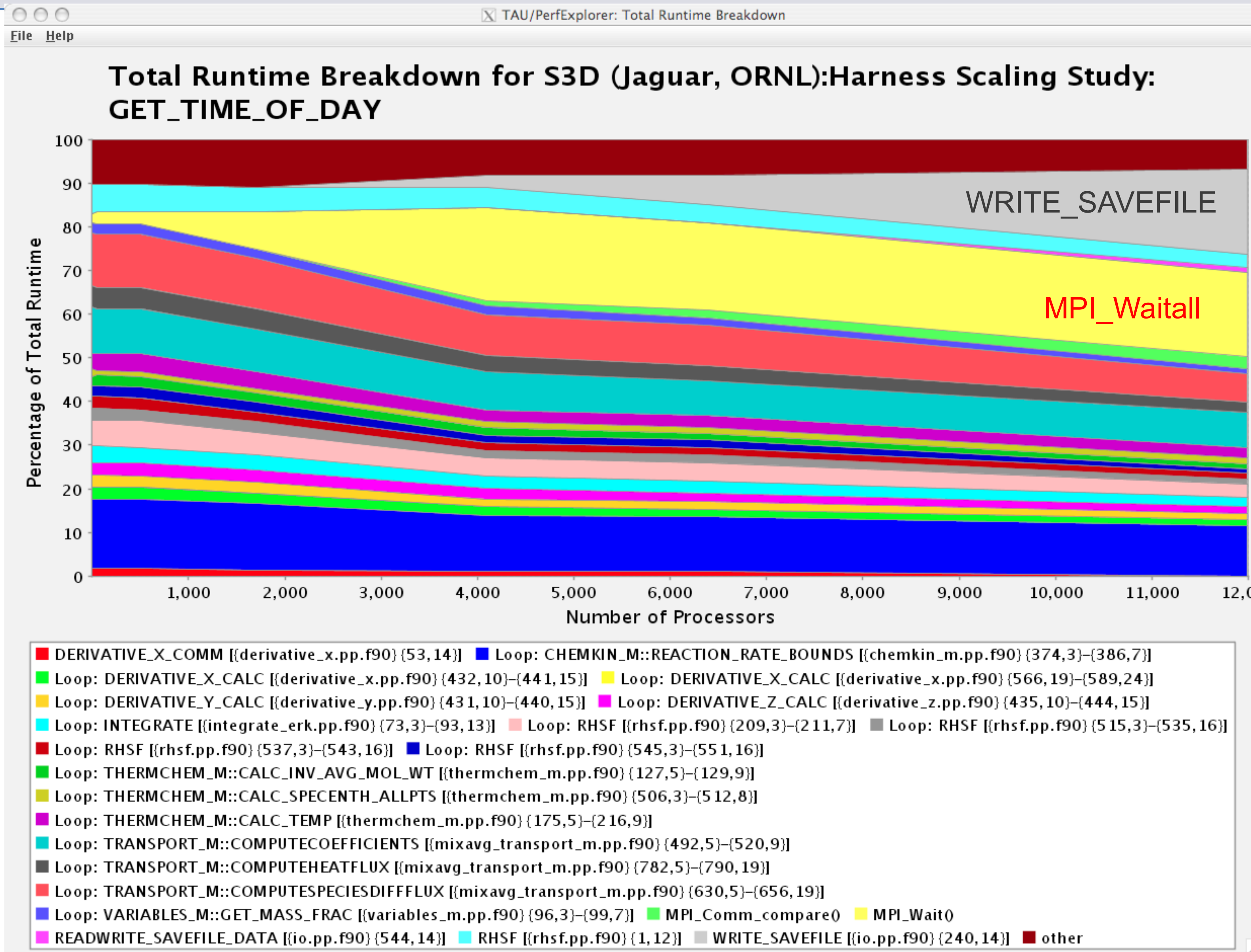




Evaluate Scalability using PerfExplorer Charts

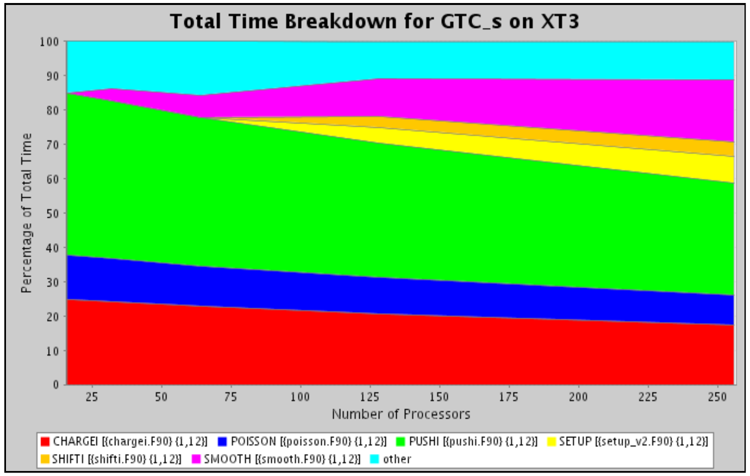
```
% setenv TAU_MAKEFILE /opt/tau-2.19.1/x86_64
           /lib/Makefile.tau-mpi-pdt
% set path=(/opt/tau-2.19.1/x86_64/bin $path)
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% qsub  run1p.job
% paraprof --pack 1p.ppk
% qsub  run2p.job …
% paraprof --pack 2p.ppk … and so on.
On your client:
% perfdmf_configure
(Choose derby, blank user/passwd, yes to save passwd, defaults)
% perfexplorer_configure
(Yes to load schema, defaults)
% paraprof
(load each trial: DB -> Add Trial -> Type (Paraprof Packed
Profile) -> OK, OR use perfdmf_loadtrial on the commandline)
% perfexplorer
(Charts -> Speedup)
```

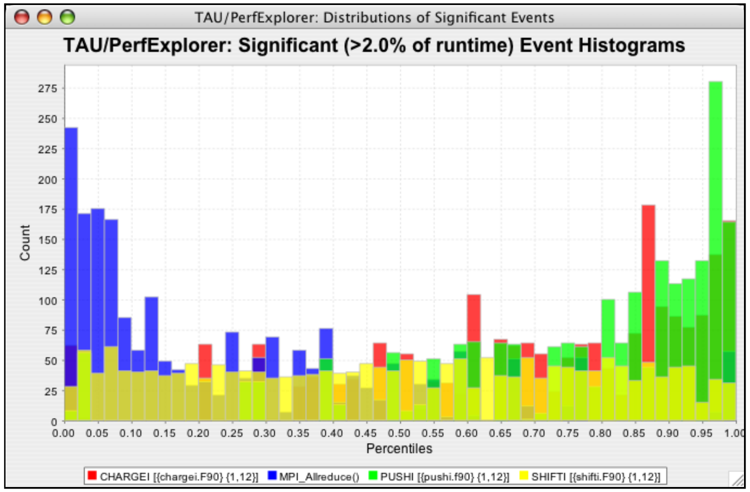
PerfExplorer – Runtime Breakdown



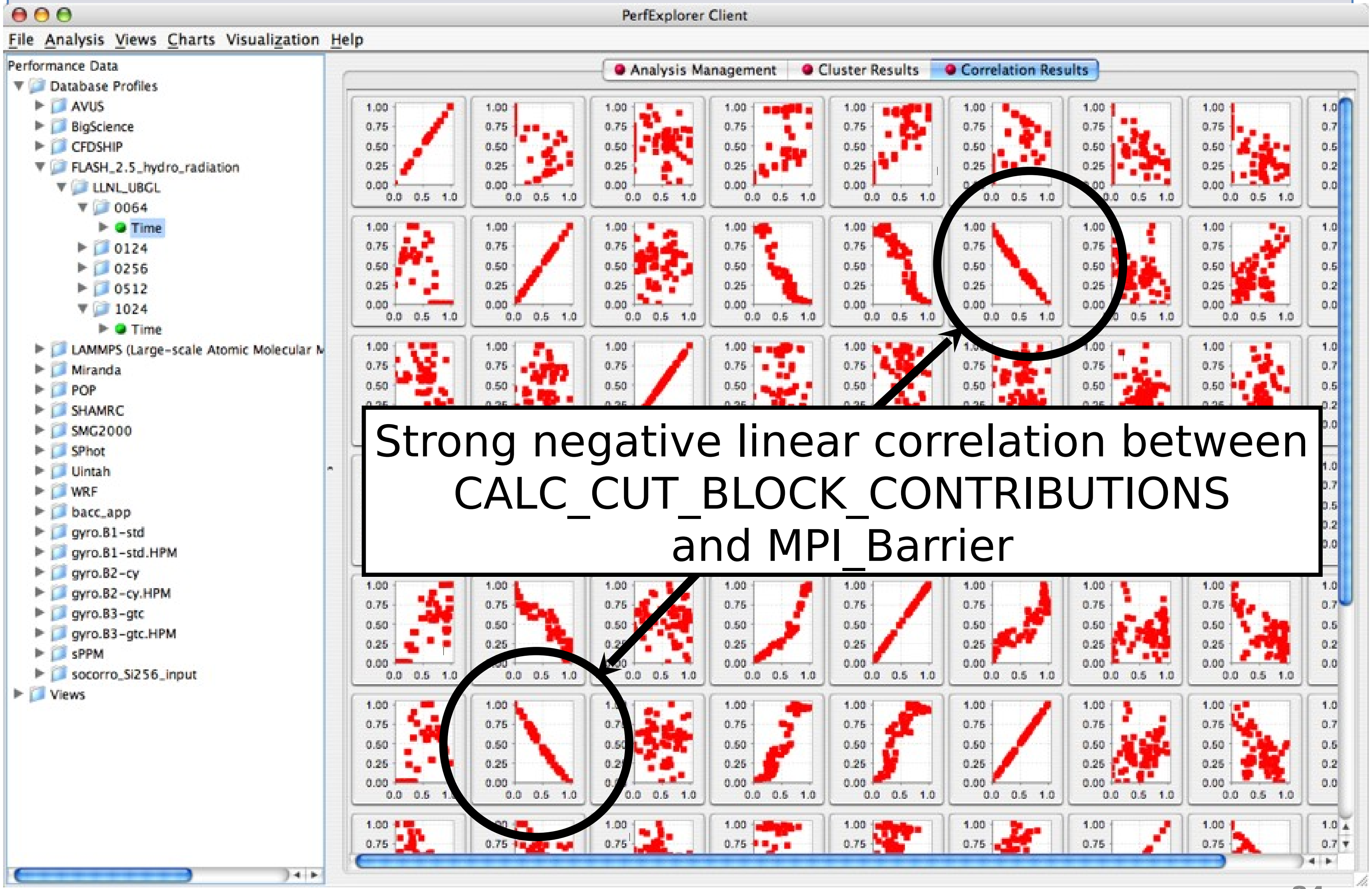
PerfExplorer – Relative Comparisons

- Total execution time
- Timesteps per second
- Relative efficiency
- Relative efficiency per event
- Relative speedup
- Relative speedup per event
- Group fraction of total
- Runtime breakdown
- Correlate events with total runtime
- Relative efficiency per phase
- Relative speedup per phase
- Distribution visualizations



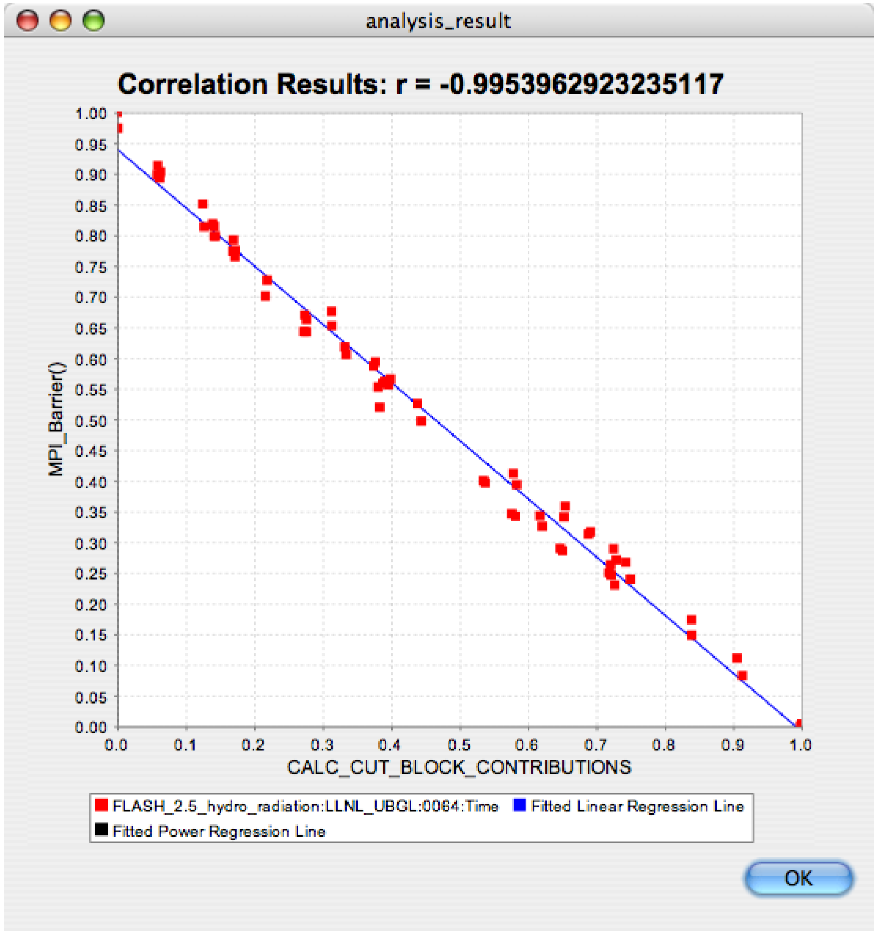


PerfExplorer – Correlation Analysis



PerfExplorer – Correlation Analysis

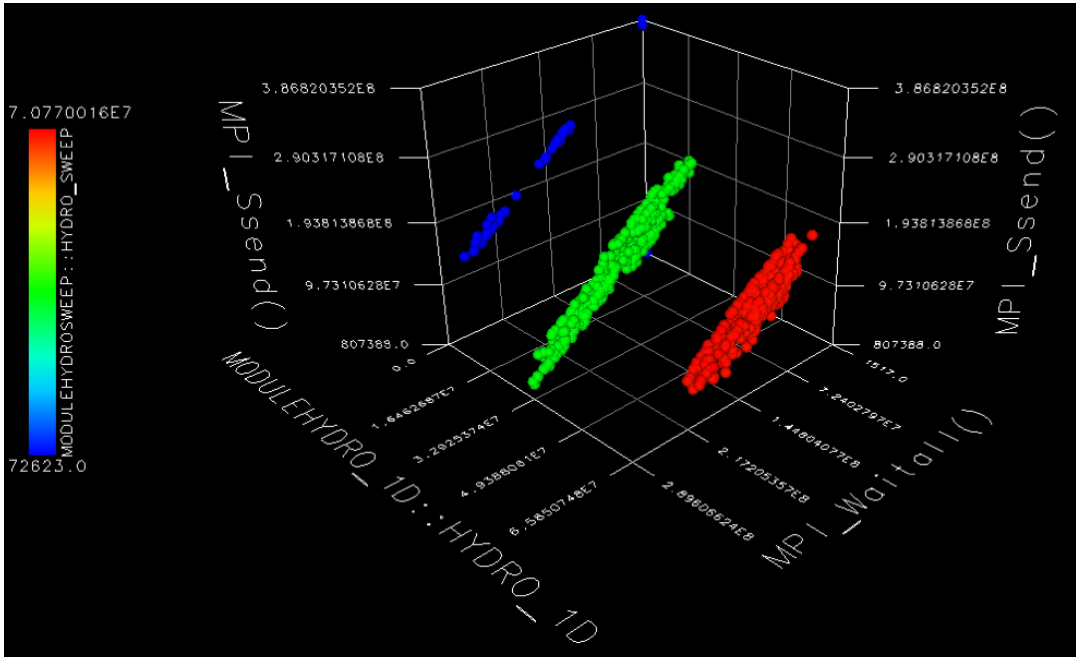
- -0.995 indicates strong, negative relationship
- As CALC_CUT_BLOCK_CONTRIBUTIONS() increases in execution time, MPI_Barrier() decreases



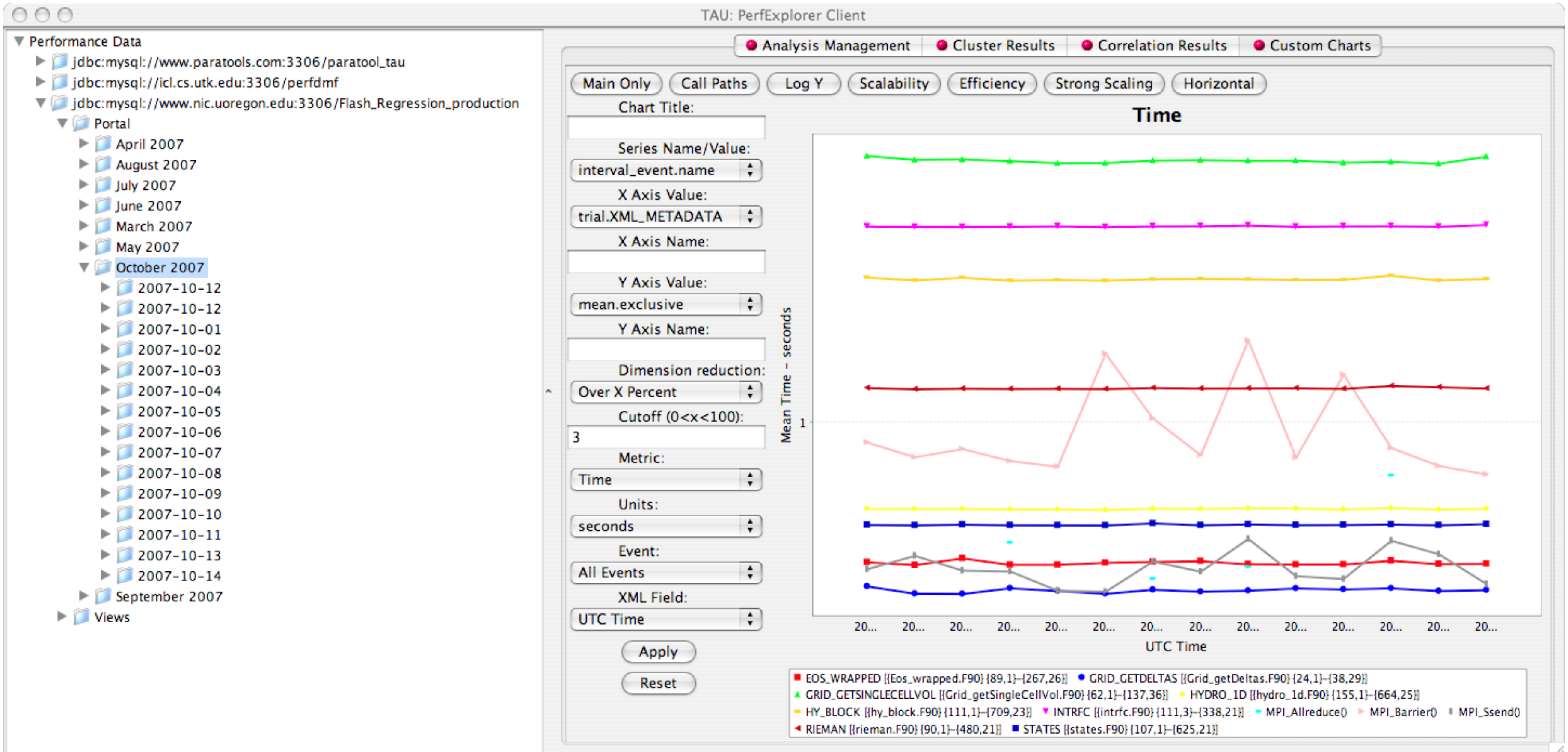
PerfExplorer – Cluster Analysis

PerfExplorer – Cluster Analysis

- Four significant events automatically selected
- Clusters and correlations are visible



PerfExplorer – Performance Regression



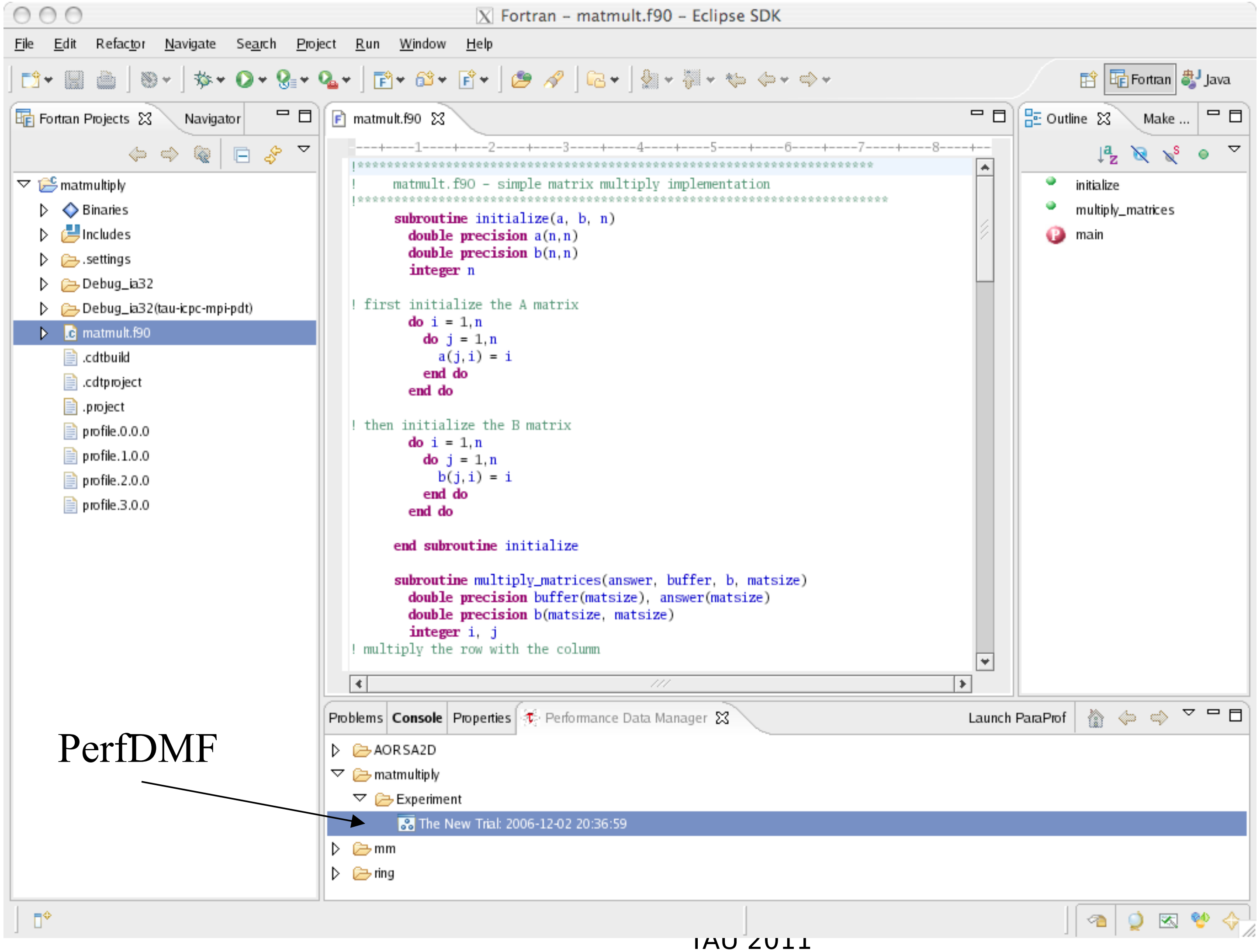
Other Projects in TAU

- TAU Portal
  - Support collaborative performance study
- Kernel-level system measurements (KTAU)
  - Application to OS noise analysis and I/O system analysis
- TAU performance monitoring
  - TAUoverSupermon and TAUoverMRNet
- PerfExplorer integration and expert-based analysis
  - OpenUH compiler optimizations
- Performance tools integration (NSF POINT project)
- Eclipse CDT and PTP integration

TAU Integration with IDEs

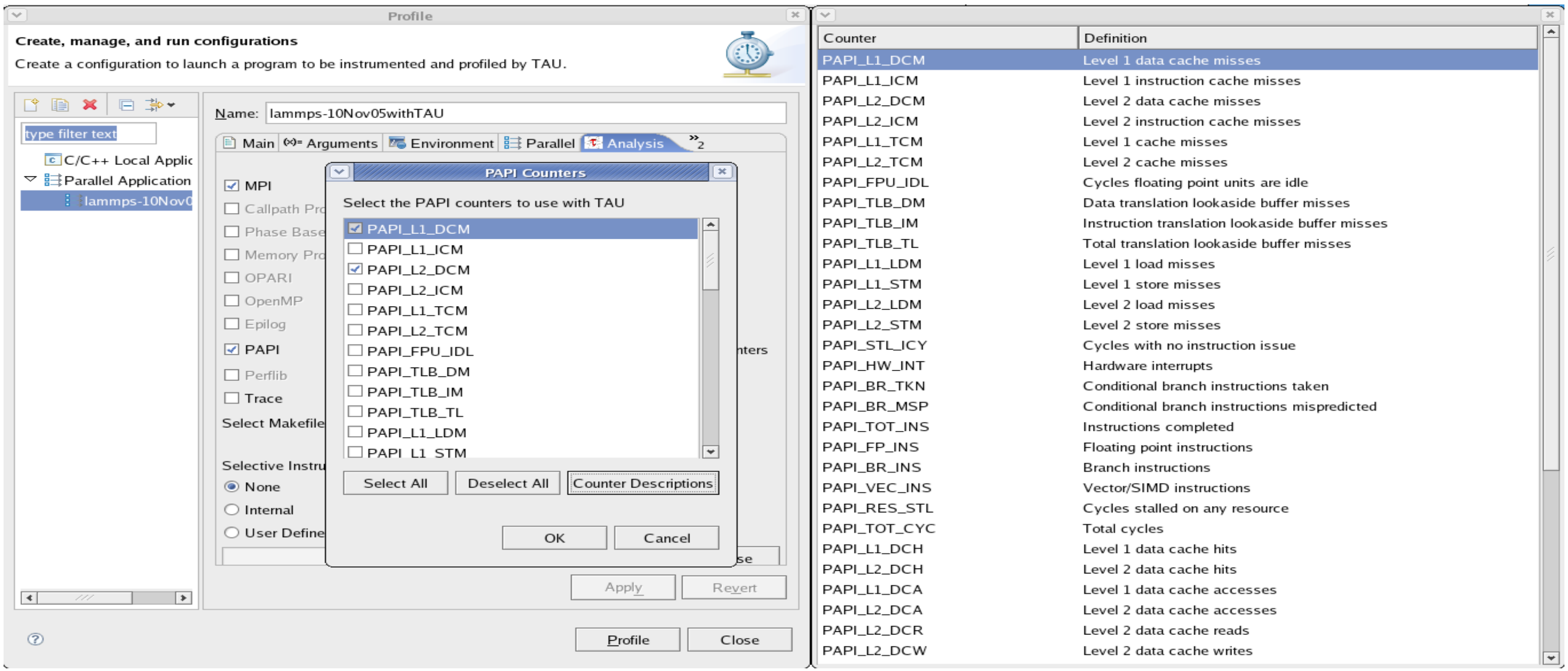
- High performance software development environments
  - Tools may be complicated to use
  - Interfaces and mechanisms differ between platforms / OS
- Integrated development environments
  - Consistent development environment
  - Numerous enhancements to development process
  - Standard in industrial software development
- Integrated performance analysis
  - Tools limited to single platform or programming language
  - Rarely compatible with 3rd party analysis tools
  - Little or no support for parallel projects

TAU and Eclipse




```
!*************************************************************
!     matmult.f90 - simple matrix multiply implementation
!*************************************************************
      subroutine initialize(a, b, n)
        double precision a(n,n)
        double precision b(n,n)
        integer n

! first initialize the A matrix
        do i = 1,n
          do j = 1,n
            a(j,i) = i
          end do
        end do

! then initialize the B matrix
        do i = 1,n
          do j = 1,n
            b(j,i) = i
          end do
        end do

      end subroutine initialize

      subroutine multiply_matrices(answer, buffer, b, matsize)
        double precision buffer(matsize), answer(matsize)
        double precision b(matsize, matsize)
        integer i, j
! multiply the row with the column
```

Choosing PAPI Counters with TAU in Eclipse



% /usr/local/packages/eclipse/eclipse

Support Acknowledgements

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  - Office of Science
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  - ASC/NNSA
    - University of Utah ASC/NNSA Level 1
    - ASC/NNSA, Lawrence Livermore National Lab
- Department of Defense (DoD)
  - HPC Modernization Office (HPCMO)
- NSF Software Development for Cyberinfrastructure (SDCI)
- Research Centre Juelich
- ANL, NASA Ames, LANL, SNL
- TU Dresden
- ParaTools, Inc.
- University of Oregon Performance Research Lab

For more information

- TAU Website:
  http://tau.uoregon.edu
  - Software
  - Release notes
  - Documentation
- To use Paraprof on your local system without installing TAU: http://tau.uoregon.edu/paraprof
- Paratools: http://www.paratools.com