Performance Evaluation using the TAU Performance System®

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http://www.paratools.com/ornl11

http://www.hpclinux.com

ParaTools

Outline - Brief tutorial on the TAU toolset

ParaTools

Hands-on analysis of own benchmark application

- Review of instrumentation process, address any problems with individual applications
- Determination of routines requiring further investigation, custom profiling if needed
- Running on the HPC system, address any problems with individual application
- Analysis of communication, input/output, scalability, Flop/s using ParaProf and/or PerfExplorer
- Refinement of instrumentation to the users' needs, possible manual instrumentation of individual routines or loops
- Optional: brief presentation of results of individual applications

References:

TAU User Guide

http://tau.uoregon.edu/tau-usersguide.pdf

Agenda: Day 1

- 8:30am - 10:30am: Introduction to TAU and a short demo. Topics:
  - Introduction to interval, atomic, and context events in TAU.
  - Instrumentation options for C++, C, and UPC programs.
  - Measurement: profiling and tracing.
  - Analysis tools: paraprof, perfexplorer.
- 10:30am - 10:45am: break
- 10:45-noon: Hands-on session #1 for TAU instrumentation on Jaguar, Cray XT5.
- noon - 1:30pm: lunch break
- 1:30pm - 3:30pm: Introduction to performance engineering, measurement options for memory and I/O evaluation, and using PAPI.
- 3:30pm - 3:45pm: break
- 3:45pm - 4:30pm: Hands-on session #2:
  - Using PAPI and TAU for performance assessment of compiler optimizations
  - Memory and I/O evaluation.

Agenda: Day 2

- 8:30am - 10:30am: Instrumentation of SHMEM, MPI, OpenCL, and CUDA programs, optimization of instrumentation, analysis of performance data collected.
- 10:30am – 10:45am: break
- 10:45am – noon: Hands-on session #3:
  - Comparing performance of sample codes with different compilers on Cray.
  - Instrumentation of OpenCL and CUDA programs on GPGPU platforms.
- noon - 1:30pm: lunch break
- 1:30pm - 3:30pm: Introduction to event tracing, performance databases, and PerfExplorer for cross-experiment performance analysis and a demo.
- 3:30pm - 3:45pm: break
- 3:45pm - 4:30pm:
- Hands-on session #4:
  - Using PerfDMF database, PerfExplorer, and Jumpshot.
  - Applying TAU to other sample applications.

Workshop Goals

- This tutorial is an introduction to portable performance evaluation tools.
- You should leave here with a better understanding of…
  - Concepts and steps involved in performance evaluation
  - Understanding key concepts in improving and understanding code performance
  - How to collect and analyze data from hardware performance counters using PAPI
  - How to instrument your programs with TAU
    - Automatic instrumentation at the routine level and outer loop level
    - Manual instrumentation at the loop/statement level
  - Measurement options provided by TAU
  - Environment variables used for choosing metrics, generating performance data
  - How to use the TAU's profile browser, ParaProf
  - How to use TAU's database for storing and retrieving performance data
  - General familiarity with TAU's use for Fortran, Python, C++,C, MPI, SHMEM for mixed language programming
  - How to generate trace data in different formats
  - How to analyze trace data using Vampir, and Jumpshot

Introduction to TAU and a brief demo

TAU Performance System

Tuning and Analysis Utilities

- http://tau.uoregon.edu/
- Multi-level performance instrumentation
  - Multi-language automatic source instrumentation
- Flexible and configurable performance measurement
- Widely-ported parallel performance profiling system
  - Computer system architectures and operating systems
  - Different programming languages and compilers
- Support for multiple parallel programming paradigms
  - Multi-threading, message passing, mixed-mode, hybrid
- Integration in complex software, systems, applications

What is TAU?

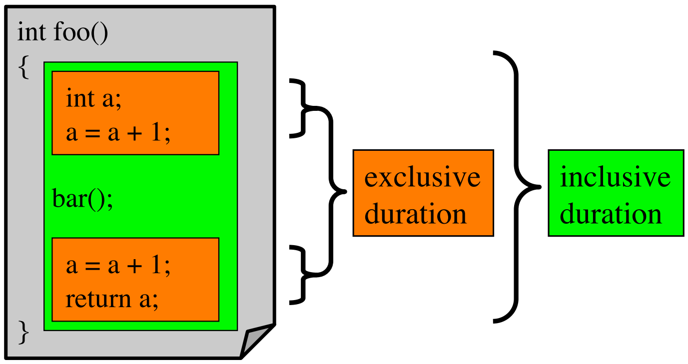
- TAU is a performance evaluation tool
- It supports parallel profiling and tracing
- Profiling shows you how much (total) time was spent in each routine
- Tracing shows you *when* the events take place in each process along a timeline
- TAU uses a package called PDT for automatic instrumentation of the source code
- Profiling and tracing can measure time as well as hardware performance counters from your CPU
- TAU can automatically instrument your source code (routines, loops, I/O, memory, phases, etc.)
- TAU runs on all HPC platforms and it is free (BSD style license)
- TAU has instrumentation, measurement and analysis tools
  - paraprof is TAU's 3D profile browser
- To use TAU's automatic source instrumentation, you need to set a couple of environment variables and substitute the name of your compiler with a TAU shell script

TAU Instrumentation Approach

- Based on direct performance observation
  - Direct instrumentation of program (system) code (probes)
  - Instrumentation invokes performance measurement
  - Event measurement: performance data, meta-data, context
- Support for standard program events
  - Routines, classes and templates
  - Statement-level blocks and loops
  - 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

Inclusive and Exclusive Profiles

- Performance with respect to code regions
- Exclusive measurements for region only
- Inclusive measurements includes child regions



Interval Events, Atomic Events in TAU

```
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

```
xterm
---------------------------------------------------------------------------------------
%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

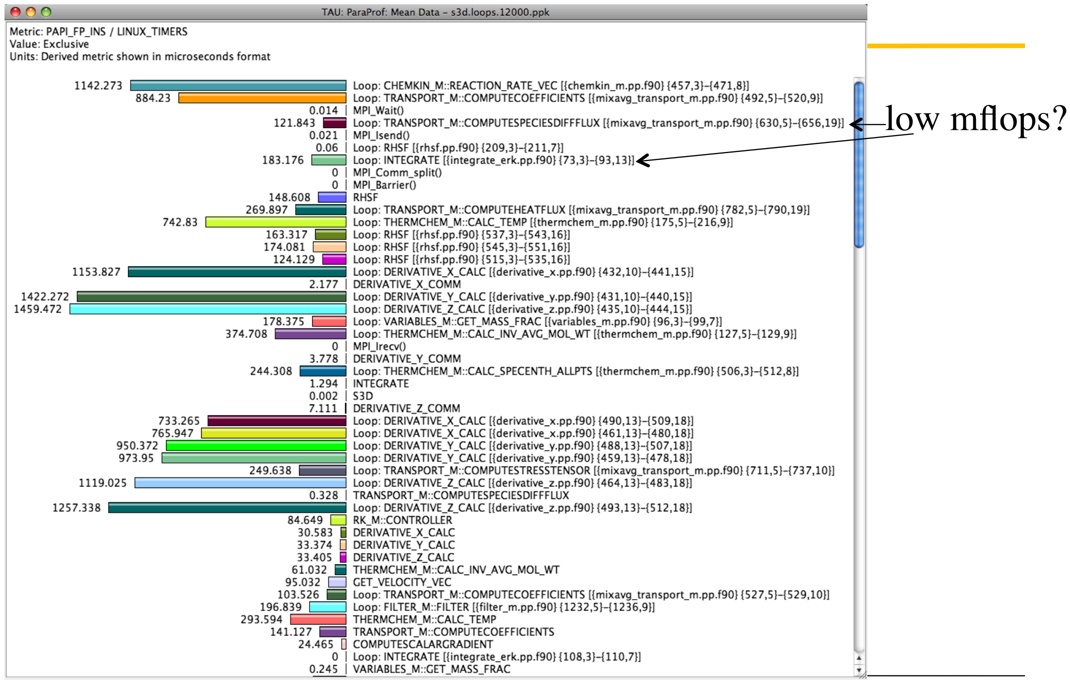
Context Events (Default)

```
xterm
NODE 0;CONTEXT 0;THREAD 0:
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0        0.357        1,114           1          44    1114040 int main(int, char **) C
 92.6        1,031        1,031           1           0    1031066 MPI_Init()
  6.7           72           74          40         320       1865 void func(int, int) C
  0.7            8            8           1           0       8002 MPI_Finalize()
  0.1            1            1         120           0         12 MPI_Recv()
  0.1        0.608        0.608          40           0         15 MPI_Barrier()
  0.0        0.136        0.136         120           0          1 MPI_Send()
  0.0        0.095        0.095          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
---------------------------------------------------------------------------------------
       365  5.139E+04      44.39  3.091E+04  1.234E+04  Heap Memory Used (KB) : Entry
         1      44.39      44.39      44.39          0  Heap Memory Used (KB) : Entry : int main(int, char **) C
         1       2068       2068       2068          0  Heap Memory Used (KB) : Entry : int main(int, char **) C => MPI_Comm_rank()
         1       2066       2066       2066          0  Heap Memory Used (KB) : Entry : int main(int, char **) C => MPI_Comm_size()
         1  5.139E+04  5.139E+04  5.139E+04          0  Heap Memory Used (KB) : Entry : int main(int, char **) C => MPI_Finalize()
         1      57.58      57.58      57.58          0  Heap Memory Used (KB) : Entry : int main(int, char **) C => MPI_Init()
        40  5.036E+04       2069  3.011E+04  1.228E+04  Heap Memory Used (KB) : Entry : int main(int, char **) C => void func(int, int) C
        40  5.139E+04       3098  3.114E+04  1.227E+04  Heap Memory Used (KB) : Entry : void func(int, int) C => MPI_Barrier()
        40  5.139E+04   1.13E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : void func(int, int) C => MPI_Bcast()
       120  5.139E+04   1.13E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : void func(int, int) C => MPI_Recv()
       120  5.139E+04   1.13E+04  3.134E+04  1.187E+04  Heap Memory Used (KB) : Entry : void func(int, int) C => MPI_Send()
       365  5.139E+04       2065  3.116E+04   1.21E+04  Heap Memory Used (KB) : Exit
                                                                              3,7            1%
```

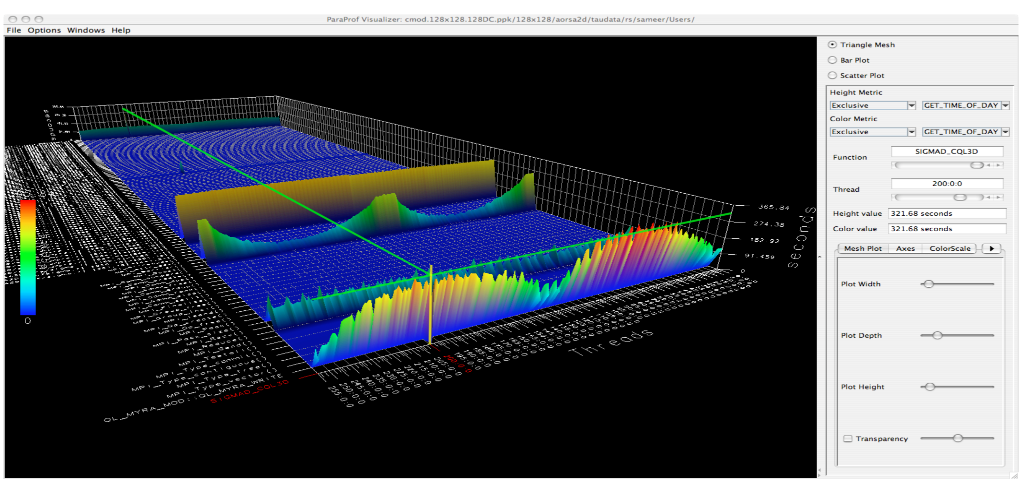
Context event = atomic event + executing context

% setenv TAU_CALLPATH_DEPTH 2
% setenv TAU_TRACK_HEAP 1

ParaProf: Mflops Sorted by Exclusive Time



Parallel Profile Visualization: ParaProf



Steps of Performance Evaluation

- Collect basic routine-level timing profile to determine where most time is being spent
- Collect routine-level hardware counter data to determine types of performance problems
- Collect callpath profiles to determine sequence of events causing performance problems
- Conduct finer-grained profiling and/or tracing to pinpoint performance bottlenecks
  - Loop-level profiling with hardware counters
  - Tracing of communication operations

Overview of different methods of instrumenting applications

Instrumentation: Events in TAU

- Event types
  - Interval events (begin/end events)
    - measures performance between begin and end
    - metrics monotonically increase
  - Atomic events
    - used to capture performance data state
- Code events
  - Routines, classes, templates
  - Statement-level blocks, loops
- User-defined events
  - Specified by the user
- Abstract mapping events

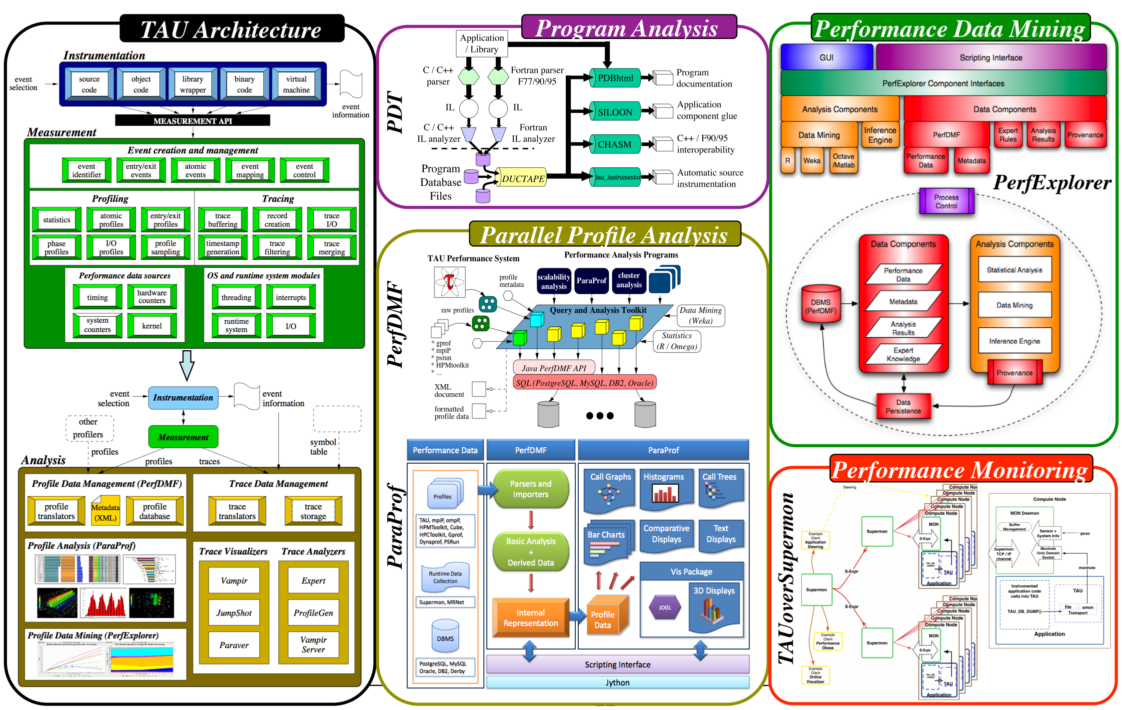
Instrumentation Techniques

- Events defined by instrumentation access
- Instrumentation levels
  - Source code
  - Object code
  - Runtime system
  - Virtual machine
  - Library code
  - Executable code
  - Operating system
  - Interpreter
- Different levels provide different information
- Different tools needed for each level
- Levels can have different granularity

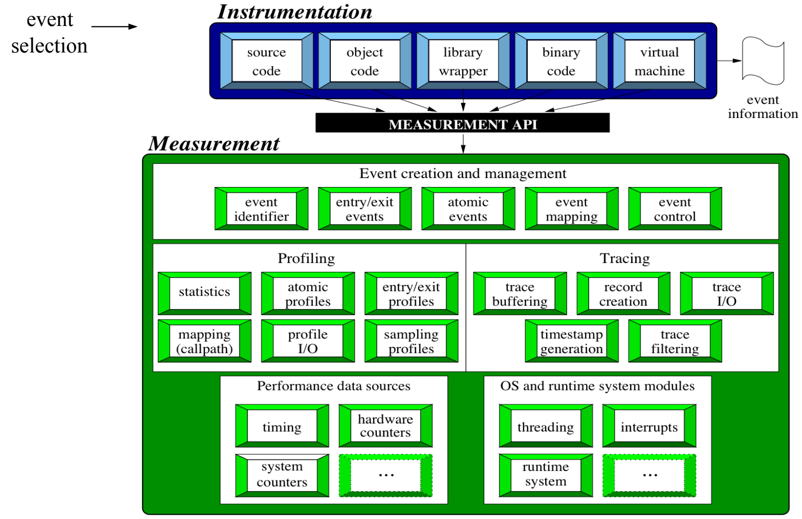
Instrumentation Techniques

- Static instrumentation
  - Program instrumented prior to execution
- Dynamic instrumentation
  - Program instrumented at runtime
- Manual and automatic mechanisms
- Tool required for automatic support
  - Source time: preprocessor, translator, compiler
  - Link time: wrapper library, preload
  - Execution time: binary rewrite, dynamic
- Advantages / disadvantages

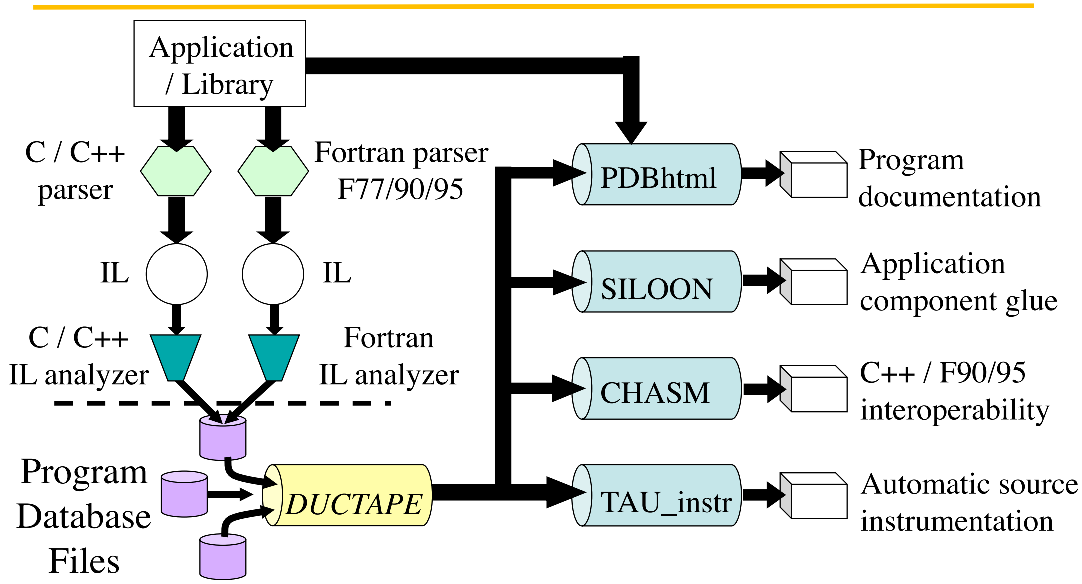
TAU Performance System Components



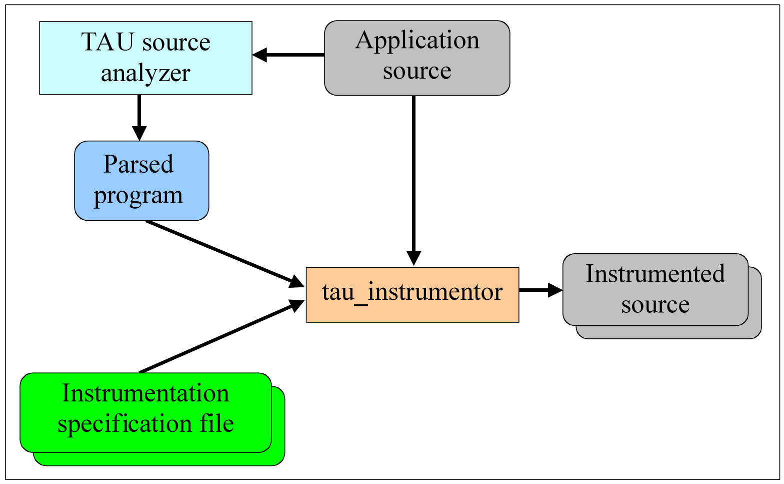
TAU Performance System Architecture



Program Database Toolkit (PDT)

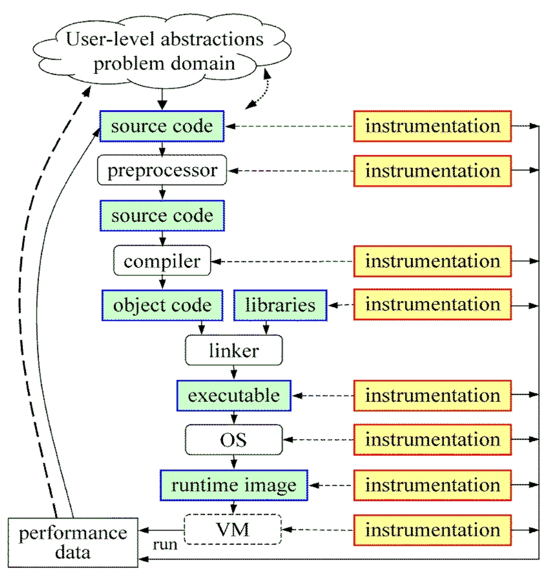


Automatic Source-Level Instrumentation in TAU using Program Database Toolkit (PDT)

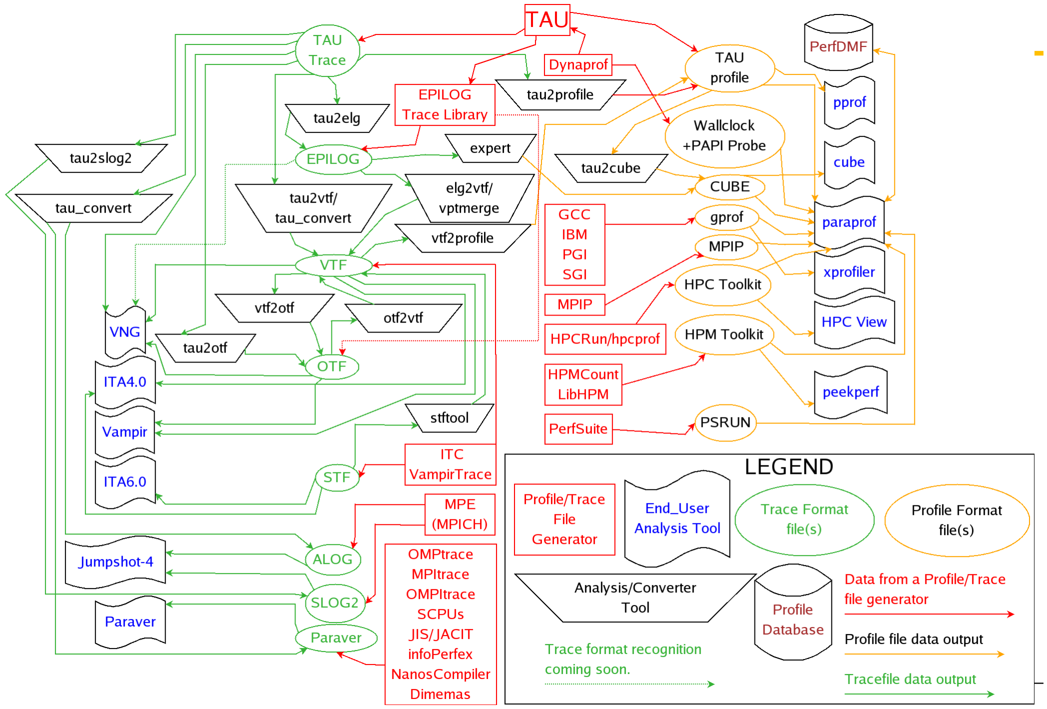


Direct Observation: Mapping

- Associate performance data with high-level semantic abstractions
- Abstract events at user-level provide semantic context



Building Bridges to Other Tools



Using TAU: A brief Introduction

- TAU supports several measurement options (profiling, tracing, profiling with hardware counters, etc.)
- Each measurement configuration of TAU corresponds to a unique stub makefile and library that is generated when you configure it
- To instrument source code using PDT
  - Choose an appropriate TAU stub makefile in <arch>/lib:

  % source /ccs/proj/perc/TOOLS/tau/tau.bashrc (or .cshrc)
  % export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-papi-mpi-pdt-pgi
  % export TAU_OPTIONS='-optVerbose …' (see tau_compiler.sh -help)

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

  % CC app.cpp

  changes to

  % tau_cxx.sh app.cpp
- Execute application and analyze performance data:

  % pprof (for text based profile display)
  % paraprof (for GUI)

TAU Measurement Configuration

```
% cd $TAU_ROOT/lib; ls Makefile.*
Makefile.tau-pdt-pgi
Makefile.tau-mpi-pdt-pgi
Makefile.tau-pthread-pdt-pgi
Makefile.tau-papi-mpi-pdt-pgi
Makefile.tau-papi-pthread-pdt-pgi
Makefile.tau-mpi-papi-pdt-pgi
```

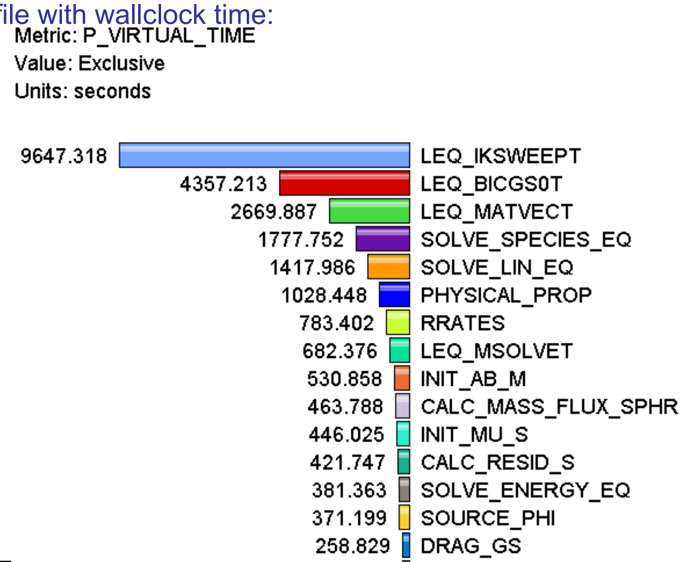
- For an MPI+F90 application, you may want to start with:

Makefile.tau-mpi-pdt-pgi

  – Supports MPI instrumentation & PDT for automatic source instrumentation
  – `% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi`
  – `% tau_f90.sh matrix.f90 -o matrix`

Usage Scenarios: Routine Level Profile

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



Solution: Generating a flat profile with MPI

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
OR
% source /ccs/proj/perc/TOOLS/tau/tau.bashrc
% tau_cxx.sh app.cpp –o app
(Or make CC=tau_cxx.sh)

% aprun -n 4./app
% pprof
% paraprof &
OR
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.

% paraprof app.ppk
(Note: you may need module load java if you have an older JVM in your
path)
Click on "node 0" to see figure shown. Right click on node to see
Other windows.
```


Automatic Instrumentation

- We now provide compiler wrapper scripts
  - Simply replace `CC` with `tau_cxx.sh`
  - Automatically instruments C++ and C source code, links with TAU MPI Wrapper libraries.
- Use `tau_cc.sh` and `tau_f90.sh` for C and Fortran

Before

```
CXX = CC
F90 = ftn
CFLAGS =
LIBS = -lm
OBJS = f1.o f2.o f3.o … fn.o

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

After

```
CXX = tau_cxx.sh
F90 = tau_f90.sh
CFLAGS =
LIBS = -lm
OBJS = f1.o f2.o f3.o … fn.o

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

TAU_COMPILER Commandline Options

- See `<taudir>/<arch>/bin/tau_compiler.sh –help`
- Compilation:

```
% ftn -c foo.f90
```

  Changes to

```
% gfparse foo.f90 $(OPT1)
% tau_instrumentor foo.pdb foo.f90 –o foo.inst.f90 $(OPT2)
% ftn –c foo.inst.f90 $(OPT3)
```

- Linking:

```
% ftn foo.o bar.o –o app
```

  Changes to

```
% ftn foo.o bar.o –o app $(OPT4)
```

- Where options OPT[1-4] default values may be overridden by the user:

```
F90 = tau_f90.sh
```


Compile-Time Environment Variables

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

-optVerbose	Turn on verbose debugging messages
-optCompInst	Use compiler based instrumentation
-optNoCompInst	Do not revert to compiler instrumentation if source instrumentation fails.
-optDetectMemoryLeaks	Turn on debugging memory allocations/ de-allocations to track leaks
-optTrackIO	Wrap POSIX I/O call and calculates vol/bw of I/O operations (Requires TAU to be configured with –iowrapper)
-optKeepFiles	Does not remove intermediate .pdb and .inst.* files
-optPreProcess	Preprocess Fortran sources before instrumentation
-optTauSelectFile=""	Specify selective instrumentation file for tau_instrumentor
-optTauWrapFile=""	Specify link_options.tau generated by tau_gen_wrapper
-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)
-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)

...

Compiling Fortran Codes with TAU

- If your Fortran code uses free format in .f files (fixed is default for .f), you may use:
  % export TAU_OPTIONS='-optPdtF95Opts="-R free" -optVerbose '

- To use the compiler based instrumentation instead of PDT (source-based):
  % export TAU_OPTIONS='-optCompInst -optVerbose'

- If your Fortran code uses C preprocessor directives (#include, #ifdef, #endif):
  % export TAU_OPTIONS='-optPreProcess -optVerbose -optDetectMemoryLeaks'

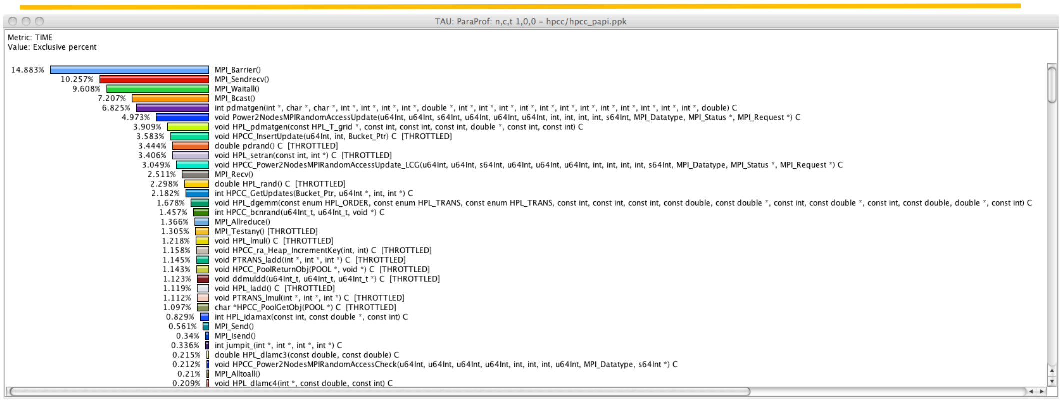
- To use an instrumentation specification file:
  % export TAU_OPTIONS='-optTauSelectFile=mycmd.tau -optVerbose -optPreProcess'
  % cat mycmd.tau
  BEGIN_INSTRUMENT_SECTION
  memory file="foo.f90" routine="#"
  # instruments all allocate/deallocate statements in all routines in foo.f90
  loops file="*" routine="#"
  io file="abc.f90" routine="FOO"
  END_INSTRUMENT_SECTION

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_MEMORY_LEAKS	0	Setting to 1 turns on leak detection (for use with tau_exec –memory)
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. 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_TRACK_IO_PARAMS	0	Setting to 1 with –optTrackIO or tau_exec –io captures arguments of I/O calls
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_INS:PAPI_NATIVE_<event>)

Throttling effect of frequently called small routines

Runtime Throttling of Events



Optimization of Program Instrumentation

- Need to eliminate instrumentation in frequently executing lightweight routines
- Throttling of events at runtime (default in tau-2.17.2+):

```
% export TAU_THROTTLE=1
```

Turns off instrumentation in routines that execute over 100000 times (TAU_THROTTLE_NUMCALLS) and take less than 10 microseconds of inclusive time per call (TAU_THROTTLE_PERCALL). Use TAU_THROTTLE=0 to disable.

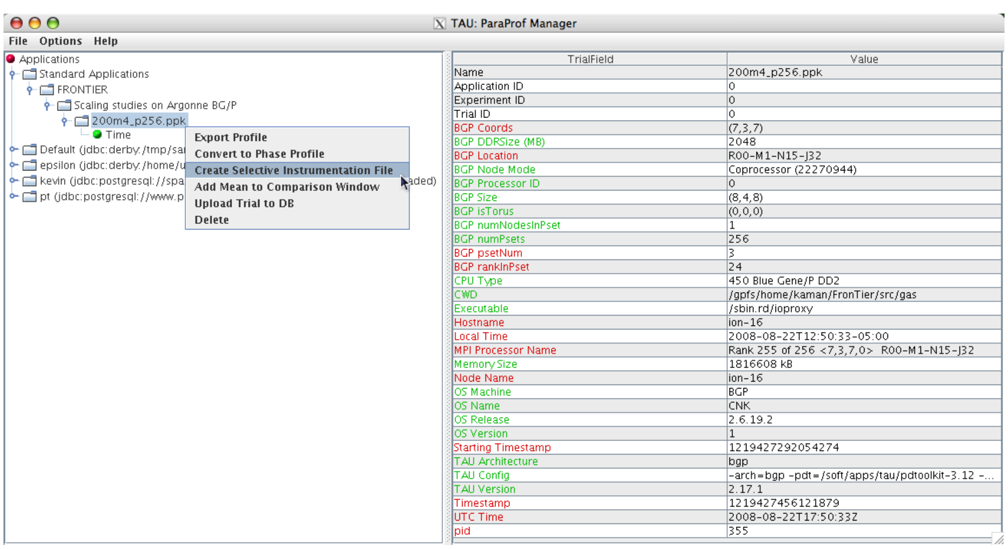
- Selective instrumentation file to filter events

```
% tau_instrumentor [options] –f <file>   OR
% export TAU_OPTIONS='-optTauSelectFile=tau.txt'
```

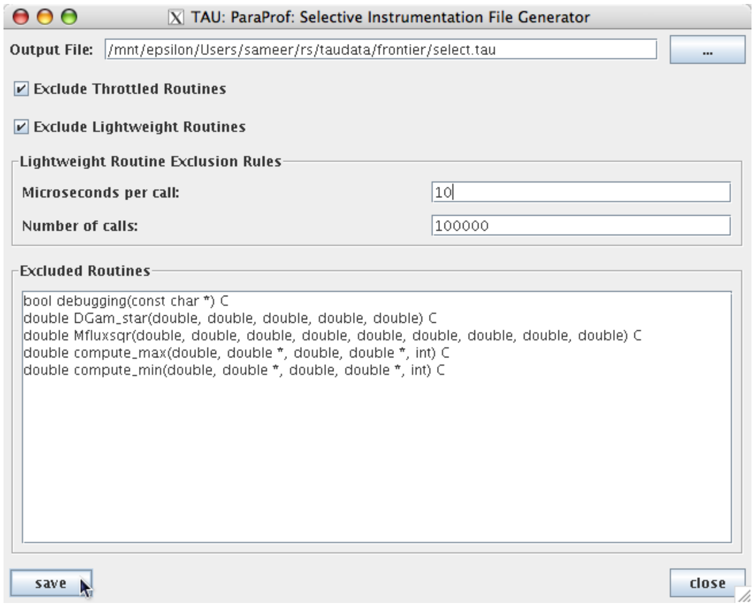
- Compensation of local instrumentation overhead

```
% export TAU_COMPENSATE=1   (in tau-2.19.2+)
```


ParaProf: Creating Selective Instrumentation File



Choosing Rules for Excluding Routines



Custom profiling

Selective Instrumentation File

- Specify a list of routines to exclude or include (case sensitive)
- # is a wildcard in a routine name. It cannot appear in the first column.

```
BEGIN_EXCLUDE_LIST
Foo
Bar
D#EMM
END_EXCLUDE_LIST
```

- Specify a list of routines to include for instrumentation

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

- Specify either an include list or an exclude list!

Selective Instrumentation File

- Optionally specify a list of files to exclude or include (case sensitive)
- * and ? may be used as wildcard characters in a file name

```
BEGIN_FILE_EXCLUDE_LIST
f*.f90
Foo?.cpp
END_FILE_EXCLUDE_LIST
```

- Specify a list of routines to include for instrumentation

```
BEGIN_FILE_INCLUDE_LIST
main.cpp
foo.f90
END_FILE_INCLUDE_LIST
```

Selective Instrumentation File

- User instrumentation commands are placed in INSTRUMENT section
- ? and * used as wildcard characters for file name, # for routine name
- \ as escape character for quotes
- Routine entry/exit, arbitrary code insertion
- Outer-loop level instrumentation

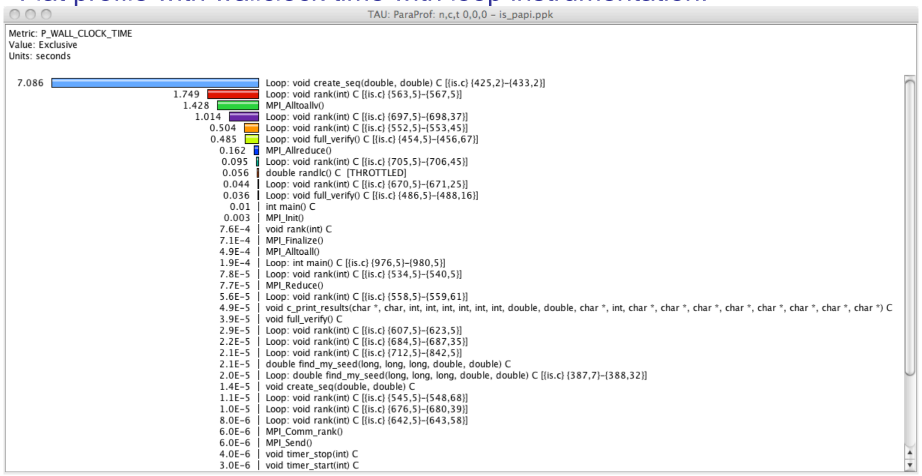
```
BEGIN_INSTRUMENT_SECTION
loops file="foo.f90" routine="matrix#"
memory file="foo.f90" routine="#"
io routine="matrix#"
[static/dynamic] phase routine="MULTIPLY"
dynamic [phase/timer] name="foo" file="foo.cpp" line=22 to line=35
file="foo.f90" line = 123 code = "  print *, \" Inside foo\""
exit routine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


Instrumentation Specification

```
% tau_instrumentor
Usage : tau_instrumentor <pdbfile> <sourcefile> [-o <outputfile>] [-noinline]
[-g groupname] [-i headerfile] [-c|-c++|-fortran] [-f <instr_req_file> ]
For selective instrumentation, use -f option
% tau_instrumentor foo.pdb foo.cpp -o foo.inst.cpp -f selective.dat
% cat selective.dat
# Selective instrumentation: Specify an exclude/include list of routines/files.
BEGIN_EXCLUDE_LIST
void quicksort(int *, int, int)
void sort_5elements(int *)
void interchange(int *, int *)
END_EXCLUDE_LIST

BEGIN_FILE_INCLUDE_LIST
Main.cpp
Foo?.c
*.C
END_FILE_INCLUDE_LIST
# Instruments routines in Main.cpp, Foo?.c and *.C files only
# Use BEGIN_[FILE]_INCLUDE_LIST with END_[FILE]_INCLUDE_LIST
```

Usage Scenarios: Loop Level Instrumentation

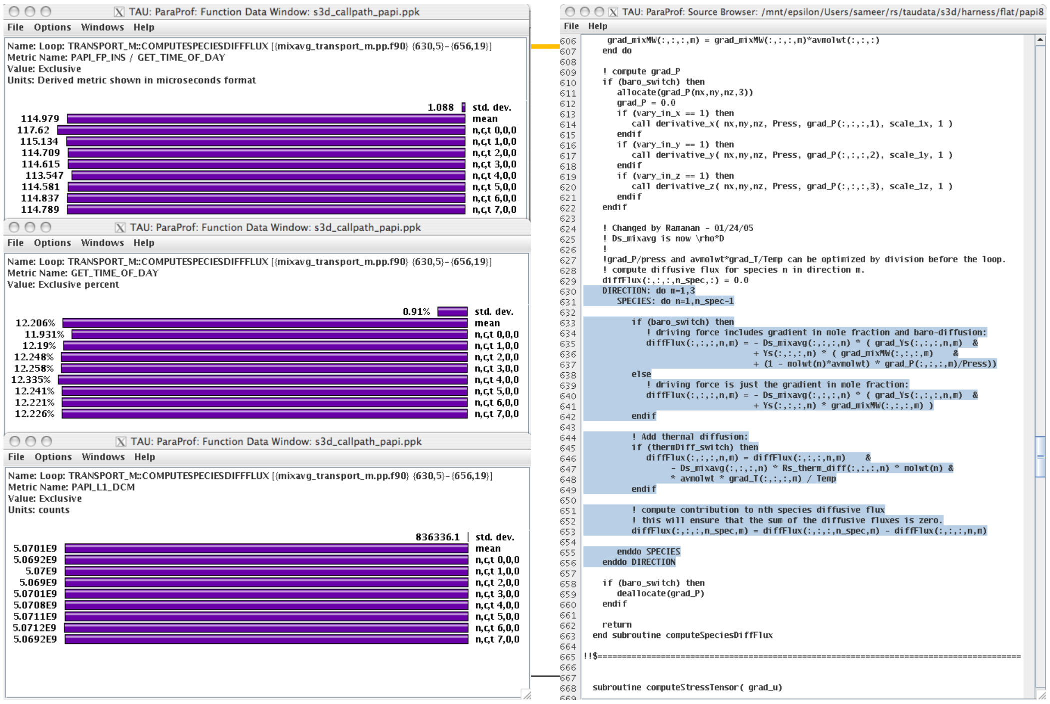
- Goal: What loops account for the most time? How much?
- Flat profile with wallclock time with loop instrumentation:



Solution: Generating a loop level profile

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi
% export TAU_OPTIONS='-optTauSelectFile=select.tau –optVerbose'
% cat select.tau
  BEGIN_INSTRUMENT_SECTION
  loops routine="#"
  END_INSTRUMENT_SECTION

% export PATH=$TAU_ROOT/bin:$PATH
% make CC=tau_cc.sh CXX=tau_cxx.sh F90=tau_f90.sh

% aprun -n 4./a.out
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.

% paraprof app.ppk
```

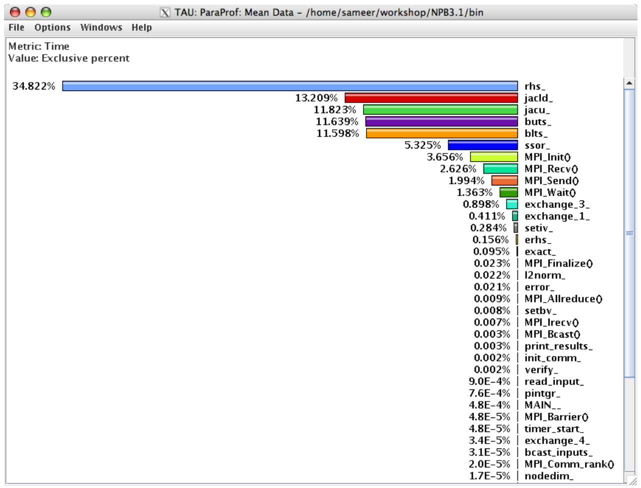
ParaProf's Source Browser: Loop Level Instrumentation



Instrumentation and Measurement Alternatives

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

```
% export TAU_MAKEFILE=$TAU_ROOT
              /lib/Makefile.tau-mpi-pdt-pgi
% export TAU_OPTIONS='-optCompInst -optVerbose'
% export PATH=$TAU_ROOT/bin:$PATH
% make CXX=tau_cxx.sh CC=tau_cc.sh
% aprun -n 4./a.out
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
```

Profiling a UPC Applications

TAU: ParaProf: Context Events for thread: n,c,t, 0,0,0 – gasp_test.ppk

Name △	Total	NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.
BUPC_STATIC_SHARED	892	6	400	4	148.667	179.739
Message size for all-gather	52	5	16	8	10.4	3.2
Message size for all-reduce	4	1	4	4	4	0
Message size for broadcast	9,157	1	9,157	9,157	9,157	0
UPC_MEMCPY	8	2	4	4	4	0
UPC_MEMGET	8	2	4	4	4	0
UPC_MEMPUT	8	2	4	4	4	0

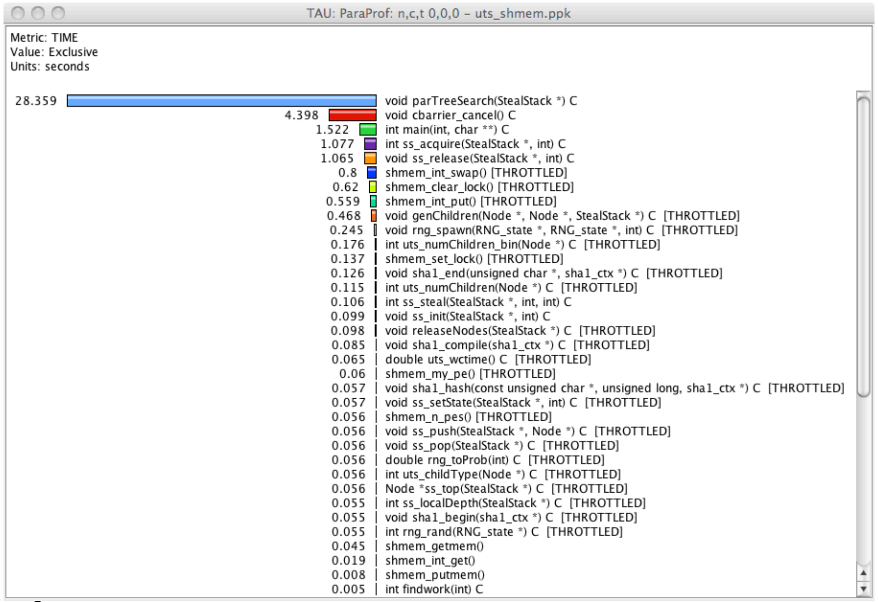
TAU: ParaProf: Thread Statistics: n,c,t, 0,0,0 – gasp_test.ppk

Name	Exclusive TIME ▽	Inclusive TIME	Exclusive TIME %	Calls	Child Calls
.TAU application	11.227	13.463	83.4%	1	306
MPI_Init_thread()	1.092	1.092	8.1%	1	0
MPI_Test()	0.907	0.907	6.7%	83,681	0
UPC_COLLECTIVE_EXIT	0.196	1.024	1.5%	1	80,623
MPI_Finalize()	0.091	0.091	0.7%	1	0
MPI_Allreduce()	0.038	0.038	0.3%	1	0
MPI_Allgather()	0.008	0.008	0.1%	5	0
UPCRI_ALLOC_gasp_test_	0.005	0.044	0.0%	2	1,842
UPC_ALL_SCATTER	0.003	0.003	0.0%	1	11
UPC_WAIT	0.002	0.015	0.0%	24	953
user_main	0.001	0.023	0.0%	144	214
MPI_Waitany()	0.001	0.001	0.0%	2	0
MPI_Bcast()	0.001	0.001	0.0%	1	0
MPI_Isend()	0.001	0.001	0.0%	193	0
MPI_Irecv()	0.001	0.001	0.0%	195	0
collectives	0	0.01	0.0%	45	73
UPC_NOTIFY	0	0.001	0.0%	24	76
MPI_Testsome()	0	0	0.0%	95	0
UPC_ALL_EXCHANGE	0	0.001	0.0%	1	80
UPC_ALL_GATHER_ALL	0	0.001	0.0%	1	63
UPC_ALL_BROADCAST	0	0.001	0.0%	1	38
MPI_Cancel()	0	0	0.0%	16	0
UPC_ALL_ALLOC	0	0	0.0%	4	24
UPC_ALL_REDUCE	0	0.001	0.0%	1	26
UPC_ALL_PREFIX_REDUCE	0	0	0.0%	1	25
MPI_Wait()	0	0	0.0%	16	0
UPC_ALL_PERMUTE	0	0.001	0.0%	1	18
UPC_ALL_GATHER	0	0	0.0%	1	20
MPI_Comm_create()	0	0	0.0%	3	0
UPC_ALL_LOCK_ALLOC	0	0	0.0%	1	18
C_MALLOC	0	0	0.0%	7	2

Profiling a UPC Application

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-upc-mpi
% export PATH=$TAU_ROOT/bin:$PATH
% export TAU_OPTIONS='-optCompInst -optVerbose'
% make CC=tau_cc.sh
(Or edit Makefile and change CXX and F90)
% export TAU_CALLPATH=1
% export TAU_CALLPATH_DEPTH=100

% aprun -n 4  ./a.out
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
(Windows -> Thread -> Call Graph)
```

Profiling a SHMEM Application



Profiling a SHMEM Application

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-papi-shmem-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
% make CC=tau_cc.sh
(Or edit Makefile and change CXX and F90)

% aprun -n 4  ./a.out
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
```

Instrumentation of OpenMP Constructs

- **O**penMP **P**ragma **A**nd **R**egion **I**nstrumentor [UTK, FZJ]
- Source-to-Source translator to insert POMP calls around OpenMP constructs and API functions
- Done: Supports
  - Fortran77 and Fortran90, OpenMP 2.0
  - C and C++, OpenMP 1.0
  - POMP Extensions
  - EPILOG and TAU POMP implementations
  - Preserves source code information (`#line` ***`line file`***)
- tau_ompcheck
  - Balances OpenMP constructs (DO/END DO) and detects errors
  - Invoked by tau_compiler.sh prior to invoking Opari
- KOJAK Project website http://icl.cs.utk.edu/kojak

OpenMP API Instrumentation

- Transform
  - `omp_#_lock()` → `pomp_#_lock()`
  - `omp_#_nest_lock()` → `pomp_#_nest_lock()`

  `[# = init|destroy|set|unset|test]`

- POMP version
  - Calls omp version internally
  - Can do extra stuff before and after call

Example: `!$OMP PARALLEL DO` Instrumentation

```
call pomp_parallel_fork(d)
!$OMP PARALLEL other-clauses...
      call pomp_parallel_begin(d)
      call pomp_do_enter(d)
      !$OMP DO schedule-clauses, ordered-clauses,
               lastprivate-clauses
            do loop
      !$OMP END DO NOWAIT
      call pomp_barrier_enter(d)
      !$OMP BARRIER
      call pomp_barrier_exit(d)
      call pomp_do_exit(d)
      call pomp_parallel_end(d)
!$OMP END PARALLEL DO
call pomp_parallel_join(d)
```


Opari Instrumentation: Example

```
pomp_for_enter(&omp_rd_2);
#line 252 "stommel.c"
#pragma omp for schedule(static) reduction(+: diff) private(j)
  firstprivate (a1,a2,a3,a4,a5) nowait
for( i=i1;i<=i2;i++) {
  for(j=j1;j<=j2;j++){
    new_psi[i][j]=a1*psi[i+1][j] + a2*psi[i-1][j] + a3*psi[i][j+1]
      + a4*psi[i][j-1] - a5*the_for[i][j];
    diff=diff+fabs(new_psi[i][j]-psi[i][j]);
  }
}
pomp_barrier_enter(&omp_rd_2);
#pragma omp barrier
pomp_barrier_exit(&omp_rd_2);
pomp_for_exit(&omp_rd_2);
```

Using Opari with TAU

Configure TAU with Opari (used here with MPI and PDT)

```
% configure -opari -arch=craycnl -mpi  -pdt=/apps/pdtoolkit-3.16
% make clean; make install
% export TAU_MAKEFILE=/tau/<arch>/lib/Makefile.tau-…opari-…
% tau_cxx.sh -c foo.cpp
% tau_cxx.sh -c bar.f90
% tau_cxx.sh *.o -o app
```


Re-writing Binaries

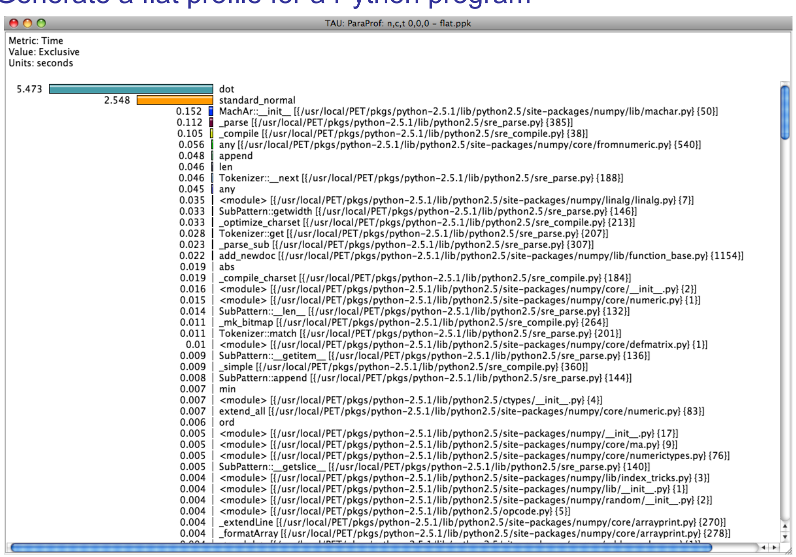
- Support for both static and dynamic executables
- Specify the list of routines to instrument/exclude from instrumentation
- Specify the TAU measurement library to be injected
- Simplify the usage of TAU:
  - To instrument:
    - % tau_run a.out –o a.inst
  - To perform measurements, execute the application:
    - % mpirun –np 4 ./a.inst
  - To analyze the data:
    - % paraprof

tau_run with NAS PBS

```
livetau@paratools01:~
/home/livetau% cd ~/tutorial
/home/livetau/tutorial% # Build an uninstrumented bt NAS Parallel Benchmark
/home/livetau/tutorial% make bt CLASS=W NPROCS=4
/home/livetau/tutorial% cd bin
/home/livetau/tutorial/bin% # Run the instrumented code
/home/livetau/tutorial/bin% mpirun -np 4 ./bt_W.4
/home/livetau/tutorial/bin%
/home/livetau/tutorial/bin% # Instrument the executable using TAU with DyninstAPI
/home/livetau/tutorial/bin%
/home/livetau/tutorial/bin% tau_run ./bt_W.4 -o ./bt.i
/home/livetau/tutorial/bin% rm -rf profile.* MULT*
/home/livetau/tutorial/bin% mpirun -np 4 ./bt.i
/home/livetau/tutorial/bin% paraprof
/home/livetau/tutorial/bin%
/home/livetau/tutorial/bin% # Choose a different TAU configuration
/home/livetau/tutorial/bin% ls $TAU/libTAUsh
libTAUsh-depthlimit-mpi-pdt.so*             libTAUsh-papi-pdt.so*
libTAUsh-mpi-pdt.so*                        libTAUsh-papi-pthread-pdt.so*
libTAUsh-mpi-pdt-upc.so*                    libTAUsh-param-mpi-pdt.so*
libTAUsh-mpi-python-pdt.so*                 libTAUsh-pdt.so*
libTAUsh-papi-mpi-pdt.so*                   libTAUsh-pdt-trace.so*
libTAUsh-papi-mpi-pdt-upc.so*               libTAUsh-phase-papi-mpi-pdt.so*
libTAUsh-papi-mpi-pdt-upc-udp.so*           libTAUsh-pthread-pdt.so*
libTAUsh-papi-mpi-pdt-vampirtrace-trace.so* libTAUsh-python-pdt.so*
libTAUsh-papi-mpi-python-pdt.so*
/home/livetau/tutorial/bin%
/home/livetau/tutorial/bin% tau_run -XrunTAUsh-papi-mpi-pdt-vampirtrace-trace bt_W.4 -o bt.vpt
/home/livetau/tutorial/bin% setenv VT_METRICS PAPI_FP_INS:PAPI_L1_DCM
/home/livetau/tutorial/bin% mpirun -np 4 ./bt.vpt
/home/livetau/tutorial/bin% vampir bt.vpt.otf &
```


Usage Scenarios: Instrument a Python program

- Goal: Generate a flat profile for a Python program



Usage Scenarios: Instrument a Python program

Original code:

```
% cat foo.py
#!/usr/bin/env python
import numpy
ra=numpy.random
la=numpy.linalg

size=2000
a=ra.standard_normal((size,size))
b=ra.standard_normal((size,size))
c=la.linalg.dot(a,b)
print c
```

Create a wrapper:

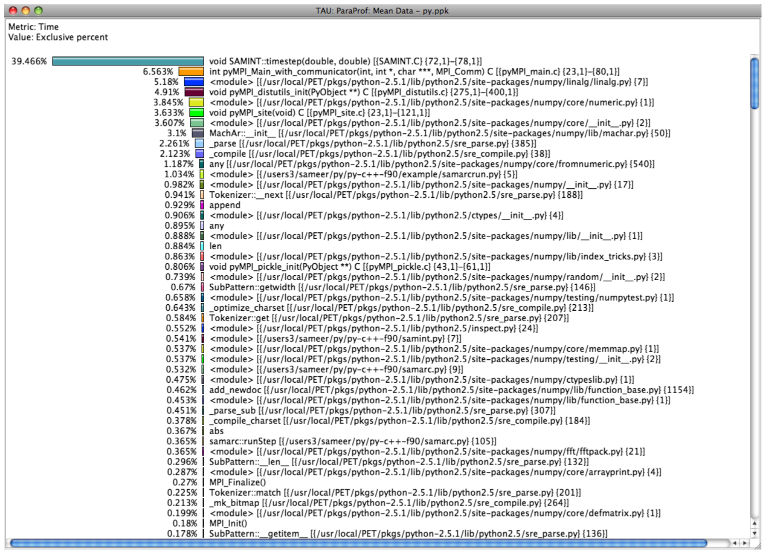
```
% cat wrapper.py
#!/usr/bin/env python

# setenv PYTHONPATH $PET_HOME/pkgs/tau-2.17.3/ppc64/lib/bindings-gnu-python-pdt

import tau

def OurMain():
    import foo

tau.run('OurMain()')
```


Generate a Python Profile

```
% export TAU_MAKEFILE=$TAU_ROOT
                /lib/Makefile.tau-python-pdt
% export PATH=$TAU_ROOT/bin:$PATH
% cat wrapper.py
  import tau
  def OurMain():
      import foo
  tau.run('OurMain()')
Uninstrumented:
% ./foo.py
Instrumented:
% export PYTHONPATH= <taudir>/x86_64/<lib>/bindings-python-pdt
(same options string as TAU_MAKEFILE)
% ./wrapper.py

Wrapper invokes foo and generates performance data
% pprof/paraprof
```

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

```
% export TAU_MAKEFILE=$TAU_ROOT
                /lib/Makefile.tau-python-mpi-pdt
% export PATH=$TAU_ROOT/bin:$PATH
% export 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 libs, pyMPI w/TAU)
% cat wrapper.py
  import tau
  def OurMain():
      import App
  tau.run('OurMain()')
Uninstrumented:
% mpirun –np 4 pyMPI ./App.py
Instrumented:
% export PYTHONPATH= <taudir>/x86_64/<lib>/bindings-python-mpi-pdt
(same options string as TAU_MAKEFILE)
% export LD_LIBRARY_PATH=<taudir>/x86_64/lib/bindings-python-mpi-pdt:
$LD_LIBRARY_PATH
% mpirun –np 4 tau_exec –T python,mpi,pdt pyMPI ./wrapper.py
(Instruments pyMPI with wrapper.py)
```

Using TAU with Java Applications

Step I: Sun JDK 1.6+ [download from www.javasoft.com]

Step II: Configure TAU with JDK (v 1.6 or better)

```
% configure -jdk=/usr/jdk1.6
% make clean; make install
```

Builds <taudir>/<arch>/lib/libTAU.so

For Java (without instrumentation):

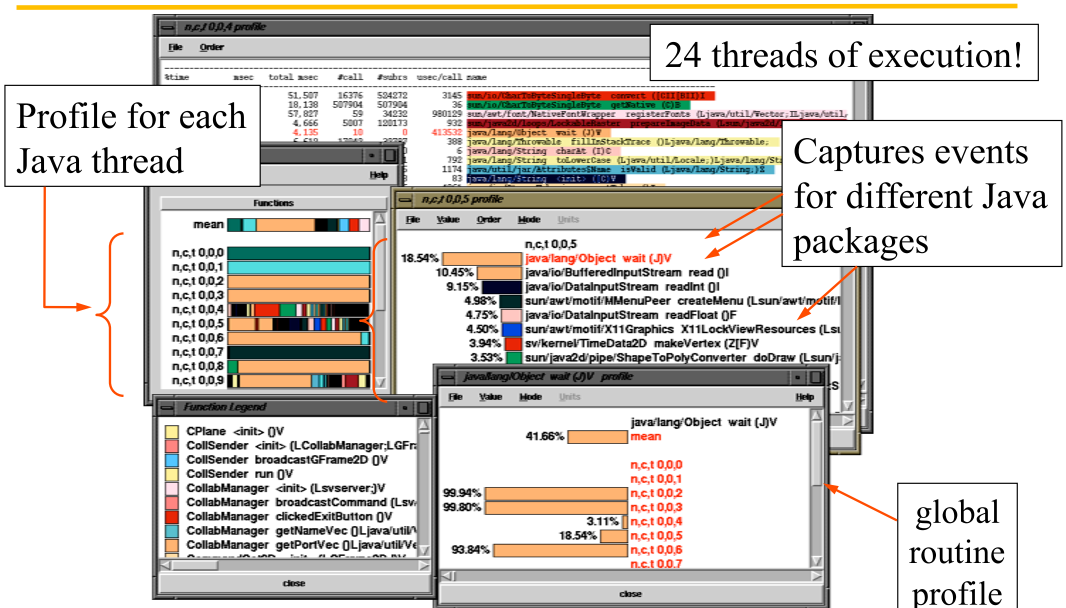
```
% java application
```

With instrumentation:

```
% tau_java application
% tau_java -tau:agentlib=<different_libTAU.so> -tau:include=<item>
    -tau:exclude=<item> application
```

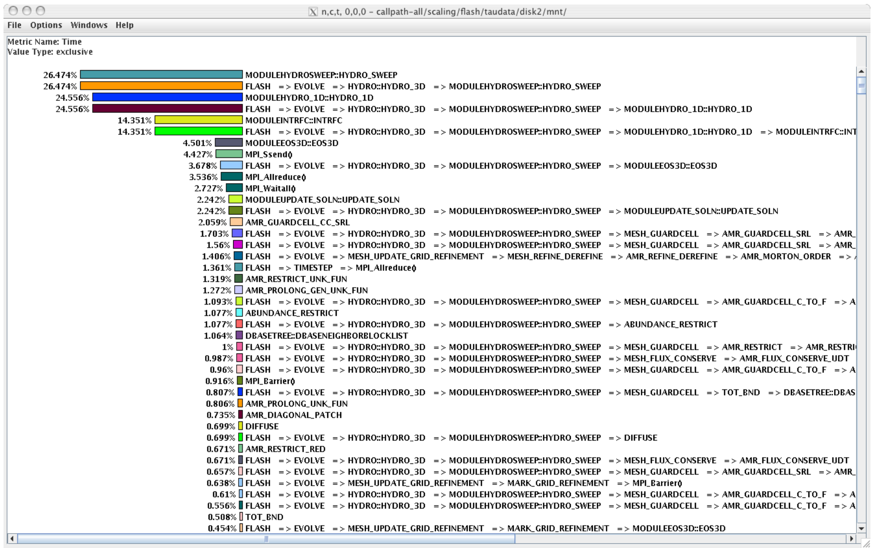
Excludes where item=*.<init>;Foobar.method;sun.*classes

TAU Profiling of Java Application (SciVis)



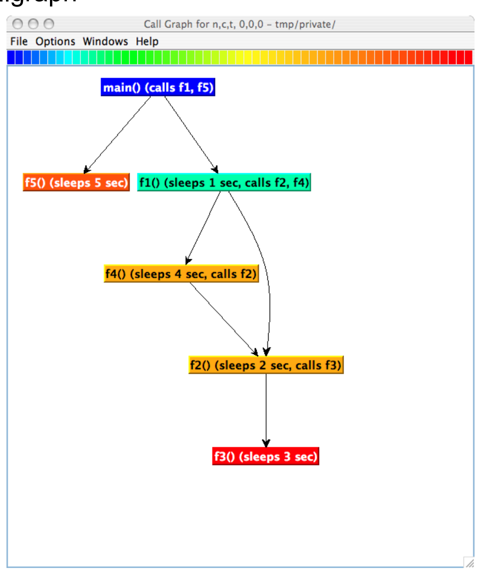
Usage Scenarios: Generating Callpath Profile

- Callpath profile for a given callpath depth:



Callpath Profile

- Generates program callgraph



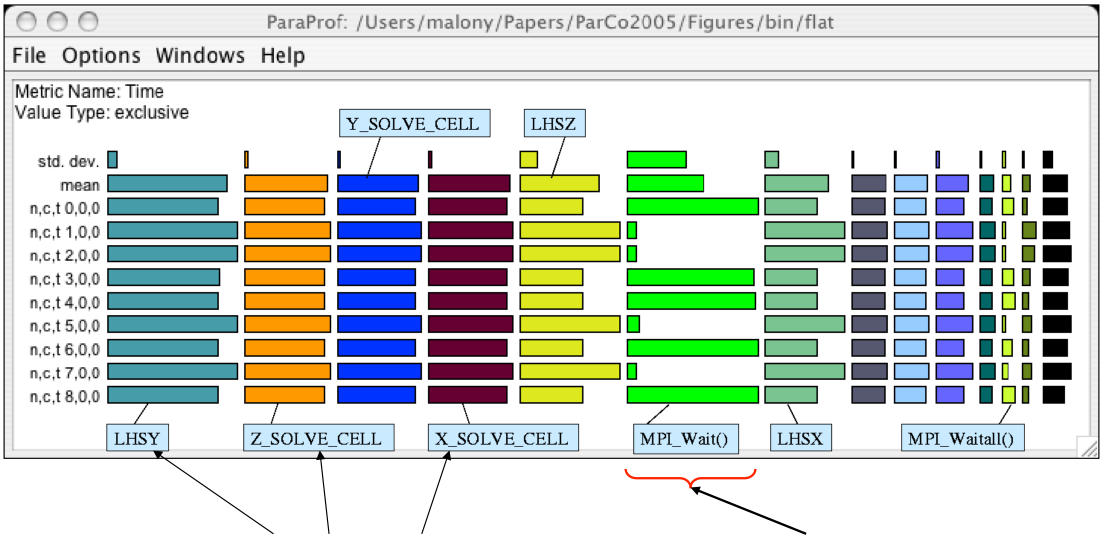
Generate a Callpath Profile

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
% make F90=tau_f90.sh CXX=tau_cxx.sh
(Or edit Makefile and change CXX and F90)
% export TAU_CALLPATH=1
% export TAU_CALLPATH_DEPTH=100

% aprun -n 4  ./a.out
% paraprof --pack app.ppk
  Move the app.ppk file to your desktop.
% paraprof app.ppk
(Windows -> Thread -> Call Graph)
```


Profile Measurement – Three Flavors

- Flat profiles
  - Time (or counts) spent in each routine (nodes in callgraph).
  - Exclusive/inclusive time, no. of calls, child calls
  - E.g,: MPI_Send, foo, …
- Callpath Profiles
  - Flat profiles, **plus**
  - Sequence of actions that led to poor performance
  - Time spent along a calling path (edges in callgraph)
  - E.g., “main=> f1 => f2 => MPI_Send” shows the time spent in MPI_Send when called by f2, when f2 is called by f1, when it is called by main. Depth of this callpath = 4 (TAU_CALLPATH_DEPTH environment variable)
- Phase based profiles
  - Flat profiles, **plus**
  - Flat profiles under a phase (nested phases are allowed)
  - Default “main” phase has all phases and routines invoked outside phases
  - Supports static or dynamic (per-iteration) phases
  - E.g., “IO => MPI_Send” is time spent in MPI_Send in IO phase

Phase Profiling (NAS BT, Flat Profile)

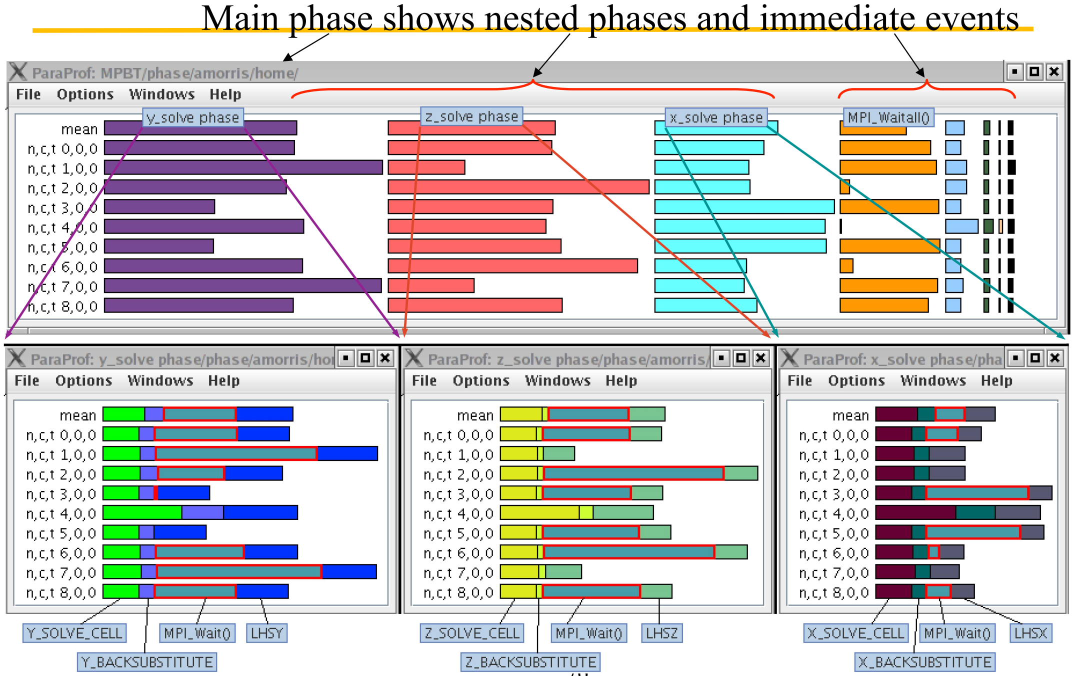


Application routine names reflect phase semantics

How is MPI_Wait() distributed relative to solver direction?

NAS BT – Phase Profile (Main and X, Y, Z)

Main phase shows nested phases and immediate events

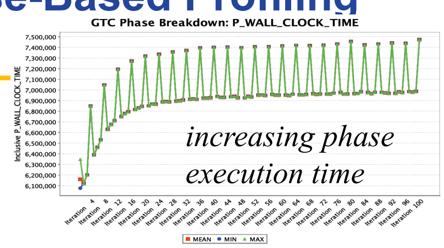


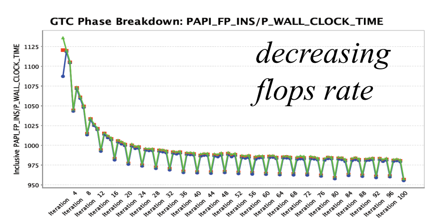
TAU Timers and Phases

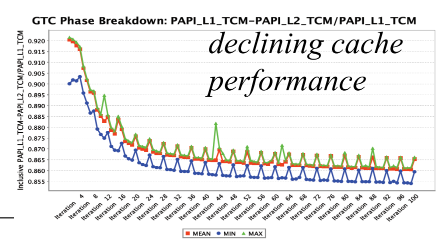
- Static timer
  - Shows time spent in all invocations of a routine (foo)
  - E.g., “foo()” 100 secs, 100 calls
- Dynamic timer
  - Shows time spent in each invocation of a routine
  - E.g., “foo() 3” 4.5 secs, “foo 10” 2 secs (invocations 3 and 10 respectively)
- Static phase
  - Shows time spent in all routines called (directly/indirectly) by a given routine (foo)
  - E.g., “foo() => MPI_Send()” 100 secs, 10 calls shows that a total of 100 secs were spent in MPI_Send() when it was called by foo.
- Dynamic phase
  - Shows time spent in all routines called by a given invocation of a routine.
  - E.g., “foo() 4 => MPI_Send()” 12 secs, shows that 12 secs were spent in MPI_Send when it was called by the 4th invocation of foo.

Performance Dynamics: Phase-Based Profiling

- Profile phases capture performance with respect to application-defined ‘phases’ of execution
  - Separate full profile produce for each phase
- GTC particle-in-cell simulation of fusion turbulence
- Phases assigned to iterations
- Data change affects cache







Library interposition/wrapping: tau_exec, tau_wrap

- TAU provides a wealth of options to measure the performance of an application
- Need to simplify TAU usage to easily evaluate performance properties, including I/O, memory, and communication
- Designed a new tool (*tau_exec*) that leverages runtime instrumentation by pre-loading measurement libraries
- Works on dynamic executables (default under Linux, not on Cray)
- Substitutes I/O, MPI, and memory allocation/deallocation routines with instrumented calls
  - Interval events (e.g., time spent in write())
  - Atomic events (e.g., how much memory was allocated)
- Measure I/O and memory usage

TAU Execution Command (tau_exec)

- Uninstrumented execution
  - % mpirun –np 256 ./a.out
- Track MPI performance (-T <options>)
  - % mpirun –np 256 tau_exec ./a.out
- Track I/O and MPI performance (MPI by default, use –T serial for serial)
  - % mpirun –np 256 tau_exec –io ./a.out
- Track memory operations
  - % setenv TAU_TRACK_MEMORY_LEAKS 1
  - % mpirun –np 256 tau_exec –T papi,mpi,pdt –memory ./a.out
- Track I/O performance and memory operations
  - % mpirun –np 256 tau_exec –io –memory ./a.out
- Track GPGPU operations
  - % mpirun –np 256 tau_exec –cuda ./a.out
  - % tau_exec –T serial –cuda ./a.out
  - % tau_exec –T serial –opencl ./a.out

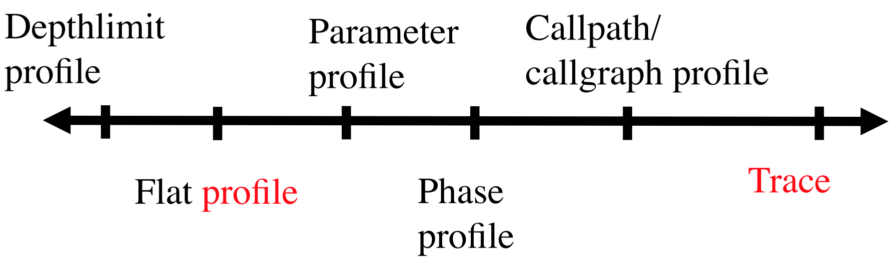
Library wrapping: tau_gen_wrapper

- How to instrument an external library without source?
  - Source may not be available
  - Library may be too cumbersome to build (with instrumentation)
- Build a library wrapper tools
  - Used PDT to parse header files
  - Generate new header files with instrumentation files
  - Three methods to instrument: runtime preloading, linking, redirecting headers to re-define functions
- Application is instrumented
- Add the –optTauWrapFile=<wrapperdir>/link_options.tau file to TAU_OPTIONS env var while compiling with tau_cc.sh, etc.
- Wrapped library
  - Redirects references at routine callsite to a wrapper call
  - Wrapper internally calls the original
  - Wrapper has TAU measurement code

HDF5 Library Wrapping

```
$ tau_gen_wrapper hdf5.h /usr/lib/libhdf5.a -f select.tau

Usage : tau_gen_wrapper <header> <library> [-r|-d|-w (default)] [-g groupname] [-i
headerfile] [-c|-c++|-fortran] [-f <instr_req_file> ]
• instruments using runtime preloading (-r), or -Wl,-wrap linker (-w), redirection
of header file to redefine the wrapped routine (-d)
• instrumentation specification file (select.tau)
• -g group may be specified (hdf5)
• tau_exec loads libhdf5_wrap.so shared library using –loadlib=<libwrap_pkg.so>
• creates the wrapper/ directory with linkoptions.tau passed to the TAU_OPTIONS
environment variable using –optTauWrapFile=<file>

NODE 0;CONTEXT 0;THREAD 0:
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0        0.057            1           1          13       1236 .TAU Application
 70.8        0.875        0.875           1           0        875 hid_t H5Fcreate()
  9.7         0.12         0.12           1           0        120 herr_t H5Fclose()
  6.0        0.074        0.074           1           0         74 hid_t H5Dcreate()
  3.1        0.038        0.038           1           0         38 herr_t H5Dwrite()
  2.6        0.032        0.032           1           0         32 herr_t H5Dclose()
  2.1        0.026        0.026           1           0         26 herr_t H5check_version()
  0.6        0.008        0.008           1           0          8 hid_t H5Screate_simple()
  0.2        0.002        0.002           1           0          2 herr_t H5Tset_order()
  0.2        0.002        0.002           1           0          2 hid_t H5Tcopy()
  0.1        0.001        0.001           1           0          1 herr_t H5Sclose()
```

Performance Evaluation Alternatives



Each alternative has:
- one metric/counter
- multiple counters

→ Volume of performance data

-PROFILEPARAM Configuration Option

- Idea: partition performance data for individual functions based on runtime parameters
- Enable by configuring with –PROFILEPARAM
- Choose TAU stub makefile with –param in its name
- TAU call: TAU_PROFILE_PARAM1L (value, "name")

```
void foo(long input) {
   TAU_PROFILE("foo", "", TAU_DEFAULT);
   TAU_PROFILE_PARAM1L(input, "input");
   ... }
```

Workload Characterization

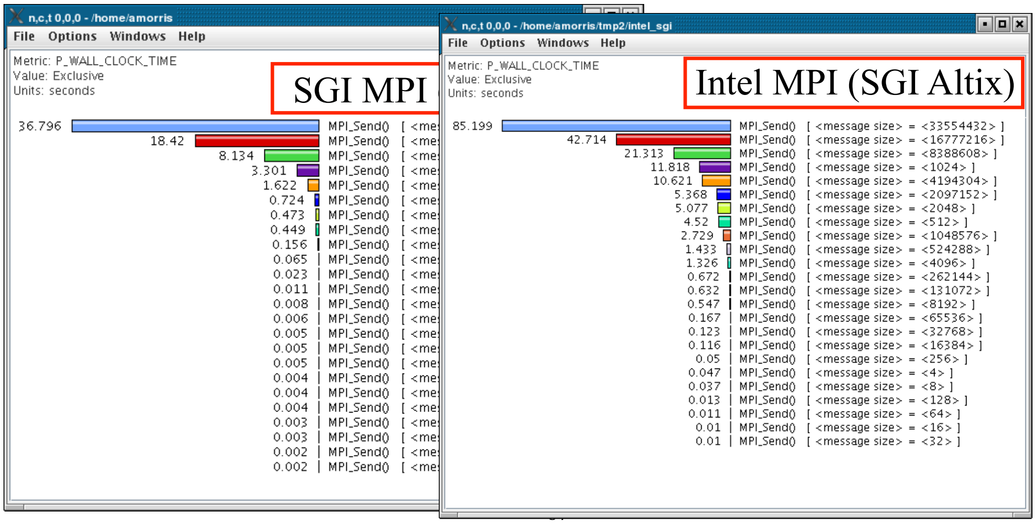
- 5 seconds spent in function "`foo`" becomes
  - 2 seconds for "`foo [ <input> = <25> ]`"
  - 1 seconds for "`foo [ <input> = <5> ]`"
  - …
- Currently used in MPI wrapper library
  - Allows for partitioning of time spent in MPI routines based on parameters (message size, message tag, destination node)
  - Can be extrapolated to infer specifics about the MPI subsystem and system as a whole

Workload Characterization

```
#include <stdio.h>
#include <mpi.h>
int buffer[8*1024*1024];

int main(int argc, char **argv) {
  int rank, size, i, j;
  MPI_Init(&argc, &argv);
  MPI_Comm_size( MPI_COMM_WORLD, &size );
  MPI_Comm_rank( MPI_COMM_WORLD, &rank );
  for (i=0;i<1000;i++)
    for (j=1;j<=8*1024*1024;j*=2) {
      if (rank == 0) {
        MPI_Send(buffer,j,MPI_INT,1,42,MPI_COMM_WORLD);
      } else {
        MPI_Status status;
        MPI_Recv(buffer,j,MPI_INT,0,42,MPI_COMM_WORLD,&status);
      }
    }
  MPI_Finalize();
}
```

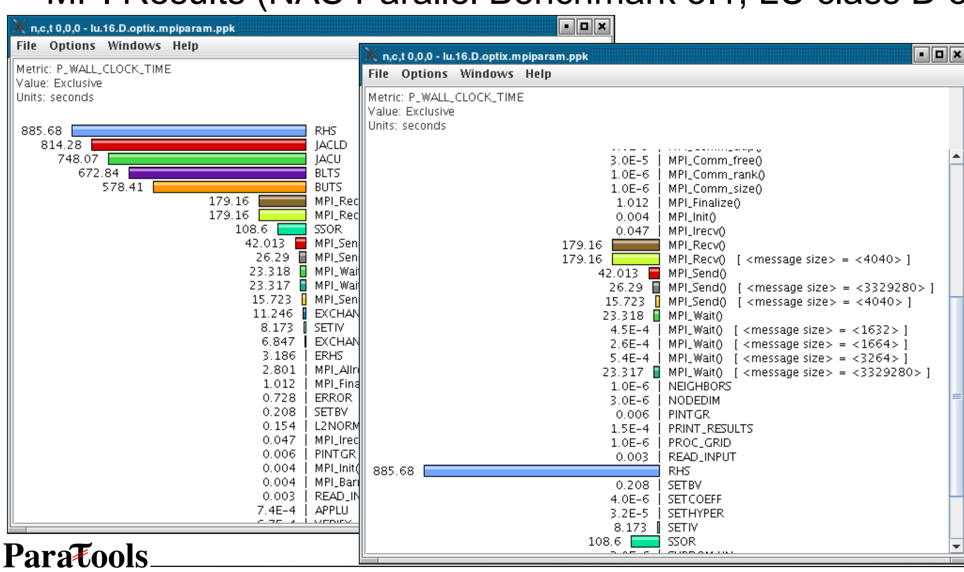
Workload Characterization

```
% icc mpi.c -lmpi
% mpirun -np 2 tauex a.out
```



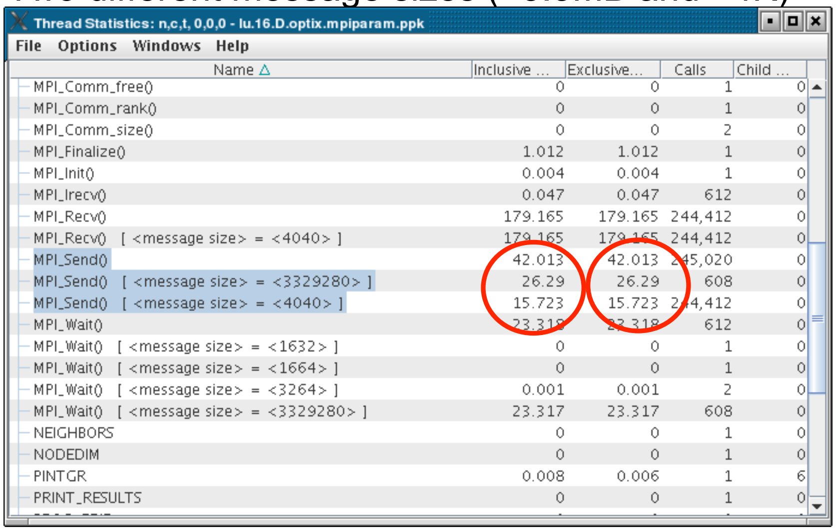
Workload Characterization

- MPI Results (NAS Parallel Benchmark 3.1, LU class D on



Workload Characterization

- Two different message sizes (~3.3MB and ~4K)

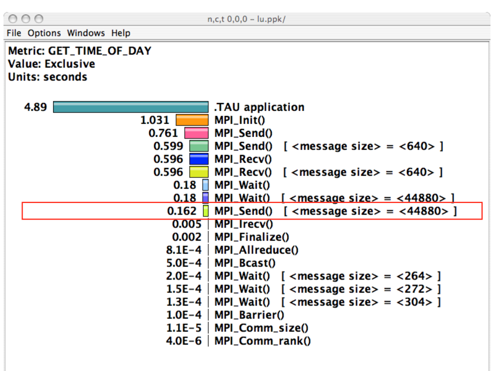


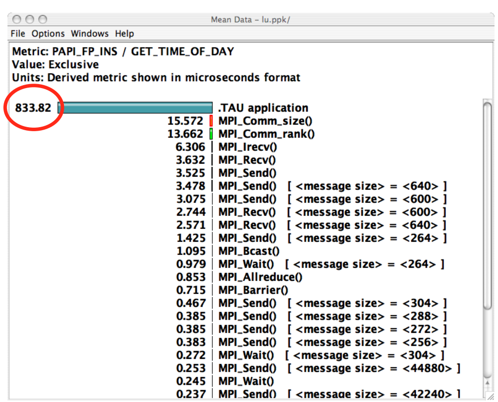
Thread Statistics: n,c,t, 0,0,0 - lu.16.D.optix.mpiparam.ppk

File Options Windows Help

Name △	Inclusive ...	Exclusive...	Calls	Child ...
MPI_Comm_free()	0	0	1	0
MPI_Comm_rank()	0	0	1	0
MPI_Comm_size()	0	0	2	0
MPI_Finalize()	1.012	1.012	1	0
MPI_Init()	0.004	0.004	1	0
MPI_Irecv()	0.047	0.047	612	0
MPI_Recv()	179.165	179.165	244,412	0
MPI_Recv() [<message size> = <4040>]	179.165	179.165	244,412	0
MPI_Send()	42.013	42.013	245,020	0
MPI_Send() [<message size> = <3329280>]	26.29	26.29	608	0
MPI_Send() [<message size> = <4040>]	15.723	15.723	244,412	0
MPI_Wait()	23.318	23.318	612	0
MPI_Wait() [<message size> = <1632>]	0	0	1	0
MPI_Wait() [<message size> = <1664>]	0	0	1	0
MPI_Wait() [<message size> = <3264>]	0.001	0.001	2	0
MPI_Wait() [<message size> = <3329280>]	23.317	23.317	608	0
NEIGHBORS	0	0	1	0
NODEDIM	0	0	1	0
PINTGR	0.008	0.006	1	6
PRINT_RESULTS	0	0	1	0

Job Tracking: ParaProf profile browser





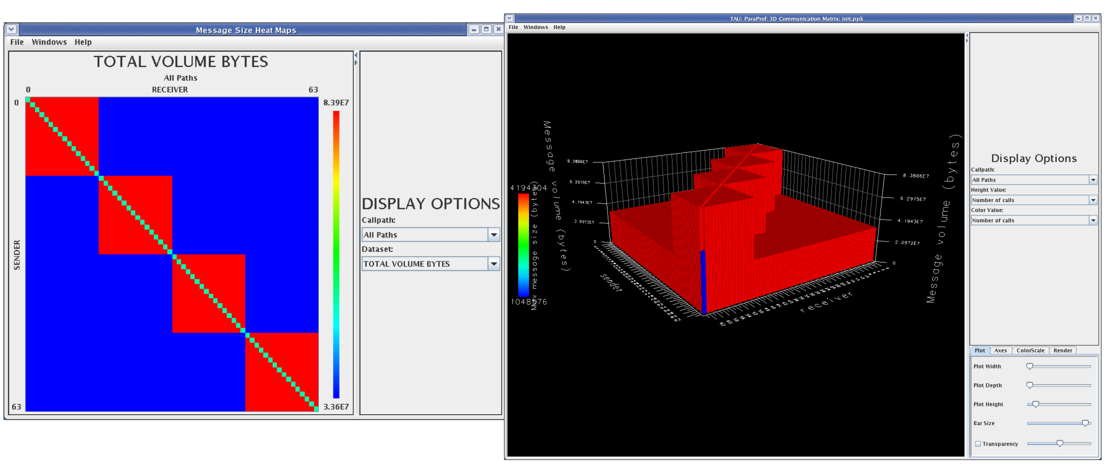
LU spent 0.162 seconds sending messages of size 44880

It got 833.82 Mflops!

Parameter Based Profiling

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-param-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
% make CC=tau_cc.sh
% aprun -n 4./a.out
% paraprof
```


ParaProf: Communication Matrix Display



Communication Matrix

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt
% export PATH=$TAU_ROOT/bin:$PATH
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)

%
% export TAU_COMM_MATRIX=1
%aprun -n 4./a.out (setting the environment variables)

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


Techniques for manual instrumentation of individual routines

Instrumenting a C code

```
#include <TAU.h>
int foo(int x) {
  TAU_START("foo");
   for (i = 0; i < x; i++) { // do work
   }
  TAU_STOP("foo");
}

int main(int argc, char **argv) {
  TAU_INIT(&argc, &argv);
  TAU_START("main");
  TAU_PROFILE_SET_NODE(rank);
  …
  TAU_STOP("main");
}
% gcc -I<taudir>/include foo.c -o foo -L<taudir>/<arch>/lib -lTAU
% ./a.out
% pprof; paraprof
NOTE: Replace TAU_START("foo") with call TAU_START('foo')
       in Fortran. See <taudir>/include/TAU.h for full API.
```


Using PAPI and TAU

Hardware Counters

Hardware performance counters available on most modern microprocessors can provide insight into:

1. Whole program timing
2. Cache behaviors
3. Branch behaviors
4. Memory and resource access patterns
5. Pipeline stalls
6. Floating point efficiency
7. Instructions per cycle

Hardware counter information can be obtained with:

1. Subroutine or basic block resolution
2. Process or thread attribution

What's PAPI?

PAPI

- Open Source software from U. Tennessee, Knoxville
- http://icl.cs.utk.edu/papi
- Middleware to provide a consistent programming interface for the performance counter hardware found in most major micro-processors.
- Countable events are defined in two ways:
  - Platform-neutral *preset* events
  - Platform-dependent native events
- Presets can be derived from multiple *native events*
- All events are referenced by name and collected in EventSets

PAPI Utilities: *papi_avail*

```
$ utils/papi_avail -h
Usage: utils/papi_avail [options]
Options:

General command options:
    -a, --avail   Display only available preset events
    -d, --detail  Display detailed information about all preset events
    -e EVENTNAME  Display detail information about specified preset or native event
    -h, --help    Print this help message

Event filtering options:
        --br          Display branch related PAPI preset events
        --cache       Display cache related PAPI preset events
        --cnd         Display conditional PAPI preset events
        --fp          Display Floating Point related PAPI preset events
        --ins         Display instruction related PAPI preset events
        --idl         Display Stalled or Idle PAPI preset events
        --l1          Display level 1 cache related PAPI preset events
        --l2          Display level 2 cache related PAPI preset events
        --l3          Display level 3 cache related PAPI preset events
        --mem         Display memory related PAPI preset events
        --msc         Display miscellaneous PAPI preset events
        --tlb         Display Translation Lookaside Buffer PAPI preset events

This program provides information about PAPI preset and native events.
PAPI preset event filters can be combined in a logical OR.
```

PAPI Utilities: *papi_avail*

```
$ utils/papi_avail
Available events and hardware information.
--------------------------------------------------------------------------------
PAPI Version             : 4.0.0.0
Vendor string and code   : GenuineIntel (1)
Model string and code    : Intel Core i7 (21)
CPU Revision             : 5.000000
CPUID Info               : Family: 6  Model: 26  Stepping: 5
CPU Megahertz            : 2926.000000
CPU Clock Megahertz      : 2926
Hdw Threads per core     : 1
Cores per Socket         : 4
NUMA Nodes               : 2
CPU's per Node           : 4
Total CPU's              : 8
Number Hardware Counters : 7
Max Multiplex Counters   : 32
--------------------------------------------------------------------------------
The following correspond to fields in the PAPI_event_info_t structure.

    [MORE…]
```

PAPI Utilities: *papi_avail*

```
     [CONTINUED…]

--------------------------------------------------------------------------------
The following correspond to fields in the PAPI_event_info_t structure.

    Name        Code    Avail Deriv Description (Note)
PAPI_L1_DCM  0x80000000  No    No   Level 1 data cache misses
PAPI_L1_ICM  0x80000001  Yes   No   Level 1 instruction cache misses
PAPI_L2_DCM  0x80000002  Yes   Yes  Level 2 data cache misses

[…]

PAPI_VEC_SP  0x80000069  Yes   No   Single precision vector/SIMD instructions
PAPI_VEC_DP  0x8000006a  Yes   No   Double precision vector/SIMD instructions
-------------------------------------------------------------------------
Of 107 possible events, 34 are available, of which 9 are derived.

avail.c                                  PASSED
```


PAPI Utilities: *papi_avail*

```
$ utils/papi_avail -e PAPI_FP_OPS
[…]
---------------------------------------------------------------------------
The following correspond to fields in the PAPI_event_info_t structure.

Event name:                    PAPI_FP_OPS
Event Code:                    0x80000066
Number of Native Events:       2
Short Description:            |FP operations|
Long Description:             |Floating point operations|
Developer's Notes:            ||
Derived Type:                 |DERIVED_ADD|
Postfix Processing String:    ||
 Native Code[0]: 0x4000801b |FP_COMP_OPS_EXE:SSE_SINGLE_PRECISION|
 Number of Register Values: 2
 Register[ 0]: 0x0000000f |Event Selector|
 Register[ 1]: 0x00004010 |Event Code|
 Native Event Description: |Floating point computational micro-ops, masks:SSE* FP single precision Uops|

 Native Code[1]: 0x4000081b |FP_COMP_OPS_EXE:SSE_DOUBLE_PRECISION|
 Number of Register Values: 2
 Register[ 0]: 0x0000000f |Event Selector|
 Register[ 1]: 0x00008010 |Event Code|
 Native Event Description: |Floating point computational micro-ops, masks:SSE* FP double precision Uops|
-------------------------------------------------------------------------
```

PAPI Utilities: *papi_native_avail*

```
UNIX> utils/papi_native_avail
Available native events and hardware information.
--------------------------------------------------------------------------------
[…]
Event Code   Symbol  | Long Description |
--------------------------------------------------------------------------------
0x40000010   BR_INST_EXEC  | Branch instructions executed                      |
  40000410   :ANY  | Branch instructions executed                            |
  40000810   :COND  | Conditional branch instructions executed               |
  40001010   :DIRECT  | Unconditional branches executed                      |
  40002010   :DIRECT_NEAR_CALL  | Unconditional call branches executed       |
  40004010   :INDIRECT_NEAR_CALL  | Indirect call branches executed          |
  40008010   :INDIRECT_NON_CALL  | Indirect non call branches executed       |
  40010010   :NEAR_CALLS  | Call branches executed                           |
  40020010   :NON_CALLS  | All non call branches executed                    |
  40040010   :RETURN_NEAR  | Indirect return branches executed               |
  40080010   :TAKEN  | Taken branches executed                               |
--------------------------------------------------------------------------------
0x40000011   BR_INST_RETIRED  | Retired branch instructions                  |
  40000411   :ALL_BRANCHES  | Retired branch instructions (Precise Event)    |
  40000811   :CONDITIONAL  | Retired conditional branch instructions (Precise |
           | Event)                                                          |
  40001011   :NEAR_CALL  | Retired near call instructions (Precise Event)    |
--------------------------------------------------------------------------------
[…]
```

PAPI Utilities: *papi_native_avail*

```
UNIX> utils/papi_native_avail -e DATA_CACHE_REFILLS
Available native events and hardware information.
--------------------------------------------------------------------------------
[…]
--------------------------------------------------------------------------------
The following correspond to fields in the PAPI_event_info_t structure.

Event name:                    DATA_CACHE_REFILLS
Event Code:                    0x4000000b
Number of Register Values:     2
Description:                  |Data Cache Refills from L2 or System|
 Register[ 0]:   0x0000000f  |Event Selector|
 Register[ 1]:   0x00000042  |Event Code|

Unit Masks:
 Mask Info:                   |:SYSTEM|Refill from System|
  Register[ 0]:  0x0000000f  |Event Selector|
  Register[ 1]:  0x00000142  |Event Code|
 Mask Info:                   |:L2_SHARED|Shared-state line from L2|
  Register[ 0]:  0x0000000f  |Event Selector|
  Register[ 1]:  0x00000242  |Event Code|
 Mask Info:                   |:L2_EXCLUSIVE|Exclusive-state line from L2|
  Register[ 0]:  0x0000000f  |Event Selector|
  Register[ 1]:  0x00000442  |Event Code|
```

PAPI Utilities: *papi_event_chooser*

```
$ utils/papi_event_chooser PRESET PAPI_FP_OPS
Event Chooser: Available events which can be added with given events.
--------------------------------------------------------------------------------
[…]
--------------------------------------------------------------------------------
    Name        Code    Deriv Description (Note)
PAPI_L1_DCM  0x80000000  No   Level 1 data cache misses
PAPI_L1_ICM  0x80000001  No   Level 1 instruction cache misses
PAPI_L2_ICM  0x80000003  No   Level 2 instruction cache misses
[…]
PAPI_L1_DCA  0x80000040  No   Level 1 data cache accesses
PAPI_L2_DCR  0x80000044  No   Level 2 data cache reads
PAPI_L2_DCW  0x80000047  No   Level 2 data cache writes
PAPI_L1_ICA  0x8000004c  No   Level 1 instruction cache accesses
PAPI_L2_ICA  0x8000004d  No   Level 2 instruction cache accesses
PAPI_L2_TCA  0x80000059  No   Level 2 total cache accesses
PAPI_L2_TCW  0x8000005f  No   Level 2 total cache writes
PAPI_FML_INS 0x80000061  No   Floating point multiply instructions
PAPI_FDV_INS 0x80000063  No   Floating point divide instructions
-------------------------------------------------------------------------
Total events reported: 34
event_chooser.c                          PASSED
```


PAPI Utilities: *papi_event_chooser*

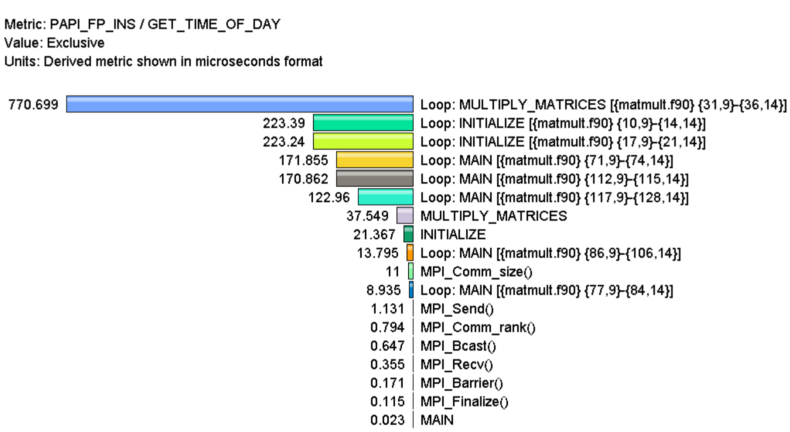
```
$ utils/papi_event_chooser PRESET PAPI_FP_OPS PAPI_L1_DCM
Event Chooser: Available events which can be added with given events.
--------------------------------------------------------------------------------
[…]
--------------------------------------------------------------------------------

    Name        Code    Deriv Description (Note)
PAPI_TOT_INS 0x80000032  No   Instructions completed
PAPI_TOT_CYC 0x8000003b  No   Total cycles
-------------------------------------------------------------------------
Total events reported: 2
event_chooser.c                          PASSED
```

PAPI Utilities: *papi_event_chooser*

```
$ utils/papi_event_chooser NATIVE RESOURCE_STALLS:LD_ST X87_OPS_RETIRED
    INSTRUCTIONS_RETIRED
[…]
--------------------------------------------------------------------------------
UNHALTED_CORE_CYCLES    0x40000000
 |count core clock cycles whenever the clock signal on the specific core is running (not
    halted). Alias to event CPU_CLK_UNHALTED:CORE_P|
 |Register Value[0]: 0x20003       Event Selector|
 |Register Value[1]: 0x3c          Event Code|
-------------------------------------------------------------------------
UNHALTED_REFERENCE_CYCLES        0x40000002
 |Unhalted reference cycles. Alias to event CPU_CLK_UNHALTED:REF|
 |Register Value[0]: 0x40000       Event Selector|
 |Register Value[1]: 0x13c         Event Code|
-------------------------------------------------------------------------
CPU_CLK_UNHALTED        0x40000028
 |Core cycles when core is not halted|
 |Register Value[0]: 0x60000       Event Selector|
 |Register Value[1]: 0x3c          Event Code|
    0x40001028  :CORE_P  |Core cycles when core is not halted|
    0x40008028  :NO_OTHER  |Bus cycles when core is active and the other is halted|
-------------------------------------------------------------------------
Total events reported: 3
event_chooser.c                          PASSED
```

Usage Scenarios: Calculate mflops in Loops

- Goal: What MFlops am I getting in all loops?
- Flat profile with PAPI_FP_INS/OPS and time with loop instrumentation:

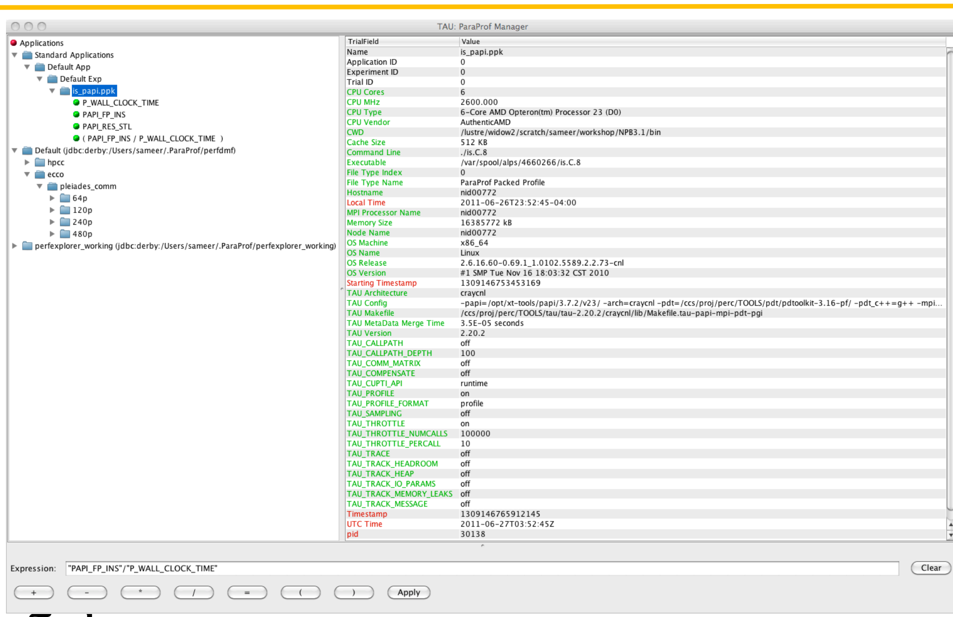


Par

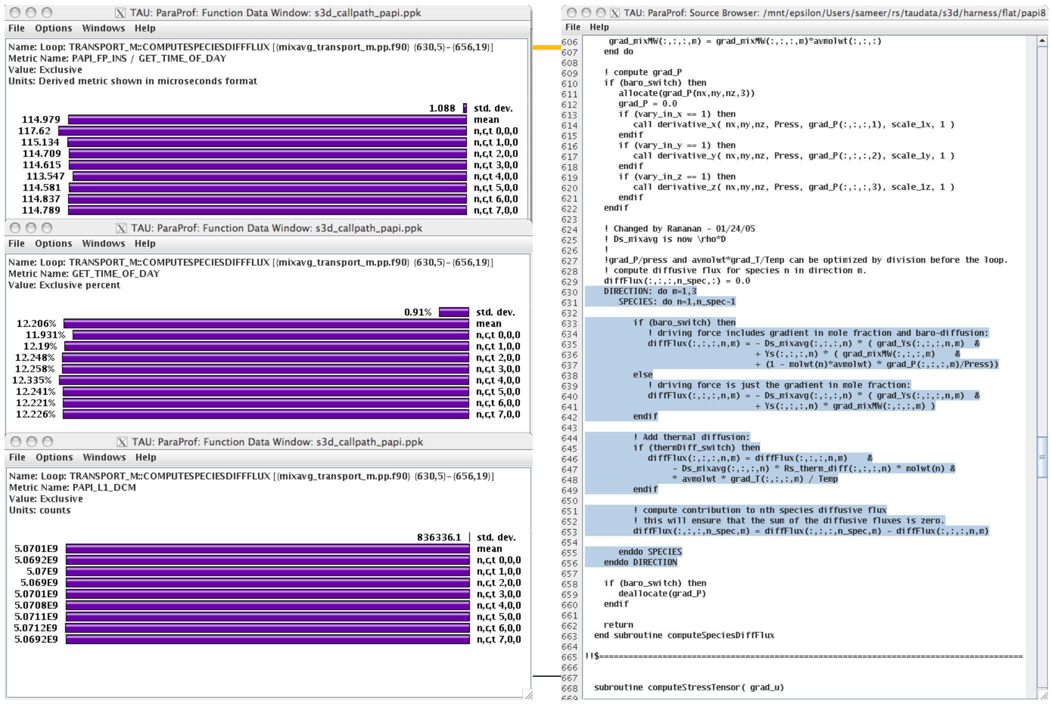
Generate a PAPI profile with 2 or more counters

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-papi-mpi-pdt-pgi
% export TAU_OPTIONS='-optTauSelectFile=select.tau -optVerbose'
% cat select.tau
  BEGIN_INSTRUMENT_SECTION
  loops routine="#"
  END_INSTRUMENT_SECTION

% export PATH=$TAU_ROOT/bin:$PATH
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
%
% export TAU_METRICS=TIME:PAPI_FP_INS:PAPI_L1_DCM
%aprun -n 4 ./a.out
% paraprof --pack app.ppk
   Move the app.ppk file to your desktop.
% paraprof app.ppk
  Choose Options -> Show Derived Metrics Panel -> "PAPI_FP_INS", click "/", "TIME", click
    "Apply" and choose the derived metric.
```


Derived Metrics in ParaProf



ParaProf's Source Browser: Loop Level Instrumentation



Estimation of tool intrusiveness

PAPI Utilities: *papi_cost*

```
$ utils/papi_cost -h
This is the PAPI cost program.
It computes min / max / mean / std. deviation for PAPI start/stop pairs;
    for PAPI reads, and for PAPI_accums.
   Usage:

    cost [options] [parameters]
    cost TESTS_QUIET

Options:

  -b BINS       set the number of bins for the graphical
                 distribution of costs. Default: 100
  -d            show a graphical distribution of costs
  -h            print this help message
  -s            show number of iterations above the first
                 10 std deviations
  -t THRESHOLD  set the threshold for the number of
                 iterations. Default: 100,000
```


PAPI Utilities: *papi_cost*

```
$ utils/papi_cost
Cost of execution for PAPI start/stop and PAPI read.
This test takes a while. Please be patient...
Performing start/stop test...

Total cost for PAPI_start/stop(2 counters) over 1000000 iterations
min cycles   : 63
max cycles   : 17991
mean cycles  : 69.000000
std deviation: 34.035263
 Performing start/stop test...

Performing read test...

Total cost for PAPI_read(2 counters) over 1000000 iterations
min cycles   : 288
max cycles   : 102429
mean cycles  : 301.000000
std deviation: 144.694053
 cost.c                                   PASSED
```

PAPI Utilities: *papi_cost*

```
Cost distribution profile

      63:**************************** 999969 counts ****************************
     153:
     243:
     [...]
    1863:
    1953:********************
    2043:
    2133:********************
    2223:
    2313:
    2403:********************
    2493:********************
    2583:****************************************
    2673:****************************************
    2763:****************************************************************************
    2853:****************************************
    2943:
    3033:********************
    3123:****************************************
    3213:****************************************
    3303:
    3393:
    3483:
    3573:
    3663:********************
```


Memory and I/O evaluation

Library interposition/wrapping: tau_exec, tau_wrap

- TAU provides a wealth of options to measure the performance of an application
- Need to simplify TAU usage to easily evaluate performance properties, including I/O, memory, and communication
- Designed a new tool (*tau_exec*) that leverages runtime instrumentation by pre-loading measurement libraries
- Works on dynamic executables (default under Linux)
- Substitutes I/O, MPI, and memory allocation/deallocation routines with instrumented calls
  - Interval events (e.g., time spent in write())
  - Atomic events (e.g., how much memory was allocated)
- Measure I/O and memory usage

ParaTools

TAU Execution Command (tau_exec)

- Configure TAU with –iowrapper configuration option
- Uninstrumented execution
  - % mpirun –np 256 ./a.out
- Track MPI performance
  - % mpirun –np 256 tau_exec ./a.out
- Track I/O and MPI performance (MPI enabled by default)
  - % mpirun –np 256 tau_exec –io ./a.out
- Track memory operations
  - % setenv TAU_TRACK_MEMORY_LEAKS 1
  - % mpirun –np 256 tau_exec –memory ./a.out
- Track I/O performance and memory operations
  - % mpirun –np 256 tau_exec –io –memory ./a.out
- Track GPGPU operations
  - % mpirun –np 256 tau_exec –cuda ./a.out

ParaTools

A New Approach: tau_exec

- Runtime instrumentation by pre-loading the measurement library
- Works on dynamic executables (default under Linux)
- Substitutes I/O, MPI and memory allocation/deallocation routines with instrumented calls
- Track interval events (e.g., time spent in write()) as well as atomic events (e.g., how much memory was allocated) in wrappers
- Accurately measure I/O and memory usage

Tracking I/O in static binaries (Cray)

- The linker can substitute TAU's I/O wrapper and intercept POSIX I/O Calls
- We can track parameters that flow through the I/O calls
- Configure TAU with –iowrappers
- Use –optTrackIO in TAU_OPTIONS

Tracking I/O in static binaries

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
% export TAU_OPTIONS='-optTrackIO -optVerbose'
% make CC=tau_cc.sh CXX=tau_cxx.sh F90=tau_f90.sh
% aprun -n 4 ./a.out
% paraprof -pack ioprofile.ppk
% export TAU_TRACK_IO_PARAMS 1
% aprun -n 4 ./a.out (to track parameters used in POSIX I/O
  calls as context events)
```


Issues

- Heap memory usage reported by the mallinfo() call is not 64-bit clean.
  - 32 bit counters in Linux roll over when > 4GB memory is used
  - We keep track of heap memory usage in 64 bit counters inside TAU
- Compensation of perturbation introduced by tool
  - Only show what application uses
  - Create guards for TAU calls to not track I/O and memory allocations/de-allocations performed inside TAU
- Provide broad POSIX I/O and memory coverage

I/O Calls Supported

Unbuffered I/O	Buffered I/O	Communication	Control	Asynchronous I/O
open	fopen	socket	fcntl	aio_read
open64	fopen64	pipe	rewind	aio_write
close	fdopen	socketpair	lseek	aio_suspend
read	freopen	bind	lseek64	aio_cancel
write	fclose	accept	fseek	aio_return
readv	fprintf	connect	dup	lio_listio
writev	fscanf	recv	dup2	
creat	fwrite	send	mkstep	
creat64	fread	sendto	tmpfile	
		recvfrom		
		pclose		

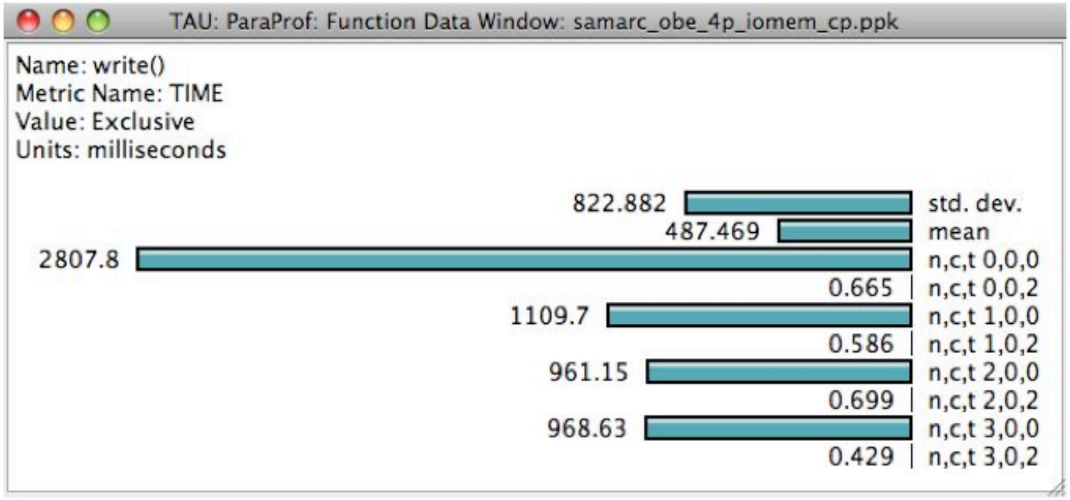
Tracking I/O in Each File

TAU: ParaProf: Context Events for thread: n,c,t, 1,0,0 - IOR_mana_iothreads_posix.ppk

File Windows Help

Name △	Total	NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.
.TAU application						
MPI_Finalize()						
MPI_Init()						
fscanf()						
read()						
Bytes Read	20,024	32	8,192	4	625.75	2,014.699
Bytes Read <file="/opt/openmpi/tm/intel/1.4/etc/openmpi-mca-params.conf">	2,812	1	2,812	2,812	2,812	0
Bytes Read <file="/opt/openmpi/tm/intel/1.4/share/openmpi/help-mpi-btl-openib.txt">	8,192	1	8,192	8,192	8,192	0
Bytes Read <file="/opt/openmpi/tm/intel/1.4/share/openmpi/mca-btl-openib-device-params.ini">	8,727	2	8,192	535	4,363.5	3,828.5
Bytes Read <file="/sys/class/infiniband/mthca0/node_type">	8	1	8	8	8	0
Bytes Read <file="/sys/class/infiniband/mthca0/ports/1/gids/0">	41	1	41	41	41	0
Bytes Read <file="/sys/class/infiniband_verbs/abi_version">	8	1	8	8	8	0
Bytes Read <file="/sys/class/infiniband_verbs/uverbs0/abi_version">	8	1	8	8	8	0
Bytes Read <file="/sys/class/infiniband_verbs/uverbs0/device/device">	24	3	8	8	8	0
Bytes Read <file="/sys/class/infiniband_verbs/uverbs0/device/vendor">	24	3	8	8	8	0
Bytes Read <file="/sys/class/infiniband_verbs/uverbs0/ibdev">	64	1	64	64	64	0
Bytes Read <file="/sys/devices/system/cpu/cpu0/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu0/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu1/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu1/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu2/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu2/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu3/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu3/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu4/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu4/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu5/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu5/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu6/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu6/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu7/topology/core_id">	7	1	7	7	7	0
Bytes Read <file="/sys/devices/system/cpu/cpu7/topology/physical_package_id">	7	1	7	7	7	0
Bytes Read <file="pipe">	4	1	4	4	4	0
READ Bandwidth (MB/s)	2,932.118	32	1,170.286	0.001	91.629	269.282
READ Bandwidth (MB/s) <file="/opt/openmpi/tm/intel/1.4/etc/openmpi-mca-params.conf">	312.444	1	312.444	312.444	312.444	0
READ Bandwidth (MB/s) <file="/opt/openmpi/tm/intel/1.4/share/openmpi/help-mpi-btl-openib.txt">	1,170.286	1	1,170.286	1,170.286	1,170.286	0
READ Bandwidth (MB/s) <file="/opt/openmpi/tm/intel/1.4/share/openmpi/mca-btl-openib-device-params.i	1,291.5	2	1,024	267.5	645.75	378.25
READ Bandwidth (MB/s) <file="/sys/class/infiniband/mthca0/node_type">	4	1	4	4	4	0
READ Bandwidth (MB/s) <file="/sys/class/infiniband/mthca0/ports/1/gids/0">	0.304	1	0.304	0.304	0.304	0
READ Bandwidth (MB/s) <file="/sys/class/infiniband_verbs/abi_version">	4	1	4	4	4	0
READ Bandwidth (MB/s) <file="/sys/class/infiniband_verbs/uverbs0/abi_version">	4	1	4	4	4	0
READ Bandwidth (MB/s) <file="/sys/class/infiniband_verbs/uverbs0/device/device">	16	3	8	4	5.333	1.886
READ Bandwidth (MB/s) <file="/sys/class/infiniband_verbs/uverbs0/device/vendor">	20	3	8	4	6.667	1.886
READ Bandwidth (MB/s) <file="/sys/class/infiniband_verbs/uverbs0/ibdev">	32	1	32	32	32	0

Time Spent in POSIX I/O write()

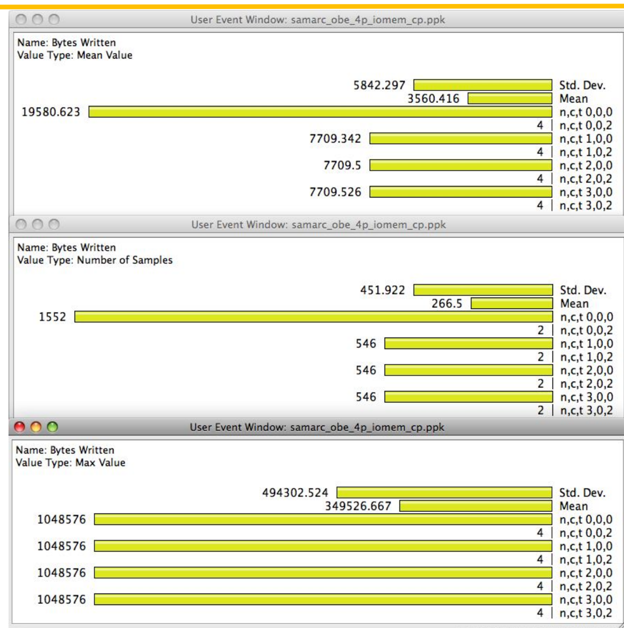


Volume of I/O by File, Memory

TAU: ParaProf: Context Events for thread: n,c,t, 1,0,0 – samarc_obe_4p_iomem_cp.ppk

Name	Total	MeanValue	NumSamples	MinValue	MaxValue	Std. Dev.
▼ .TAU application						
▶ read()						
▶ fopen64()						
▶ fclose()						
▼ OurMain()						
malloc size	25,235	1,097.174	23	11	12,032	2,851.143
free size	22,707	1,746.692	13	11	12,032	3,660.642
▼ OurMain [{wrapper.py}{3}]						
▶ read()						
malloc size	3,877	323.083	12	32	981	252.72
free size	1,536	219.429	7	32	464	148.122
▶ fopen64()						
▶ fclose()						
▼ <module> [{obe.py}{8}]						
▼ writeRestartData [{samarcInterface.py}{145}]						
▼ samarcWriteRestartData						
▼ write()						
WRITE Bandwidth (MB/s) <file="samarc/restore.00002/nodes.00004/proc.00001">		74.565	117	0	2,156.889	246.386
WRITE Bandwidth (MB/s) <file="samarc/restore.00001/nodes.00004/proc.00001">		77.594	117	0	1,941.2	228.366
WRITE Bandwidth (MB/s)		76.08	234	0	2,156.889	237.551
Bytes Written <file="samarc/restore.00002/nodes.00004/proc.00001">	2,097,552	17,927.795	117	1	1,048,576	133,362.946
Bytes Written <file="samarc/restore.00001/nodes.00004/proc.00001">	2,097,552	17,927.795	117	1	1,048,576	133,362.946
Bytes Written	4,195,104	17,927.795	234	1	1,048,576	133,362.946
▶ open64()						

Bytes Written



Memory Leaks in MPI

TAU: ParaProf: Context Events for thread: n,c,t, 0,0,0 – samarc_obe_4p_iomem_cp.ppk

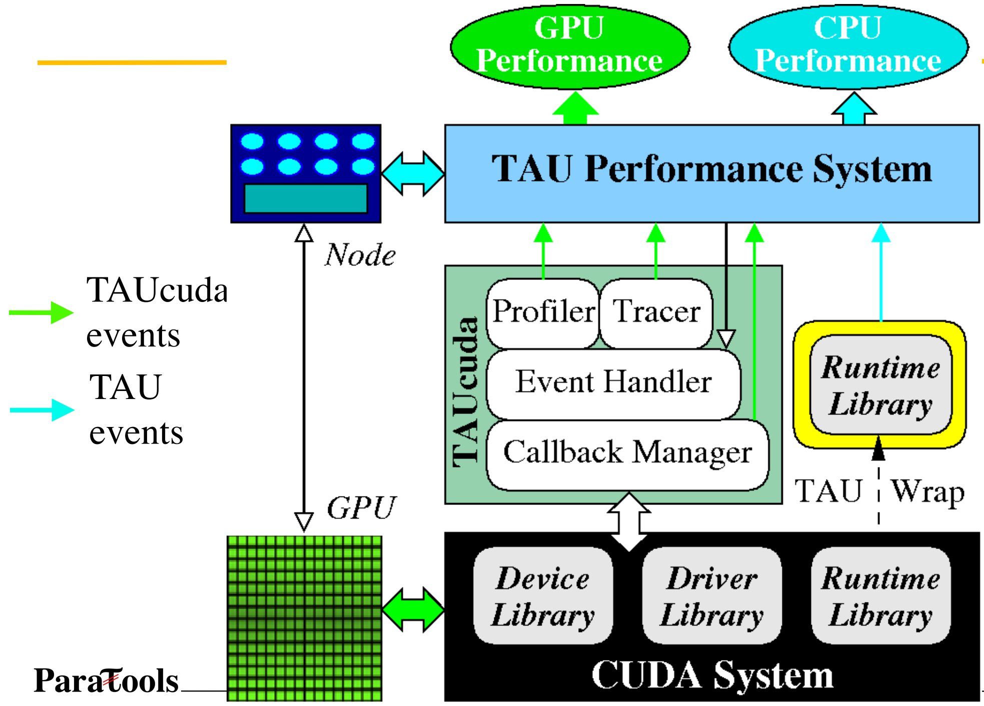
Name	Total	MeanValue	NumSamples	MaxValue	MinValue	Std. Dev.
.TAU application						
MPI_Finalize()						
free size	23,901,253	22,719.822	1,052	2,099,200	2	186,920.948
malloc size	5,013,902	65,972.395	76	5,000,000	2	569,732.815
MEMORY LEAK!	5,000,264	500,026.4	10	5,000,000	3	1,499,991.2
read()						
Bytes Read	4	4	1	4	4	0
READ Bandwidth (MB/s) <file="pipe">		0.308	1	0.308	0.308	0
Bytes Read <file="pipe">	4	4	1	4	4	0
READ Bandwidth (MB/s)		0.308	1	0.308	0.308	0
write()						
WRITE Bandwidth (MB/s)		0.635	102	12	0	1.472
Bytes Written <file="/dev/infiniband/rdma_cm">	24	24	1	24	24	0
Bytes Written	1,456	14.275	102	28	4	5.149
WRITE Bandwidth (MB/s) <file="/dev/infiniband/uverbs0">		0.528	97	12	0.089	1.32
Bytes Written <file="pipe">	64	16	4	28	4	12
WRITE Bandwidth (MB/s) <file="/dev/infiniband/rdma_cm">		1.714	1	1.714	1.714	0
Bytes Written <file="/dev/infiniband/uverbs0">	1,368	14.103	97	24	12	4.562
WRITE Bandwidth (MB/s) <file="pipe">		2.967	4	5.6	0	2.644
writev()						
WRITE Bandwidth (MB/s)		4.108	2	7.667	0.549	3.559
Bytes Written	297	148.5	2	230	67	81.5
WRITE Bandwidth (MB/s) <file="socket">		4.108	2	7.667	0.549	3.559
Bytes Written <file="socket">	297	148.5	2	230	67	81.5
readv()						
Bytes Read	112	28	4	36	20	8
READ Bandwidth (MB/s) <file="socket">		25.5	4	36	10	11.079
Bytes Read <file="socket">	112	28	4	36	20	8
READ Bandwidth (MB/s)		25.5	4	36	10	11.079
MPI_Comm_free()						
free size	10,952	195.571	56	1,024	48	255.353
read()						
MPI_Type_free()						
MPI_Init()						
fopen64()						
free size	231,314	263.456	878	568	35	221.272
MEMORY LEAK!	1,105,956	1,868.169	592	7,200	32	3,078.574
malloc size	1,358,286	901.318	1,507	7,200	32	2,087.737
OurMain()						
fclose()						

Profiling GPGPU Executions

Profiling GPGPU Executions

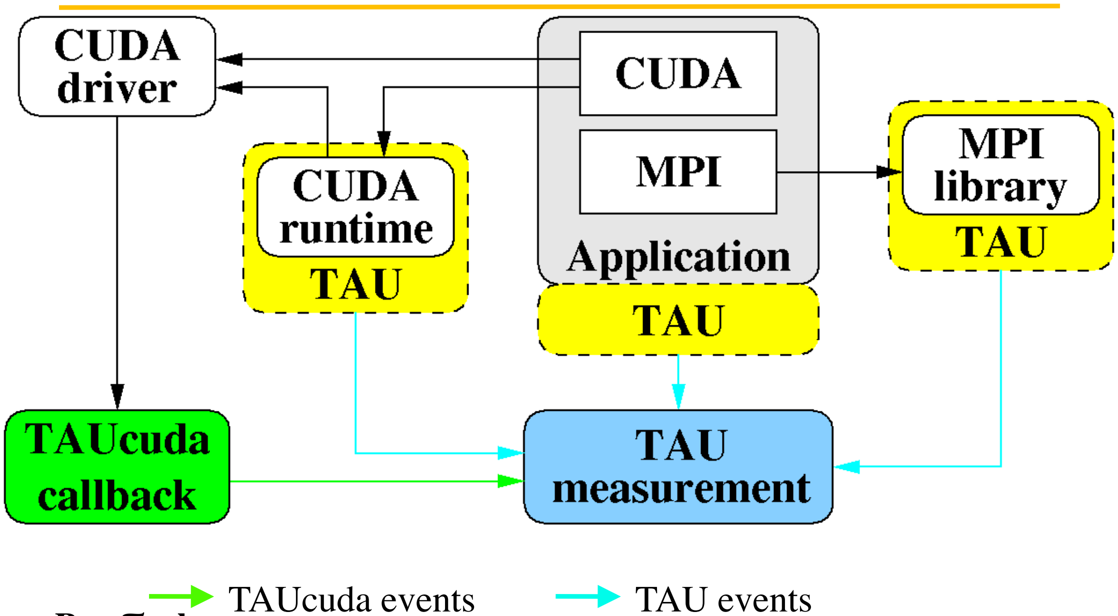
- GPGPU compilers (e.g., CAPS hmpp and PGI) can now automatically generate GPGPU code using manual annotation of loop-level constructs and routines (hmpp)
- The loops (and routines for HMPP) are transferred automatically to the GPGPU
- TAU intercepts the runtime library routines and examines the arguments
- Shows events as seen from the host
- Profiles and traces GPGPU execution

TAUcuda Architecture



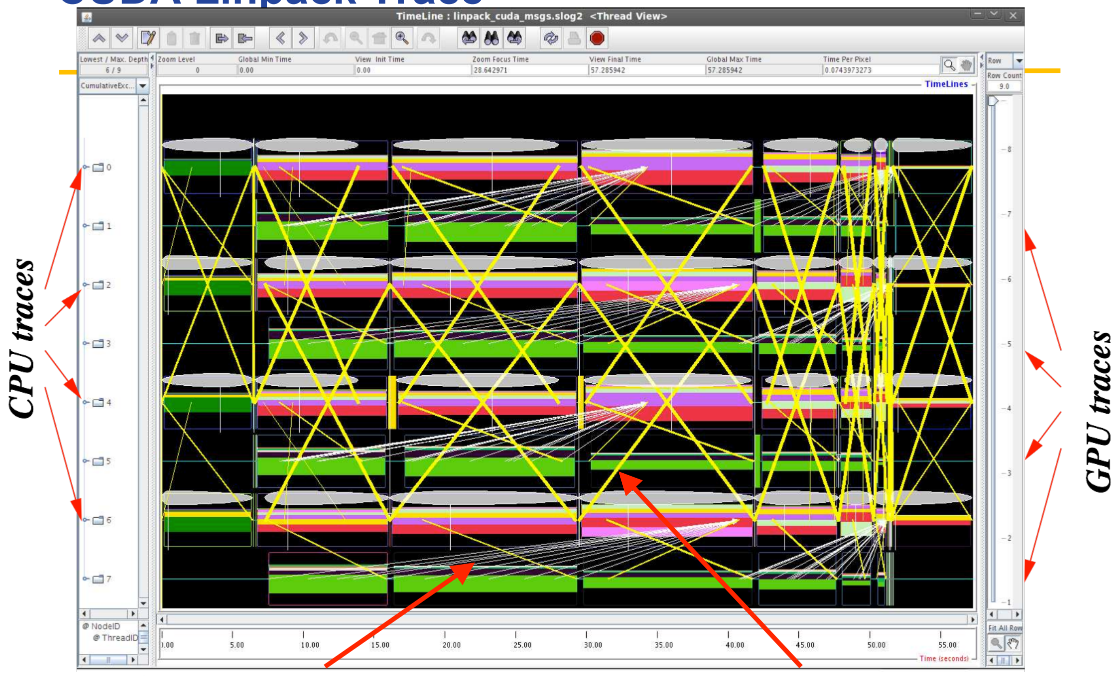
ParaTools

TAUcuda Instrumentation



ParaTools

CUDA Linpack Trace



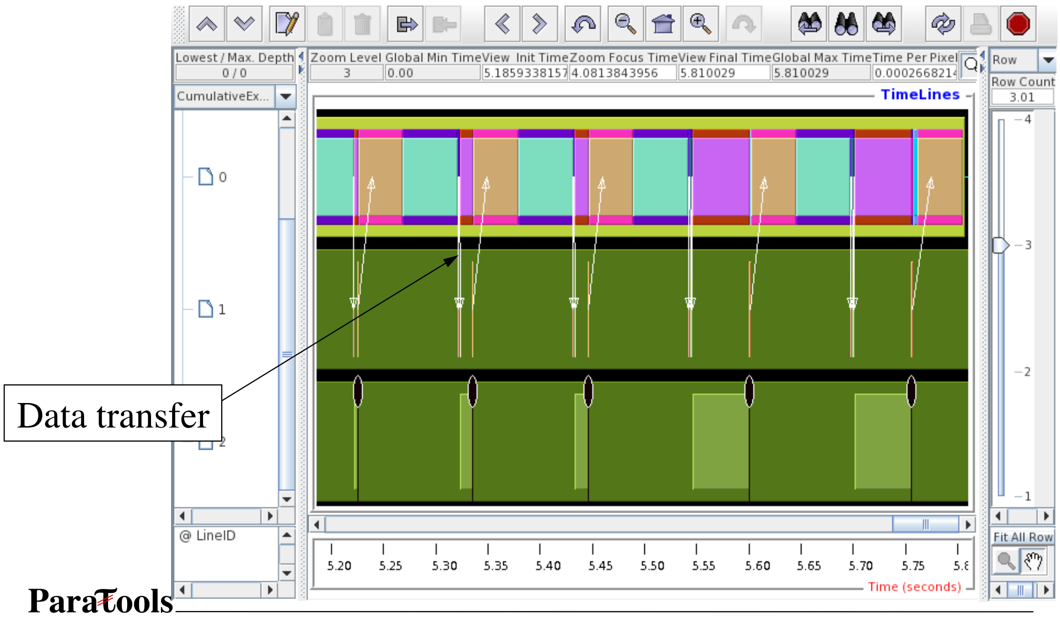
CUDA memory transfer (white) MPI communication (yellow)

SHOC Stencil2D (512 iterations, 4 CPUxGPU)

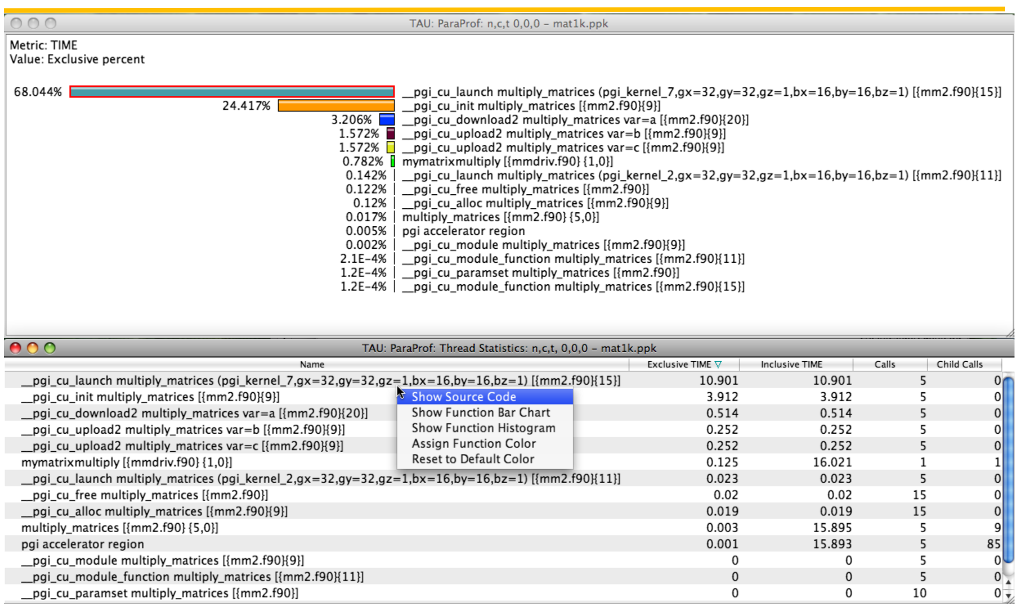
- Scalable HeterOgenerous Computing benchmark suite

CUDA memory transfer (white)

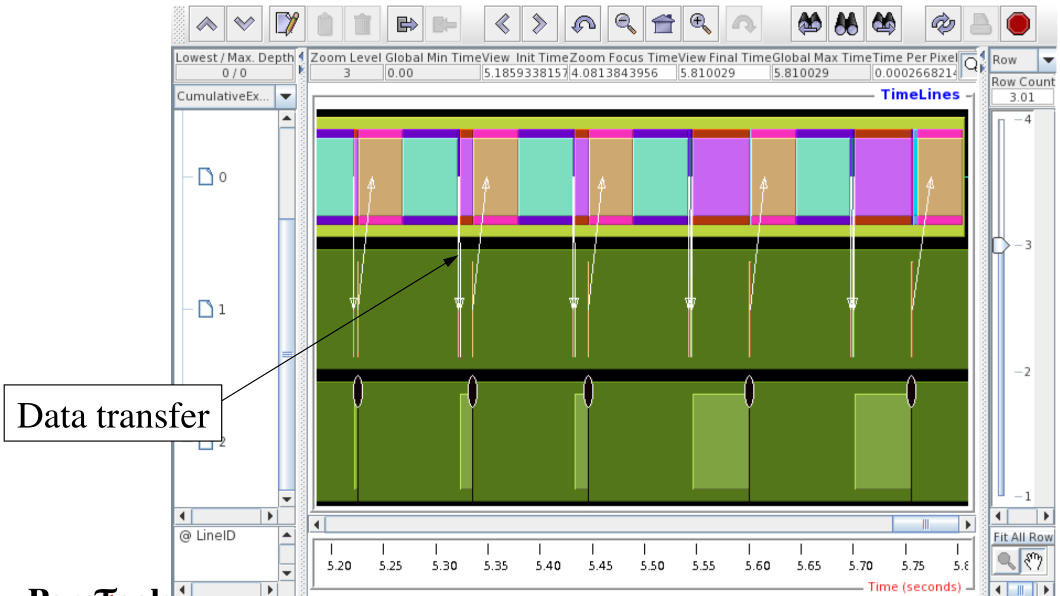
Scaling NAMD with CUDA (Jumpshot with TAU)



Measuring Performance of PGI GPGPU Accelerated Code



Scaling NAMD with CUDA (Jumpshot with TAU)



Using TAU for Tracing GPGPU Applications

Step I: Configure TAU with –cuda=<dir> for the SDK directory

Step II: Use the tau_exec script to launch the application

```
% export TAU_TRACE=1   (to enable tracing)
% tau_exec –T serial –cuda ./oceanFFT  (for non-MPI code)
```

Step III: Merge trace files to create tau.trc and tau.edf:

```
% tau_multimerge
```

Step IV: Convert traces to Jumpshot, Vampir (OTF), ParaVer or other formats

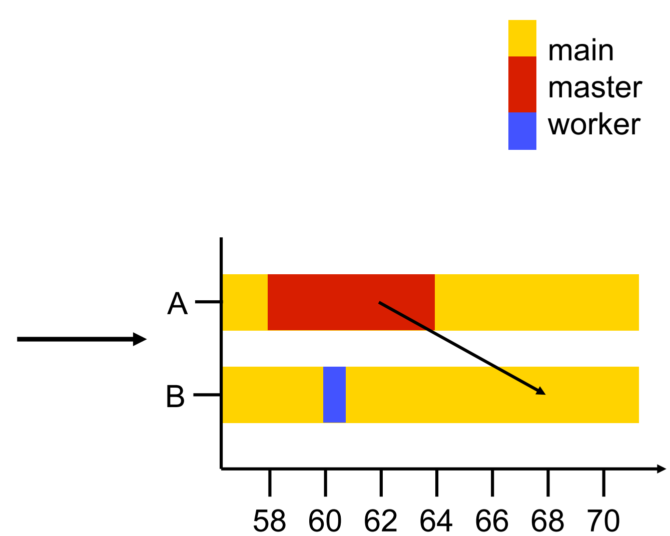
```
% tau2slog2 tau.trc tau.edf –o app.slog2; jumpshot app.slog2
% tau_convert –paraver tau.trc tau.edf app.prv; paraver app.prv
% tau2otf tau.trc tau.edf app.otf; vampir app.otf
```

Generating event traces

Tracing Analysis and Visualization

1	master
2	worker
3	...

...			
58	A	ENTER	1
60	B	ENTER	2
62	A	SEND	B
64	A	EXIT	1
68	B	RECV	A
69	B	EXIT	2
...			



Profiling / Tracing Comparison

- Profiling
  - ☺ Finite, bounded performance data size
  - ☺ Applicable to both direct and indirect methods
  - 😐 Loses time dimension (not entirely)
  - ☹ Lacks ability to fully describe process interaction
- Tracing
  - ☺ Temporal and spatial dimension to performance data
  - ☺ Capture parallel dynamics and process interaction
  - 😐 Some inconsistencies with indirect methods
  - ☹ Unbounded performance data size (large)
  - ☹ Complex event buffering and clock synchronization

Event Trace Visualization

Trace Visualization

- Alternative and supplement to automatic analysis
- Show dynamic run-time behavior visually
- Provide statistics and performance metrics
  - global timeline for parallel processes/threads
  - process timeline plus performance counters
  - statistic summary display
  - communication statistics, more …
- Interactive browsing, zooming, selecting
  - adapt statistics to zoom level (time interval)
  - also for very large and highly parallel traces

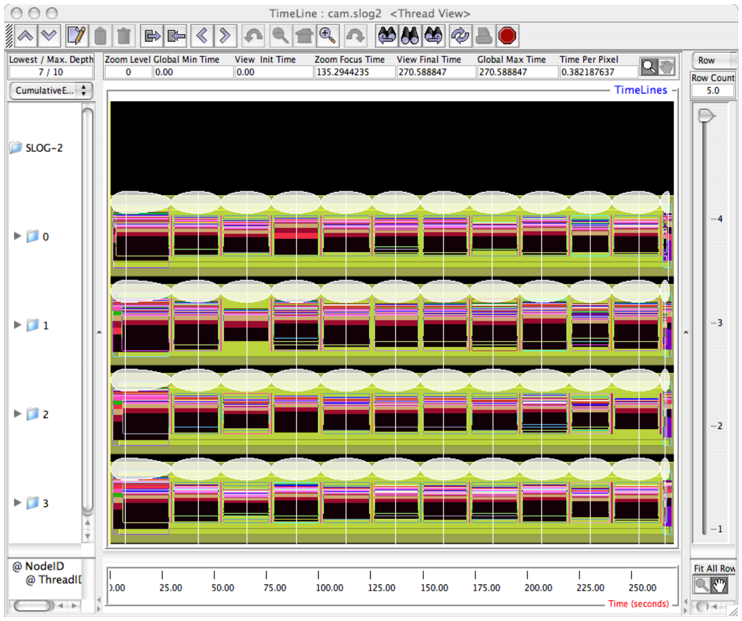
Trace Formats

- Different tools produce different formats
  - Differ by event types supported
  - Differ by ASCII and binary representations
    - Vampir Trace Format (VTF)
    - KOJAK/Scalasca (EPILOG)
    - Jumpshot (SLOG-2)
    - Paraver
- Open Trace Format (OTF)
  - Supports interoperation between tracing tools

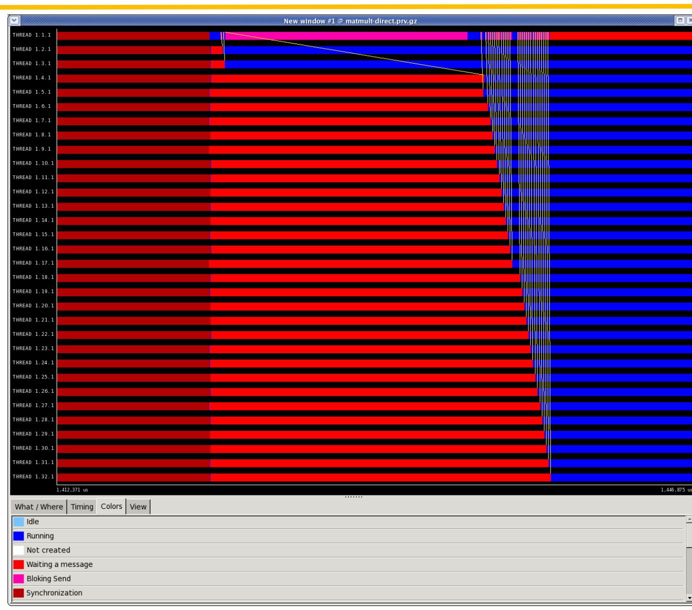
Jumpshot

- 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
  - 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

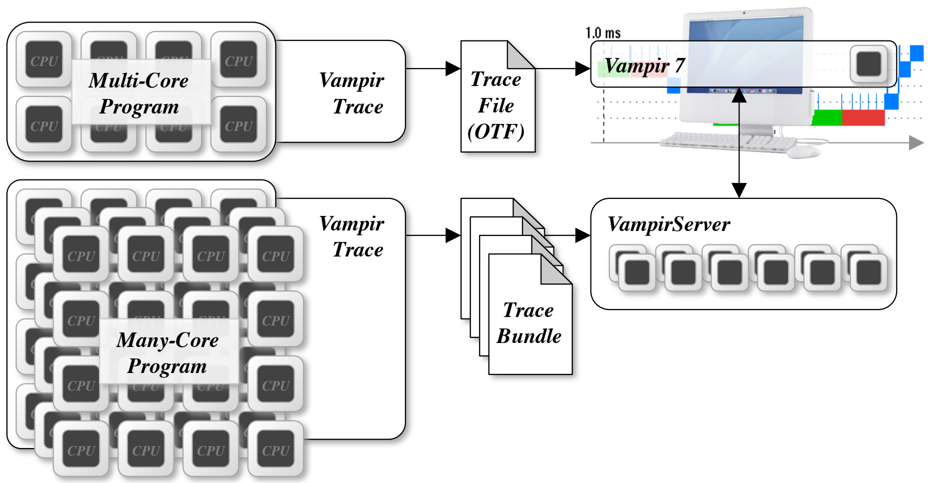
Jumpshot



ParaVer [http://www.bsc.es/paraver]



Vampir Toolset Architecture [T.U. Dresden]



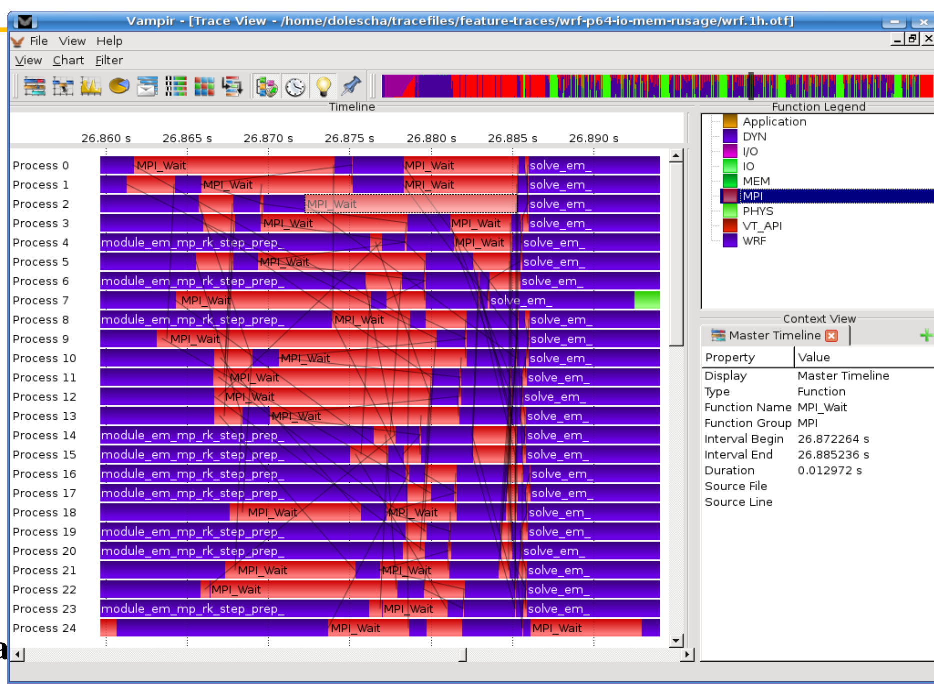
Vampir Displays

The main displays of Vampir:

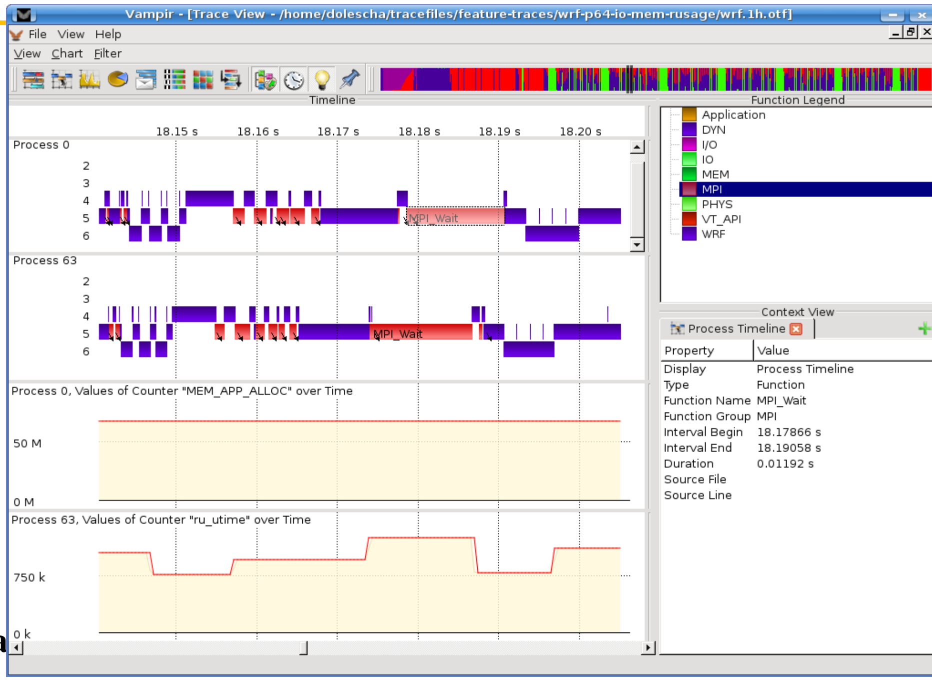
- Master Timeline
- Process and Counter Timeline
- Function Summary
- Message Summary
- Process Summary
- Communication Matrix
- Call Tree

Vampir 7 Display Overview

Master Timeline

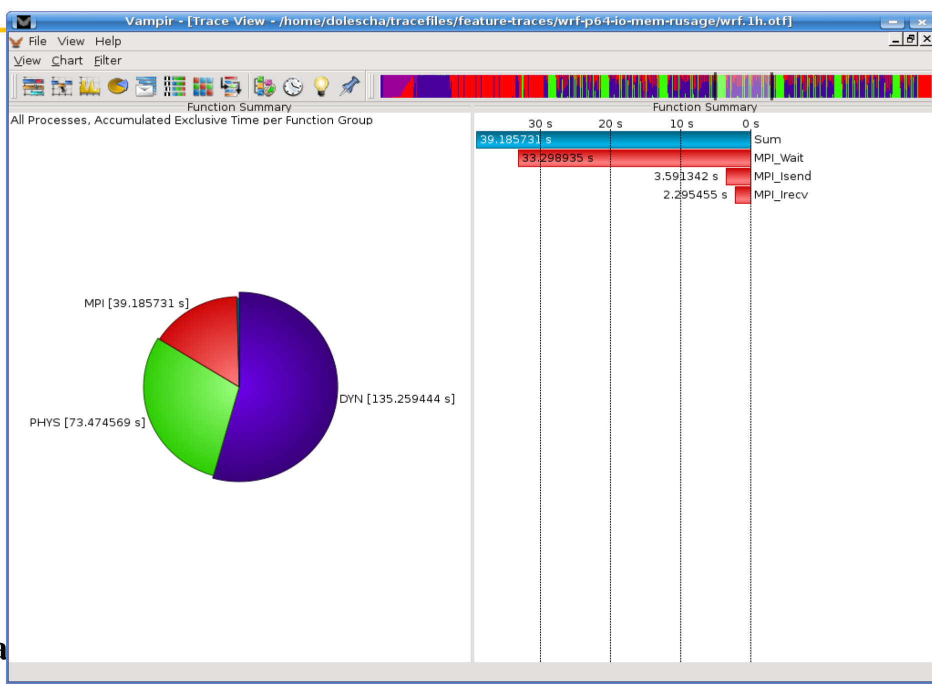


Process and Counter Timelines



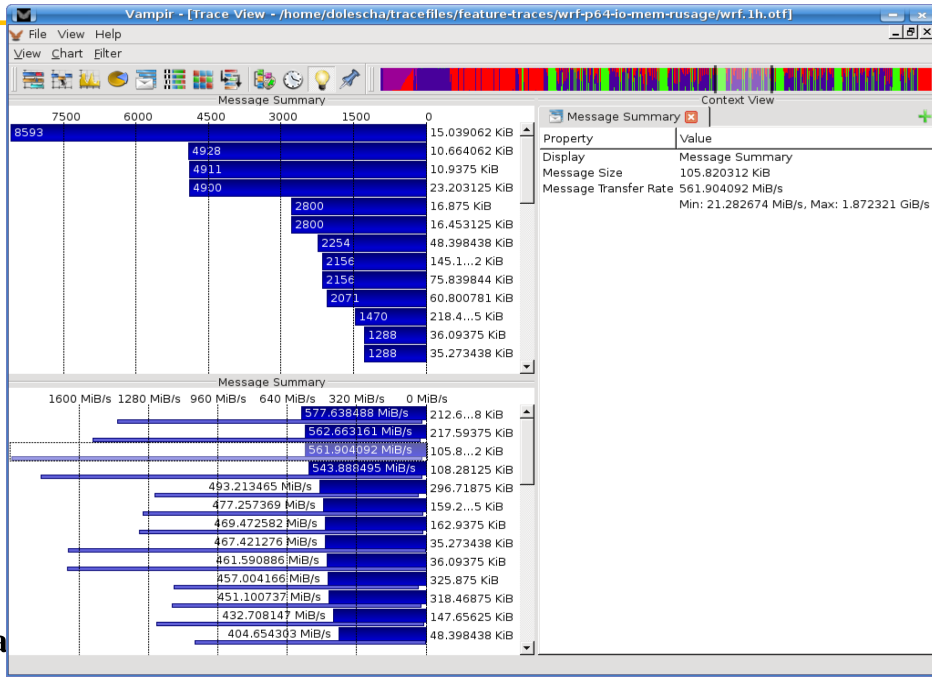
Pa

Function Summary



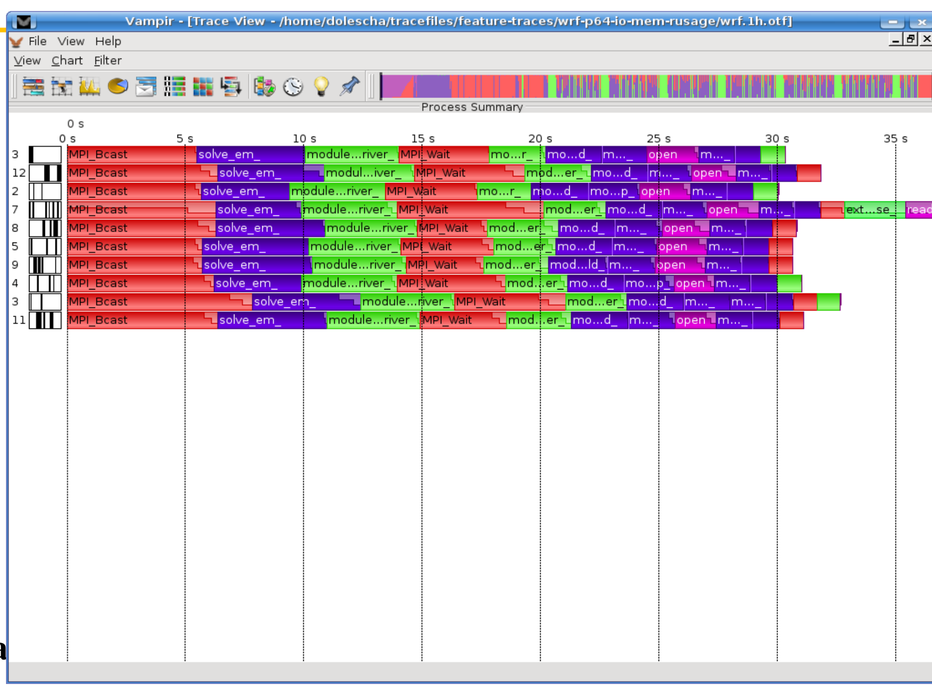
Pa

Message Summary



Pa

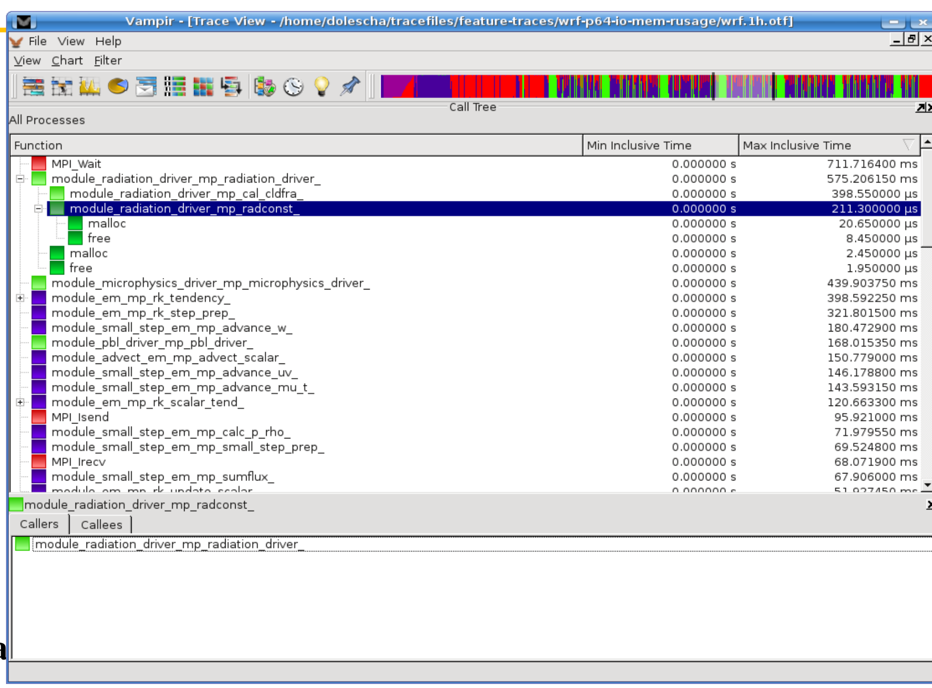
Process Summary



Pa

Communication Matrix

Call Tree



Profiling and Tracing

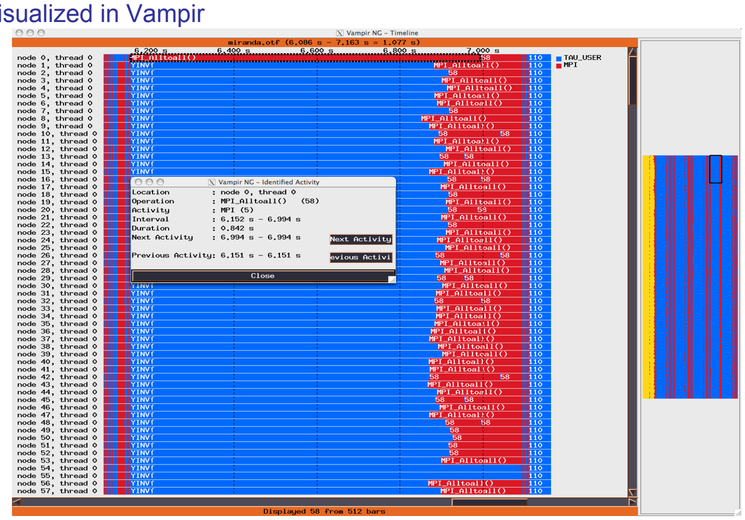
- Tracing Advantages
  - preserve temporal and spatial relationships
  - allow reconstruction of dynamic behavior on any required abstraction level
  - profiles can be calculated from trace
- Tracing Disadvantages
  - traces can become very large
  - may cause perturbation
  - instrumentation and tracing is complicated (event buffering, clock synchronization, …)

Common Event Types

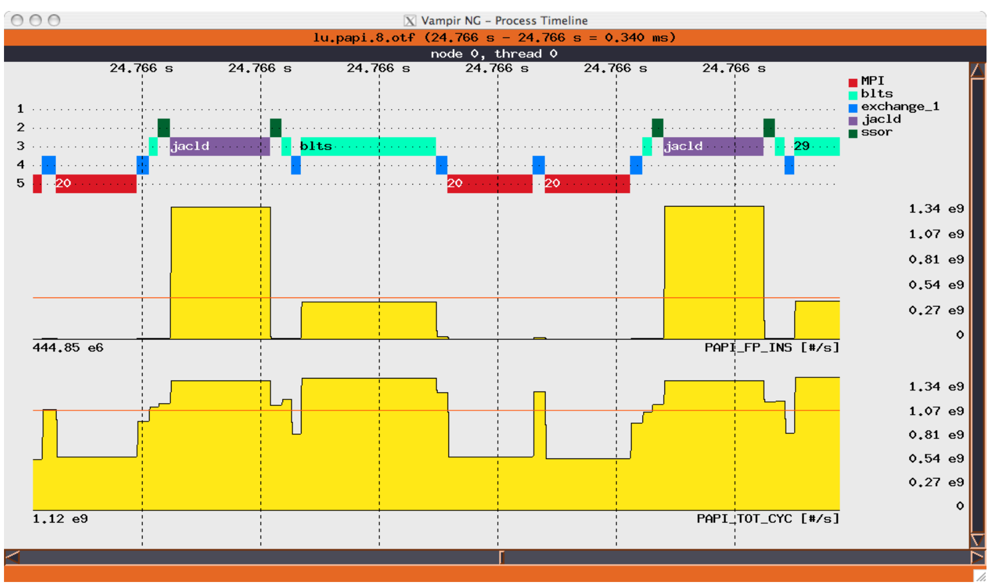
- Enter/leave of function/routine/region
  - time, process/thread, function ID
- Send/receive of P2P message (MPI)
  - time, sender, receiver, length, tag, comm.
- Collective communication (MPI)
  - time, process, root, communicator, # bytes
- Hardware performance counter values
  - time, process, counter ID, value

Using TAU with Vampir

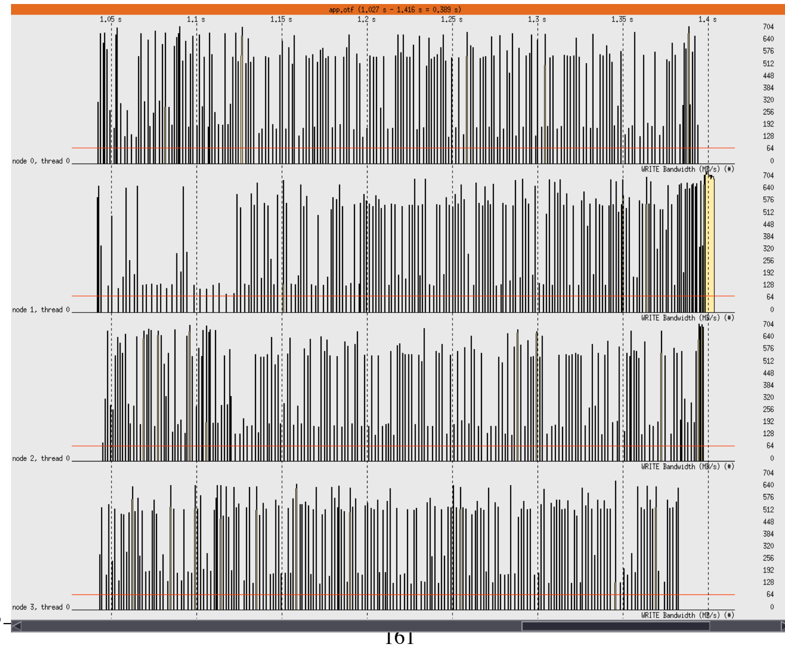
- Goal: Identify the temporal aspect of performance. What happens in my code at a given time? When?
- Event trace visualized in Vampir



Vampir Process Timeline with PAPI Counters



Vampir Counter Timeline Showing I/O BW

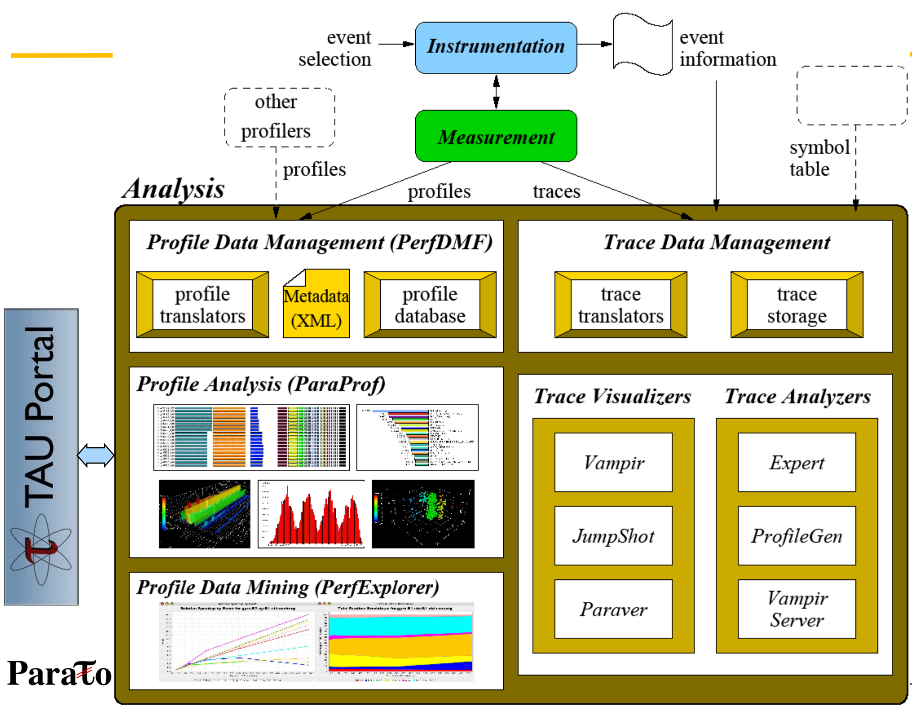


Generate a Trace File

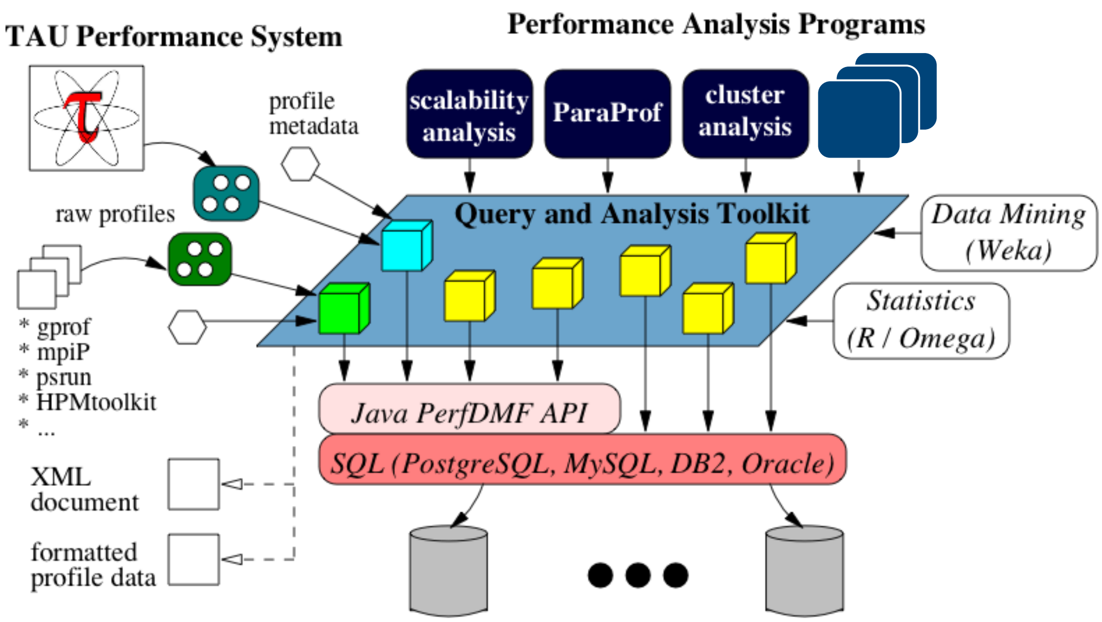
```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt-pgi
% export PATH=$TAU_ROOT/bin:$PATH
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
%
% export TAU_TRACE=1
%aprun -n 4 ./a.out
% tau_multimerge
JUMPSHOT:
% tau2slog2 tau.trc tau.edf -o app.slog2
% jumpshot app.slog2
   OR
VAMPIR:
% tau2otf tau.trc tau.edf app.otf -n 4 -z
(4 streams, compressed output trace)
% vampir app.otf
OR
PARAVER:
% tau_convert -paraver tau.trc tau.edf app.prv
% paraver app.prv
```

Analyzing performance data with ParaProf, PerfExplorer

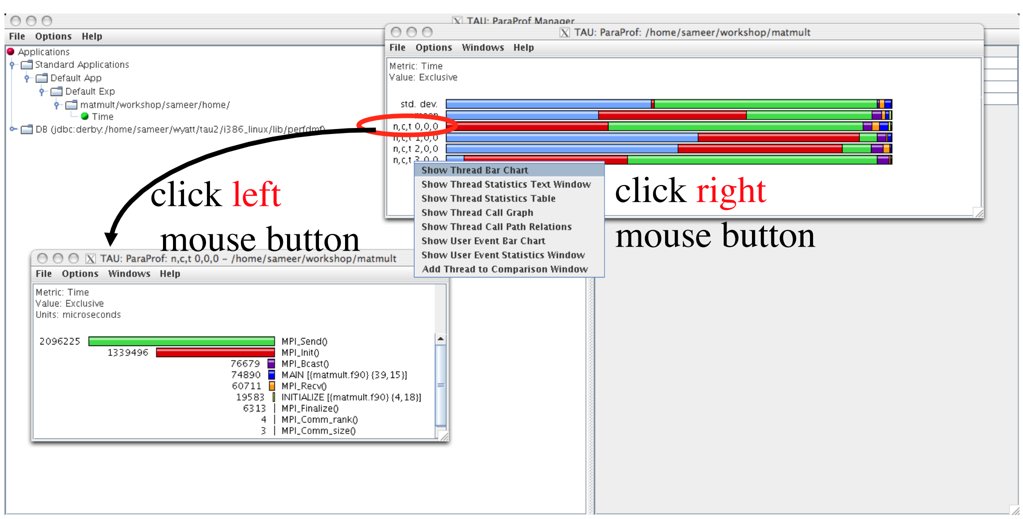
TAU Performance System Architecture



PerfDMF: Performance Data Mgmt. Framework

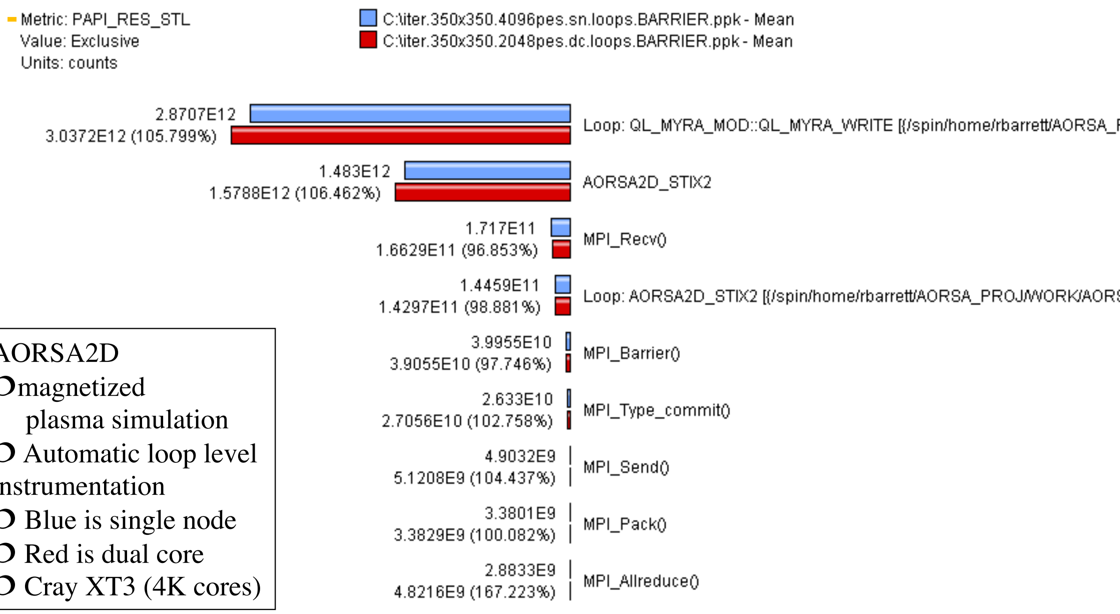


ParaProf Main Window



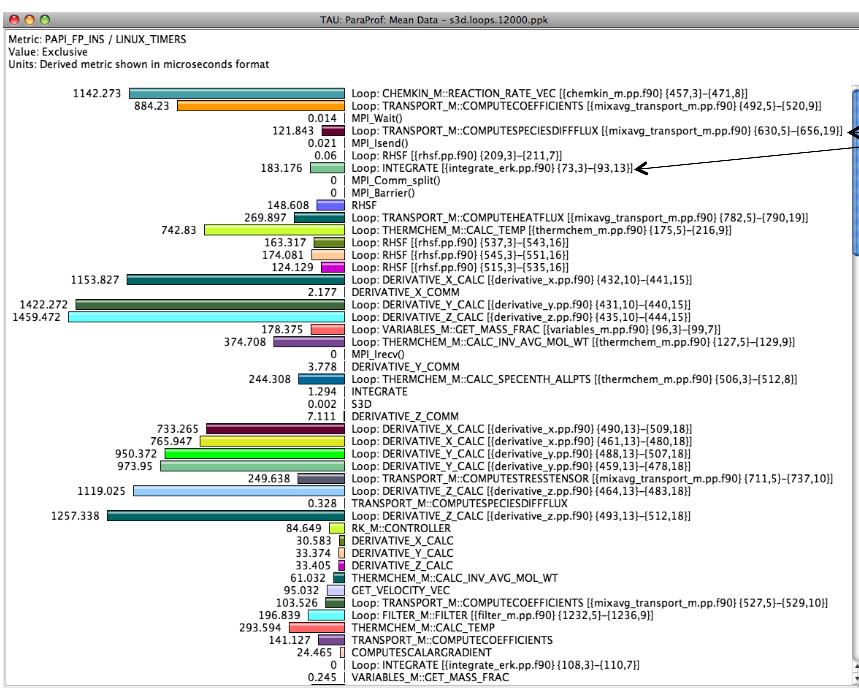

```
% paraprof matmult.ppk
```

Comparing Effects of Multi-Core Processors



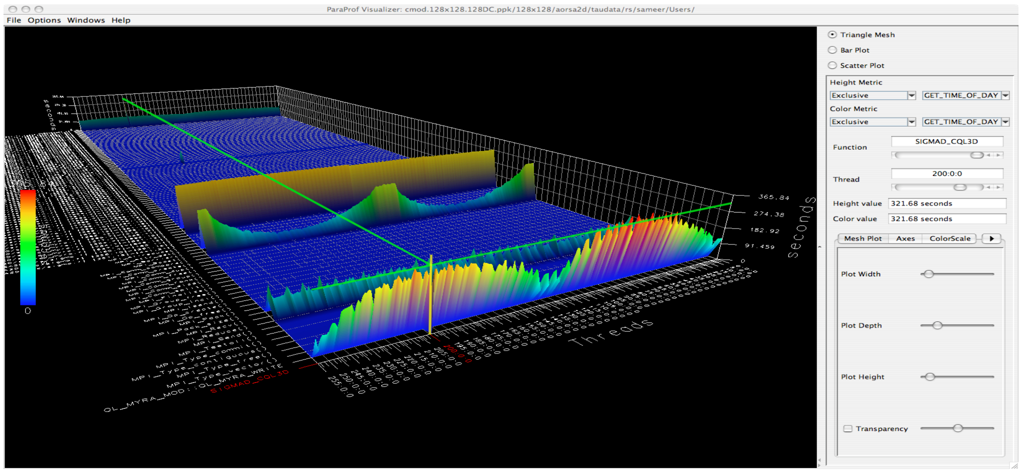
AORSA2D
- magnetized plasma simulation
- Automatic loop level instrumentation
- Blue is single node
- Red is dual core
- Cray XT3 (4K cores)

ParaProf: Mflops Sorted by Exclusive Time

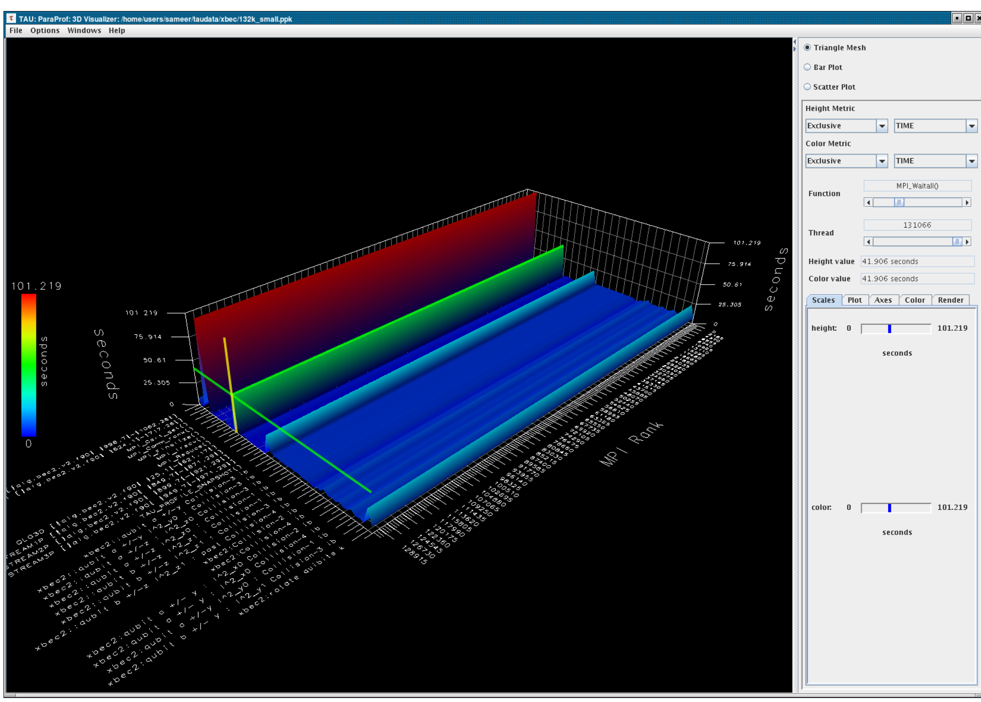


low mflops?

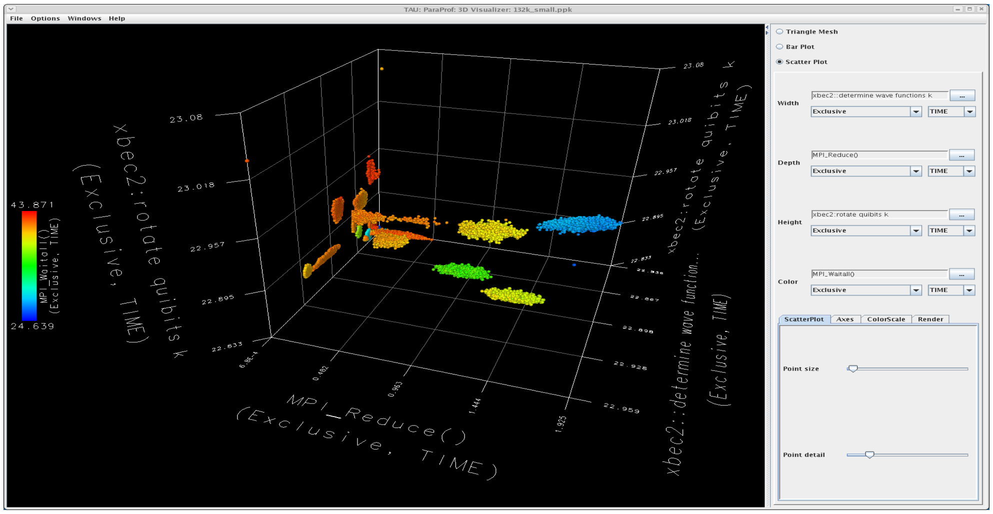
Parallel Profile Visualization: ParaProf



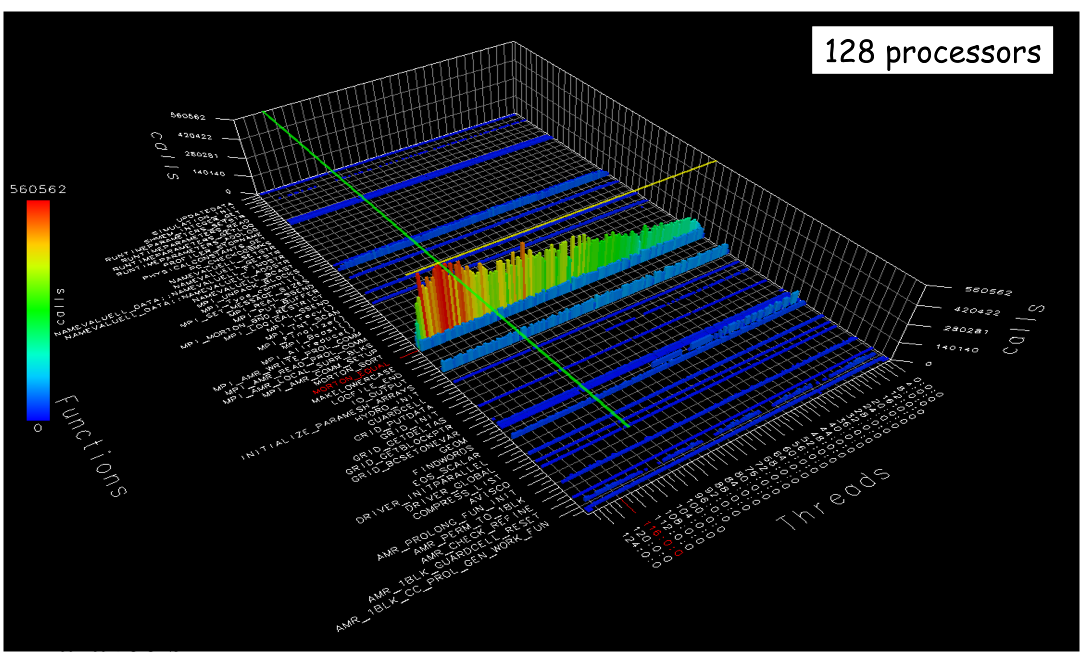
Scalable Visualization: ParaProf (128k cores)



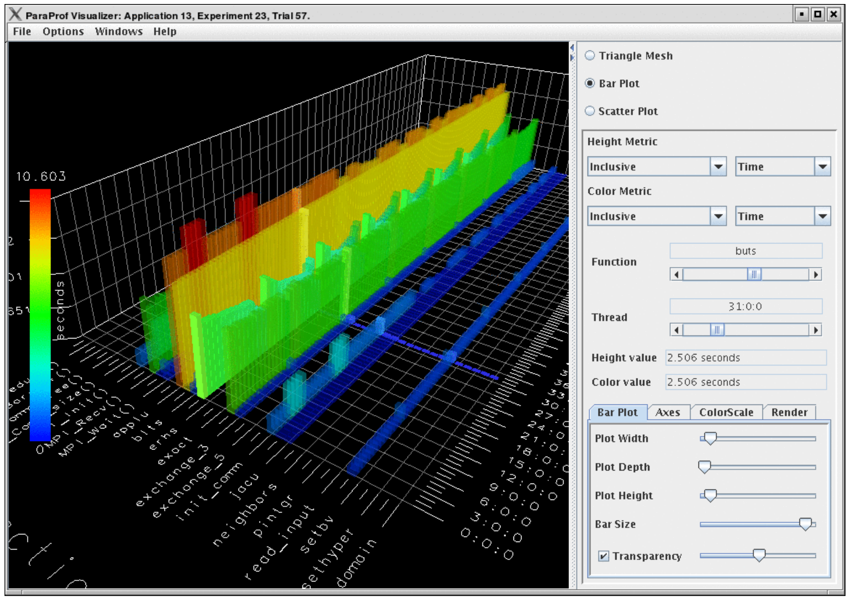
Scatter Plot: ParaProf (128k cores)



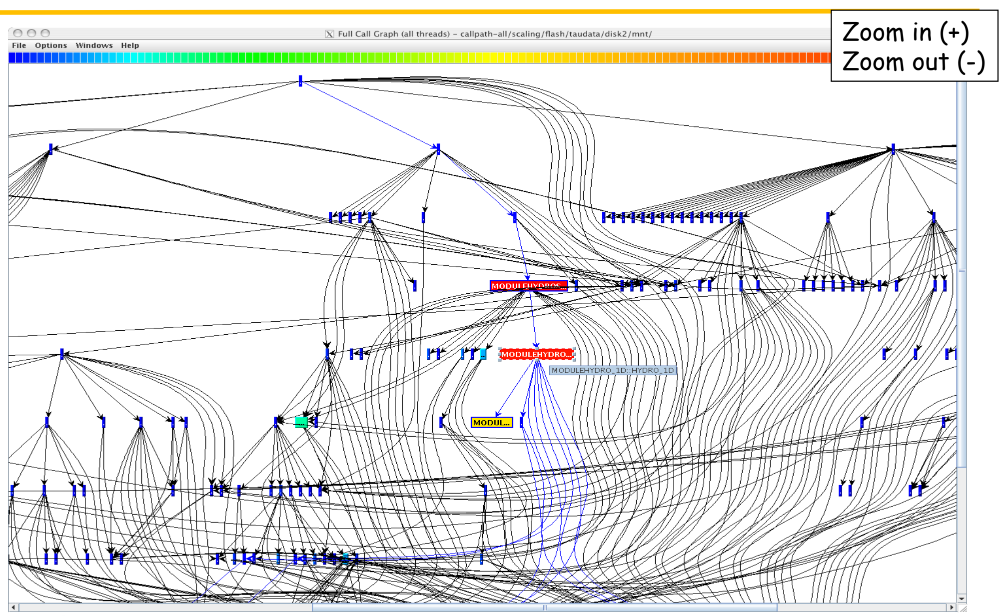
ParaProf – 3D Full Profile Bar Plot (Flash)



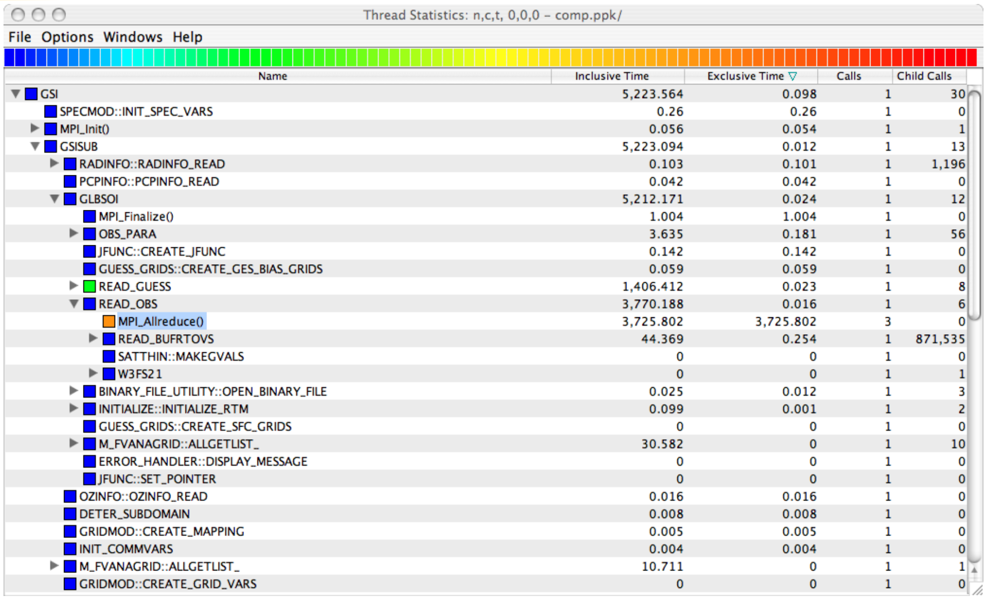
ParaProf Bar Plot (Zoom in/out +/-)



ParaProf – Callgraph Zoomed (Flash)

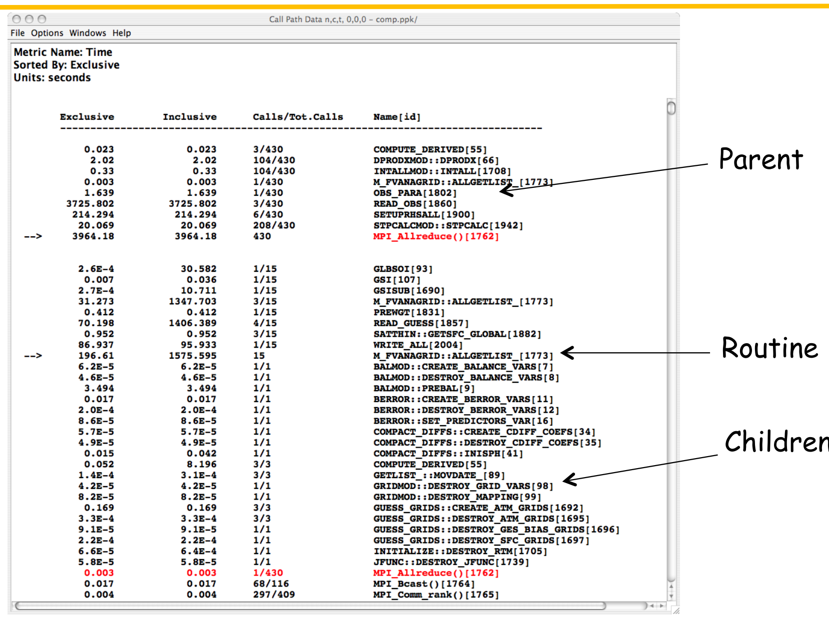


ParaProf - Thread Statistics Table (GSI)



Name	Inclusive Time	Exclusive Time ▽	Calls	Child Calls
▼ GSI	5,223.564	0.098	1	30
SPECMOD::INIT_SPEC_VARS	0.26	0.26	1	0
▶ MPI_Init()	0.056	0.054	1	1
▼ GSISUB	5,223.094	0.012	1	13
▶ RADINFO::RADINFO_READ	0.103	0.101	1	1,196
PCPINFO::PCPINFO_READ	0.042	0.042	1	0
▼ GLBSOI	5,212.171	0.024	1	12
MPI_Finalize()	1.004	1.004	1	0
▶ OBS_PARA	3.635	0.181	1	56
JFUNC::CREATE_JFUNC	0.142	0.142	1	0
GUESS_GRIDS::CREATE_GES_BIAS_GRIDS	0.059	0.059	1	0
▶ READ_GUESS	1,406.412	0.023	1	8
▼ READ_OBS	3,770.188	0.016	1	6
MPI_Allreduce()	3,725.802	3,725.802	3	0
▶ READ_BUFRTOVS	44.369	0.254	1	871,535
SATTHIN::MAKEGVALS	0	0	1	0
▶ W3FS21	0	0	1	1
▶ BINARY_FILE_UTILITY::OPEN_BINARY_FILE	0.025	0.012	1	3
▶ INITIALIZE::INITIALIZE_RTM	0.099	0.001	1	2
GUESS_GRIDS::CREATE_SFC_GRIDS	0	0	1	0
▶ M_FVANAGRID::ALLGETLIST_	30.582	0	1	10
ERROR_HANDLER::DISPLAY_MESSAGE	0	0	1	0
JFUNC::SET_POINTER	0	0	1	0
OZINFO::OZINFO_READ	0.016	0.016	1	0
DETER_SUBDOMAIN	0.008	0.008	1	0
GRIDMOD::CREATE_MAPPING	0.005	0.005	1	0
INIT_COMMVARS	0.004	0.004	1	0
▶ M_FVANAGRID::ALLGETLIST_	10.711	0	1	1
GRIDMOD::CREATE_GRID_VARS	0	0	1	0

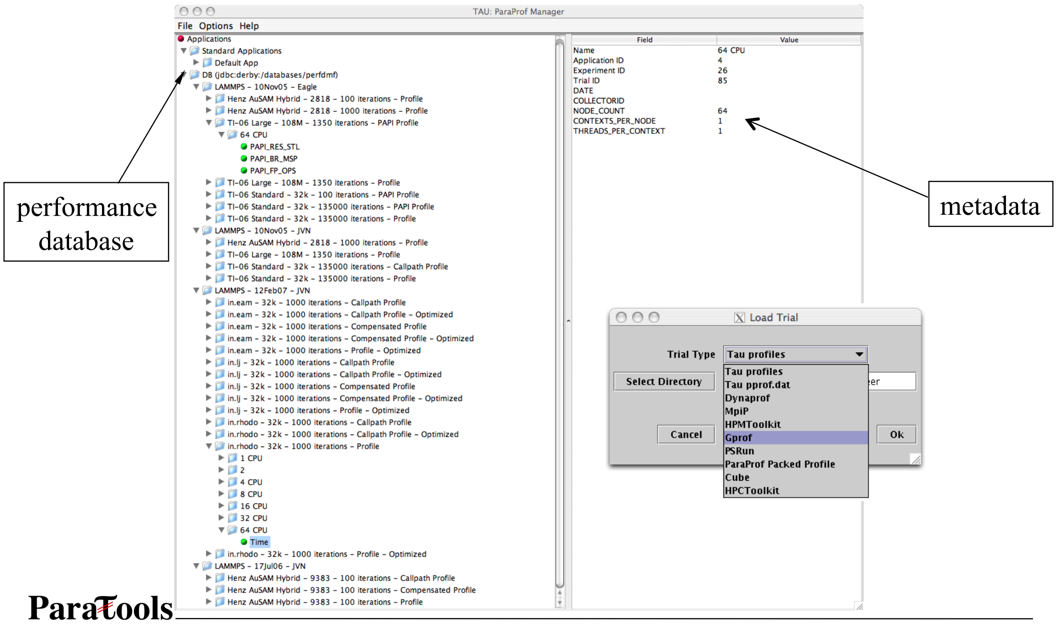
ParaProf - Callpath Thread Relations Window



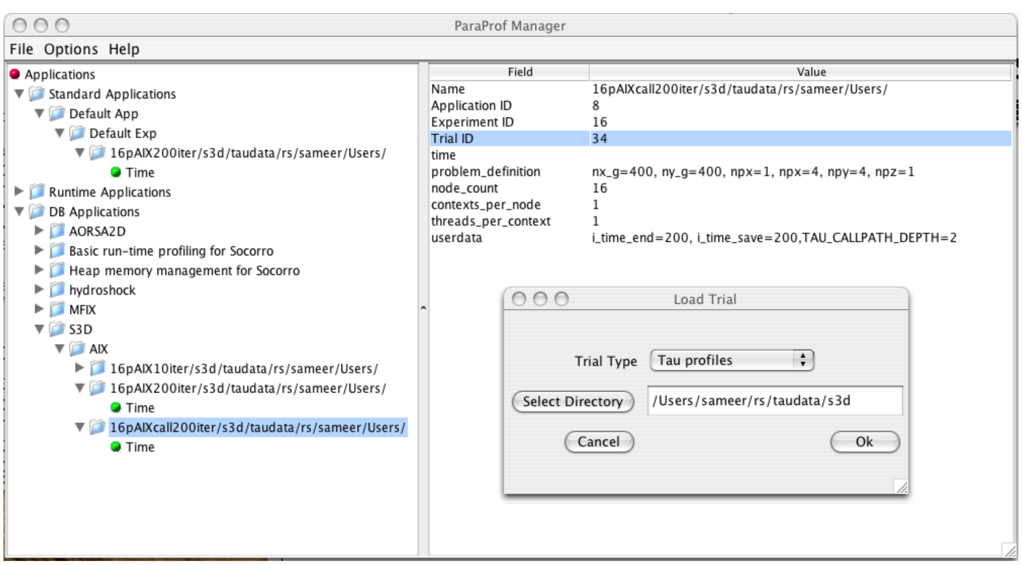
Metric Name: Time
Sorted By: Exclusive
Units: seconds

	Exclusive	Inclusive	Calls/Tot.Calls	Name[id]
	0.023	0.023	3/430	COMPUTE_DERIVED[55]
	2.02	2.02	104/430	DPRODXMOD::DPRODX[66]
	0.33	0.33	104/430	INTALLMOD::INTALL[1708]
	0.003	0.003	1/430	M_FVANAGRID::ALLGETLIST_[1773]
	1.639	1.639	1/430	OBS_PARA[1802]
	3725.802	3725.802	3/430	READ_OBS[1860]
	214.294	214.294	6/430	SETUPRHSALL[1900]
	20.069	20.069	208/430	STPCALCMOD::STPCALC[1942]
-->	3964.18	3964.18	430	MPI_Allreduce()[1762]
	2.6E-4	30.582	1/15	GLBSOI[93]
	0.007	0.036	1/15	GSI[107]
	2.7E-4	10.711	1/15	GSISUB[1690]
	31.273	1347.703	3/15	M_FVANAGRID::ALLGETLIST_[1773]
	0.412	0.412	1/15	PREWGT[1831]
	70.198	1406.389	4/15	READ_GUESS[1857]
	0.952	0.952	3/15	SATTHIN::GETSFC_GLOBAL[1882]
	86.937	95.933	1/15	WRITE_ALL[2004]
-->	196.61	1575.595	15	M_FVANAGRID::ALLGETLIST_[1773]
	6.2E-5	6.2E-5	1/1	BALMOD::CREATE_BALANCE_VARS[7]
	4.6E-5	4.6E-5	1/1	BALMOD::DESTROY_BALANCE_VARS[8]
	3.494	3.494	1/1	BALMOD::PREBAL[9]
	0.017	0.017	1/1	BERROR::CREATE_BERROR_VARS[11]
	2.0E-4	2.0E-4	1/1	BERROR::DESTROY_BERROR_VARS[12]
	8.6E-5	8.6E-5	1/1	BERROR::SET_PREDICTORS_VAR[16]
	5.7E-5	5.7E-5	1/1	COMPACT_DIFFS::CREATE_CDIFF_COEFS[34]
	4.9E-5	4.9E-5	1/1	COMPACT_DIFFS::DESTROY_CDIFF_COEFS[35]
	0.015	0.042	1/1	COMPACT_DIFFS::INISPH[41]
	0.052	8.196	3/3	COMPUTE_DERIVED[55]
	1.4E-4	3.1E-4	3/3	GETLIST_::MOVDATE_[89]
	4.2E-5	4.2E-5	1/1	GRIDMOD::DESTROY_GRID_VARS[98]
	8.2E-5	8.2E-5	1/1	GRIDMOD::DESTROY_MAPPING[99]
	0.169	0.169	3/3	GUESS_GRIDS::CREATE_ATM_GRIDS[1692]
	3.3E-4	3.3E-4	3/3	GUESS_GRIDS::DESTROY_ATM_GRIDS[1695]
	9.1E-5	9.1E-5	1/1	GUESS_GRIDS::DESTROY_GES_BIAS_GRIDS[1696]
	2.2E-4	2.2E-4	1/1	GUESS_GRIDS::DESTROY_SFC_GRIDS[1697]
	6.6E-5	6.4E-4	1/1	INITIALIZE::DESTROY_RTM[1705]
	5.8E-5	5.8E-5	1/1	JFUNC::DESTROY_JFUNC[1739]
	0.003	0.003	1/430	MPI_Allreduce()[1762]
	0.017	0.017	68/116	MPI_Bcast()[1764]
	0.004	0.004	297/409	MPI_Comm_rank()[1765]

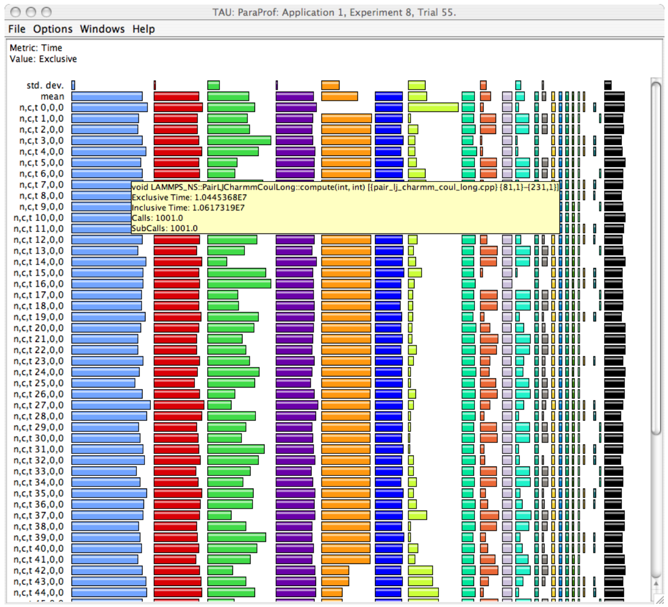
ParaProf – Manager Window



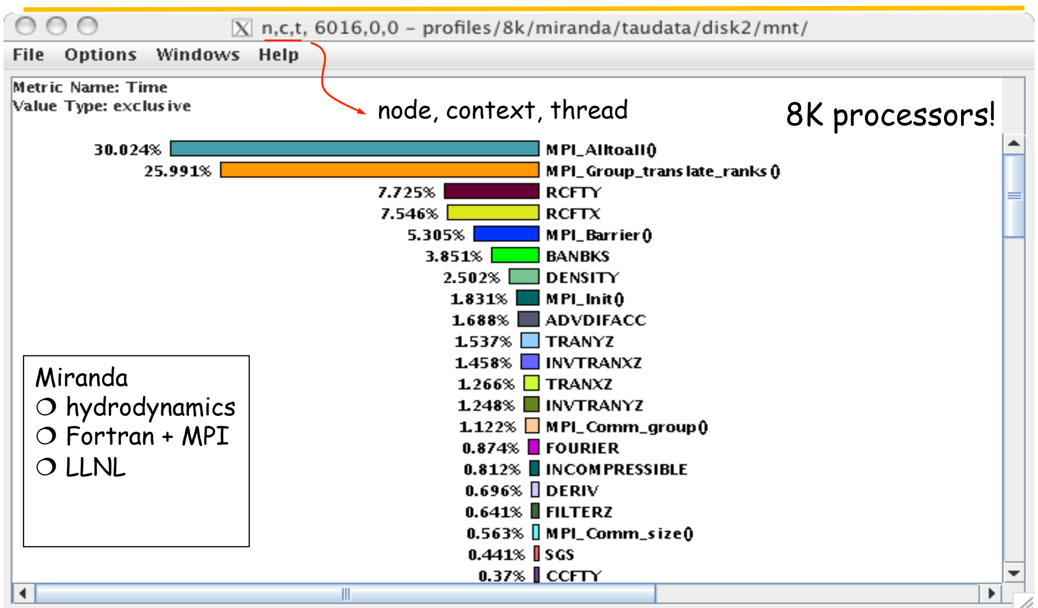
Performance Database: Storage of MetaData



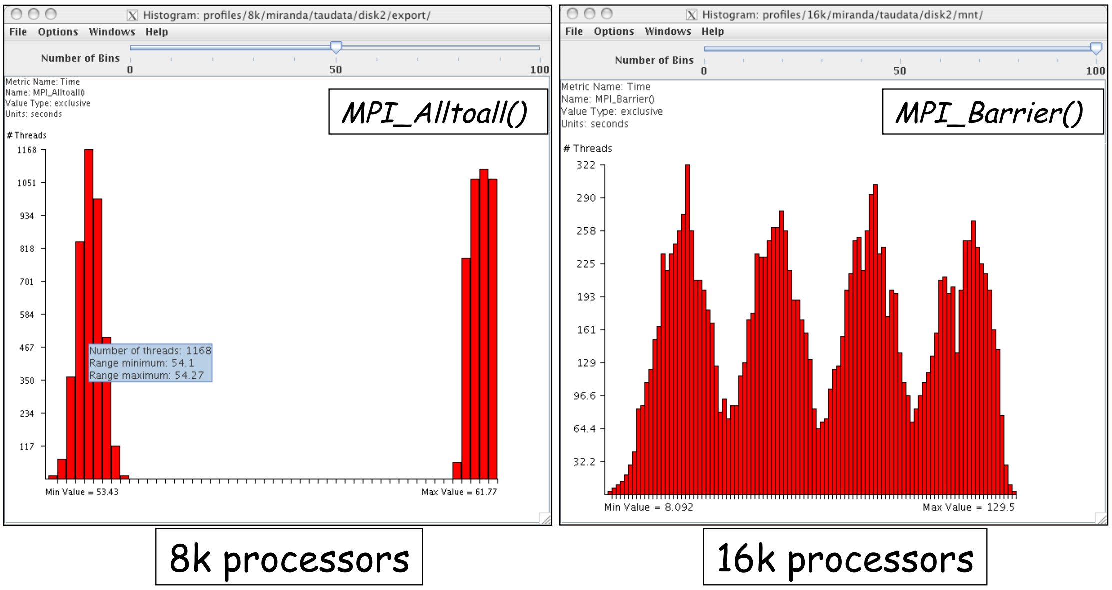
ParaProf Main Window (Lammps)



ParaProf – Flat Profile (Miranda)



ParaProf – Histogram View (Miranda)



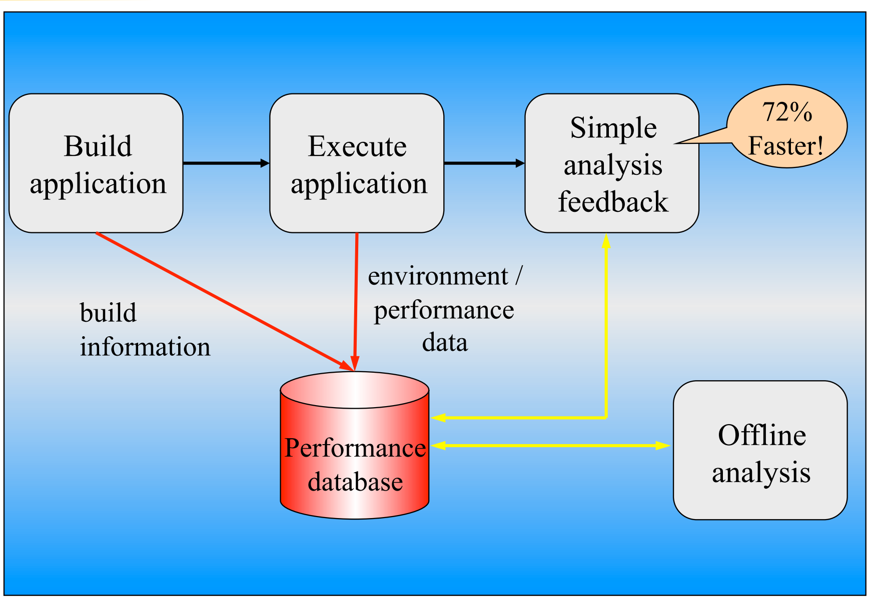
Performance Problem Solving Goals

- Answer questions at multiple levels of interest
  - High-level performance data spanning dimensions
    - machine, applications, code revisions, data sets
    - examine broad performance trends
  - Data from low-level measurements
    - use to predict application performance
- Discover general correlations
  - performance and features of external environment
  - Identify primary performance factors
- Benchmarking analysis for application prediction
- Workload analysis for machine assessment

Performance Analysis Questions

- How does performance vary with different compilers?
- Is poor performance correlated with certain OS features?
- Has a recent change caused unanticipated performance?
- How does performance vary with MPI variants?
- Why is one application version faster than another?
- What is the reason for the observed scaling behavior?
- Did two runs exhibit similar performance?
- How are performance data related to application events?
- Which machines will run my code the fastest and why?
- Which benchmarks predict my code performance best?

Automatic Performance Analysis



Performance Data Management

- Performance diagnosis and optimization involves multiple performance experiments
- Support for common performance data management tasks augments tool use
  - Performance experiment data and metadata storage
  - Performance database and query
- What type of performance data should be stored?
  - Parallel profiles or parallel traces
  - Storage size will dictate
  - Experiment metadata helps in meta analysis tasks
- Serves tool integration objectives

Metadata Collection

- Integration of metadata with each parallel profile
  - Separate information from performance data
- Three ways to incorporate metadata
  - Measured hardware/system information
    - CPU speed, memory in GB, MPI node IDs, …
  - Application instrumentation (application-specific)
    - Application parameters, input data, domain decomposition
    - Capture arbitrary name/value pair and save with experiment
  - Data management tools can read additional metadata
    - Compiler flags, submission scripts, input files, …
    - Before or after execution
- Enhances analysis capabilities

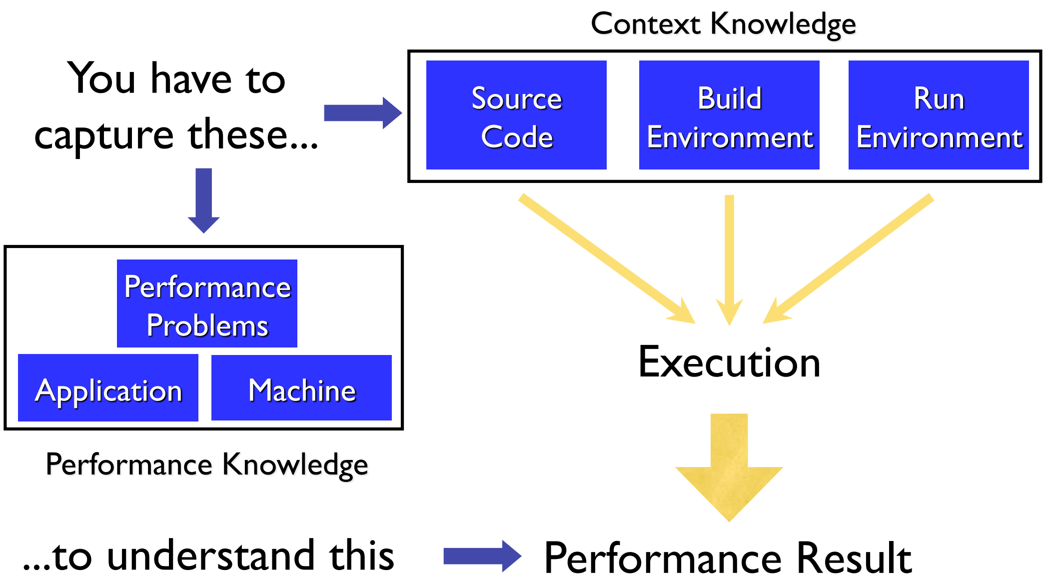
Performance Data Mining

- Conduct parallel performance analysis in a systematic, collaborative and reusable manner
  - Manage performance complexity and automate process
  - Discover performance relationship and properties
  - Multi-experiment performance analysis
- Data mining applied to parallel performance data
  - Comparative, clustering, correlation, characterization, …
  - Large-scale performance data reduction
- Implement extensible analysis framework
  - Abtraction / automation of data mining operations
  - Interface to existing analysis and data mining tools

How to explain performance?

- Should not just redescribed 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
- Add *knowledge* to do more intelligent things
  - Automated analysis needs good informed feedback
  - Performance model generation requires interpretation
- Performance knowledge discovery framework
  - Integrating meta-information
  - Knowledge-based performance problem solving

Metadata and Knowledge Role



Performance Optimization Process

- Performance characterization
  - Identify major performance contributors
  - Identify sources of performance inefficiency
  - Utilize timing and hardware measures
- Performance diagnosis (Performance Debugging)
  - Look for conditions of performance problems
  - Determine if conditions are met and their severity
  - What and where are the performance bottlenecks
- Performance tuning
  - Focus on dominant performance contributors
  - Eliminate main performance bottlenecks

Using Performance Database (PerfDMF)

- Configure PerfDMF (Done by each user)
  % perfdmf_configure --create-default
  - Choose derby, PostgreSQL, MySQL, Oracle or DB2
  - Hostname
  - Username
  - Password
  - Say yes to downloading required drivers (we are not allowed to distribute these)
  - Stores parameters in your ~/.ParaProf/perfdmf.cfg file
- Configure PerfExplorer (Done by each user)
  % perfexplorer_configure
- Execute PerfExplorer
  % perfexplorer

PerfDMF and the TAU Portal

- Development of the TAU portal
  - Common repository for collaborative data sharing
  - Profile uploading, downloading, user management
  - Paraprof, PerfExplorer can be launched from the portal using Java Web Start (no TAU installation required)
- Portal URL
  http://tau.nic.uoregon.edu

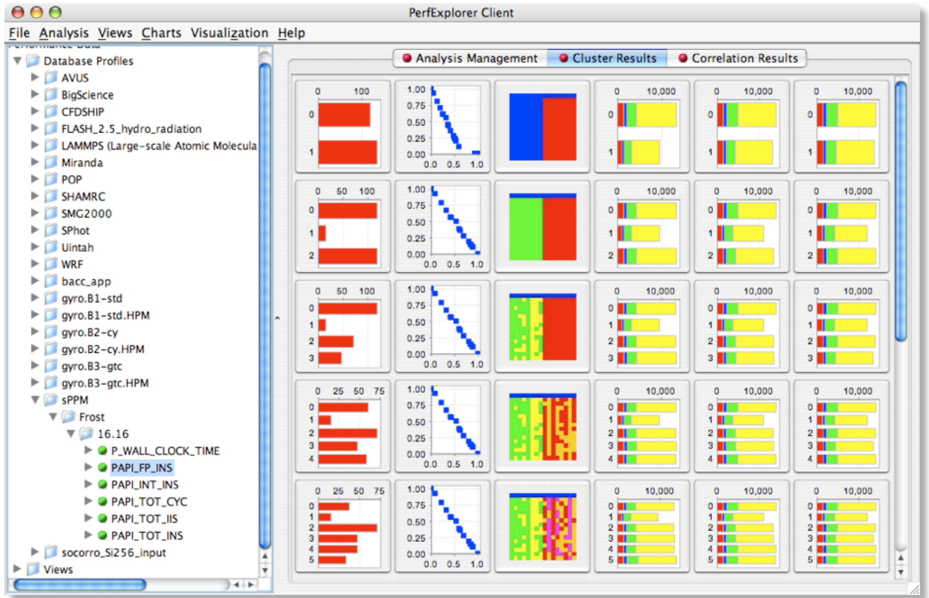
Performance Data Mining (PerfExplorer)

- Performance knowledge discovery framework
  - Data mining analysis applied to parallel performance data
    - comparative, clustering, correlation, dimension reduction, …
  - Use the existing TAU infrastructure
    - TAU performance profiles, PerfDMF
  - Client-server based system architecture
- Technology integration
  - Java API and toolkit for portability
  - PerfDMF
  - R-project/Omegahat, Octave/Matlab statistical analysis
  - WEKA data mining package
  - JFreeChart for visualization, vector output (EPS, SVG)

PerfExplorer - Cluster Analysis

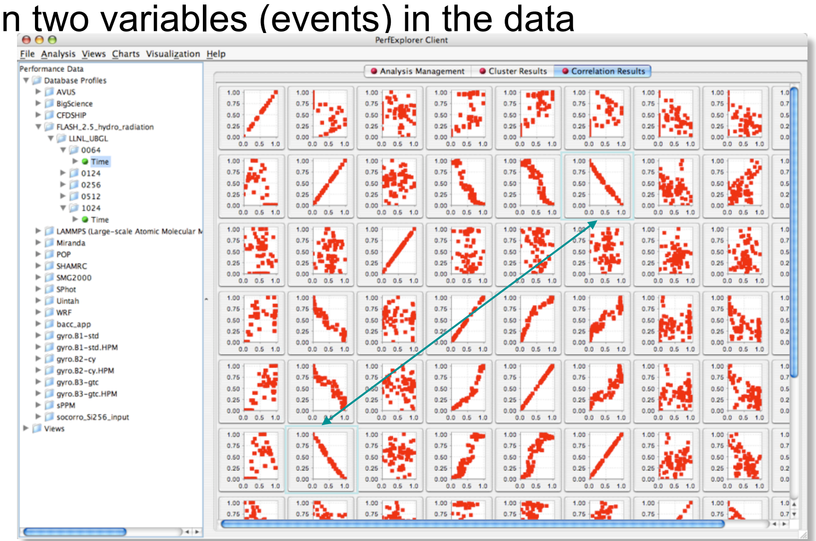
- Performance data represented as vectors - each dimension is the cumulative time for an event
- *k*-means: *k* random centers are selected and instances are grouped with the "closest" (Euclidean) center
- New centers are calculated and the process repeated until stabilization or max iterations
- Dimension reduction necessary for meaningful results
- Virtual topology, summaries constructed

PerfExplorer - Cluster Analysis (sPPM)



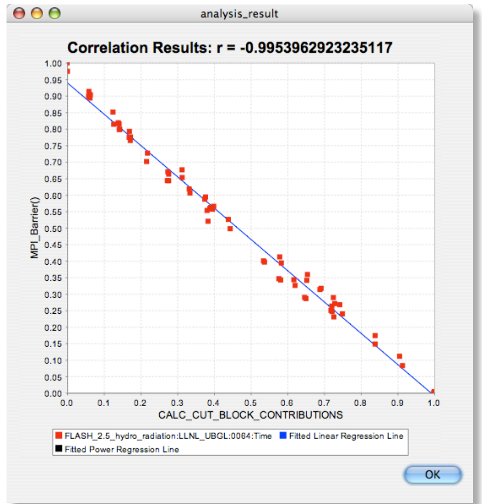
PerfExplorer - Correlation Analysis (Flash)

- Describes strength and direction of a linear relationship between two variables (events) in the data



PerfExplorer - Correlation Analysis (Flash)

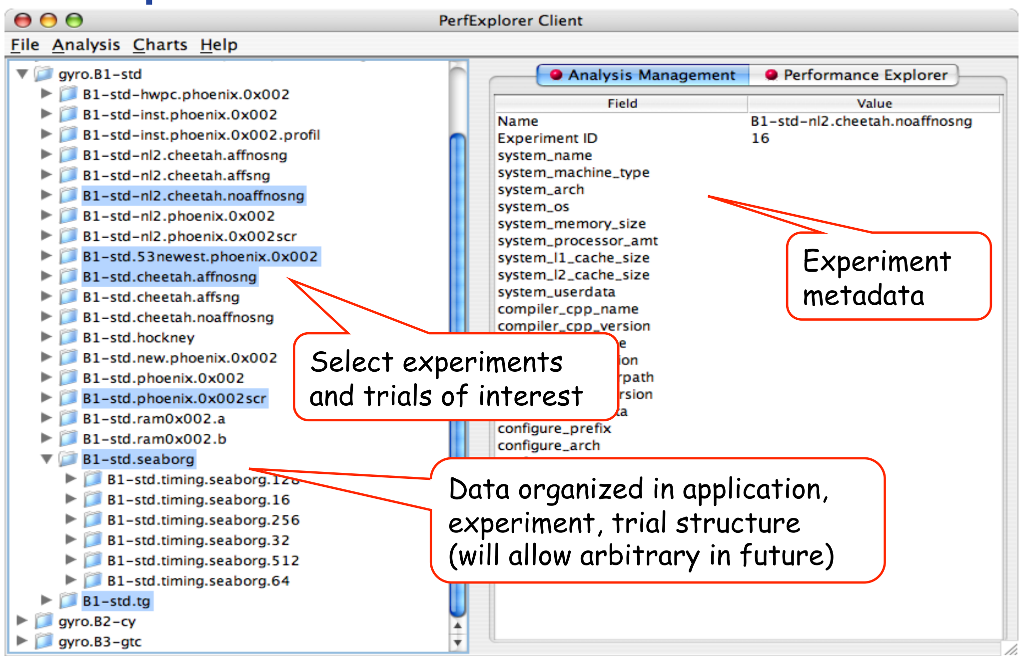
- -0.995 indicates strong, negative relationship
- As CALC_CUT_ BLOCK_CONTRIBUTIO NS() increases in execution time, MPI_Barrier() decreases



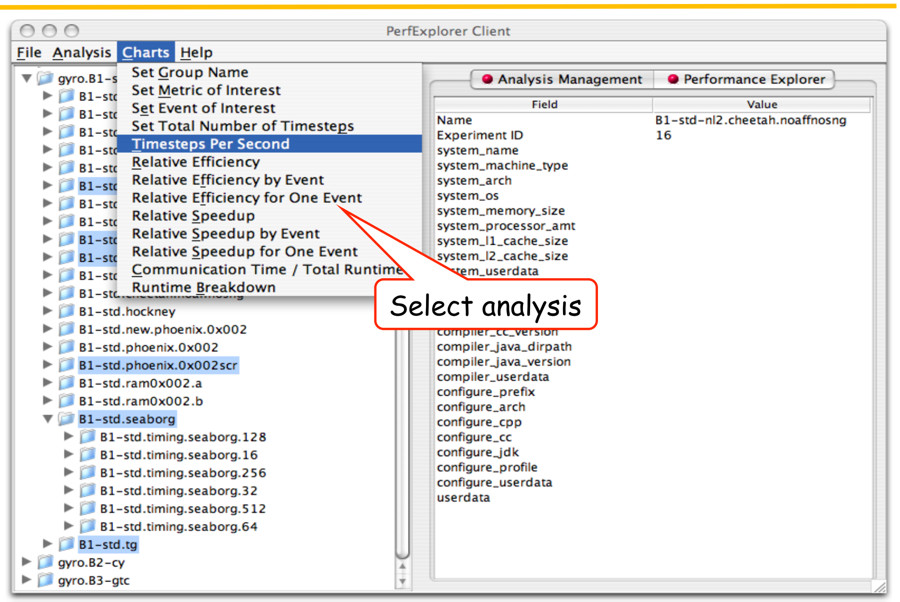
PerfExplorer - Comparative Analysis

- Relative speedup, efficiency
  - total runtime, by event, one event, by phase
- Breakdown of total runtime
- Group fraction of total runtime
- Correlating events to total runtime
- Timesteps per second
- Performance Evaluation Research Center (PERC)
  - PERC tools study (led by ORNL, Pat Worley)
  - In-depth performance analysis of select applications
  - Evaluation performance analysis requirements
  - Test tool functionality and ease of use

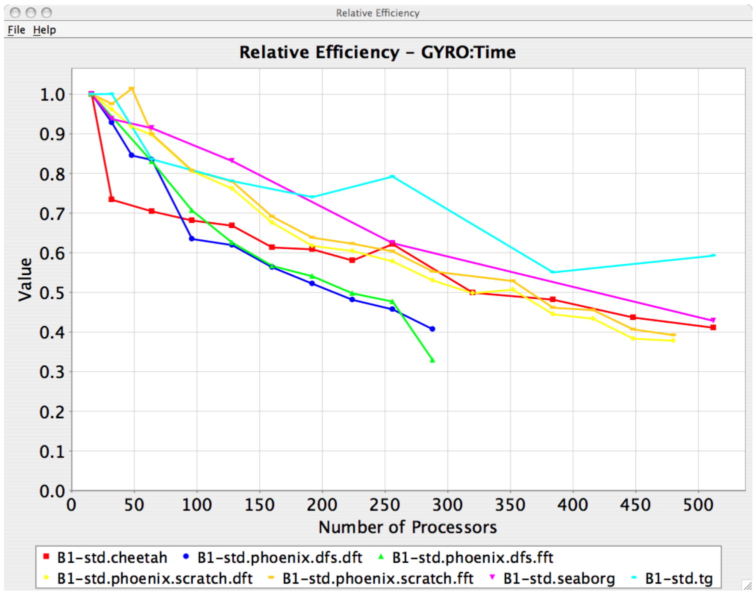
PerfExplorer - Interface



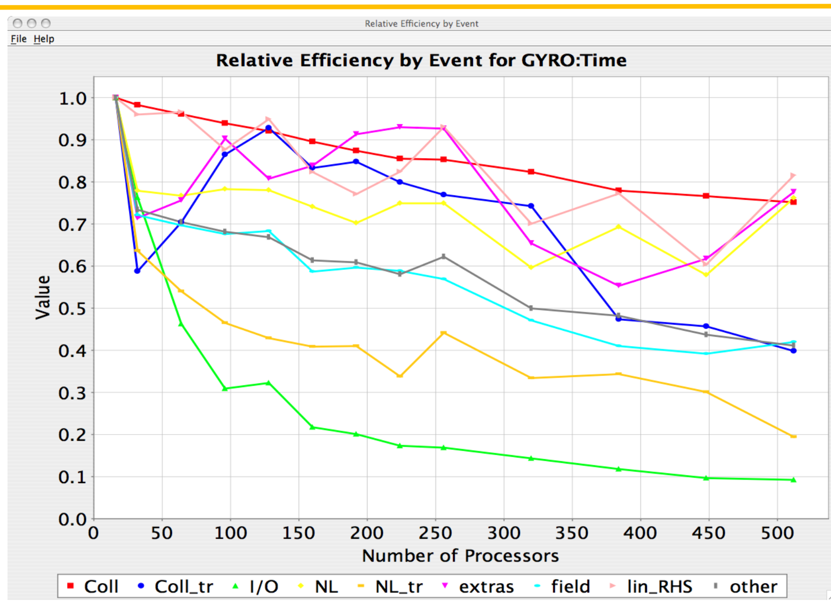
PerfExplorer - Interface



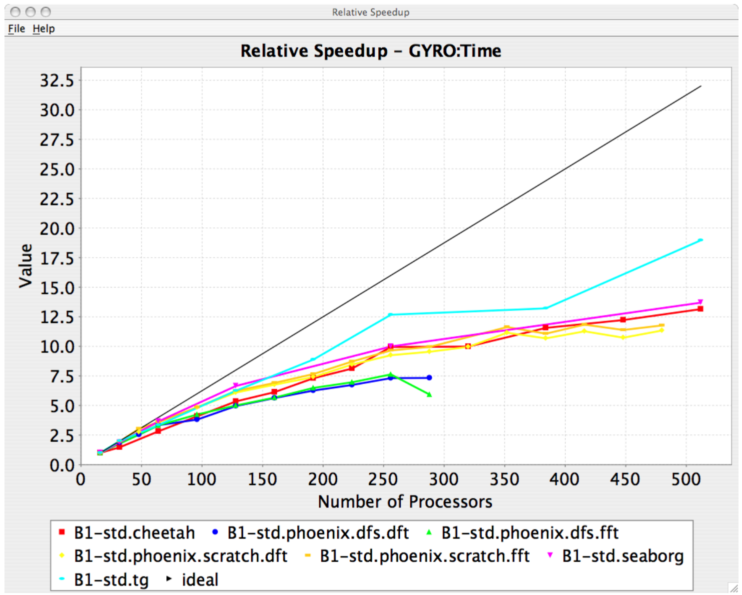
PerfExplorer - Relative Efficiency Plots



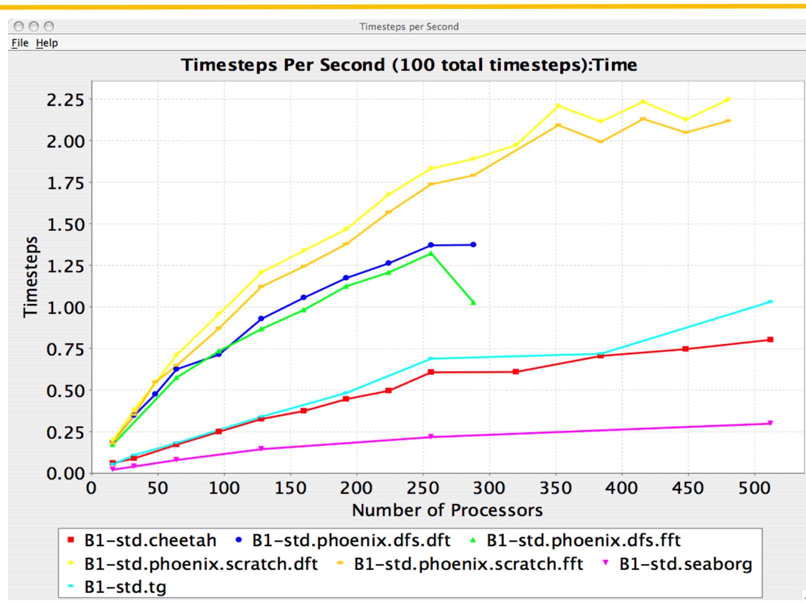
PerfExplorer - Relative Efficiency by Routine



PerfExplorer - Relative Speedup

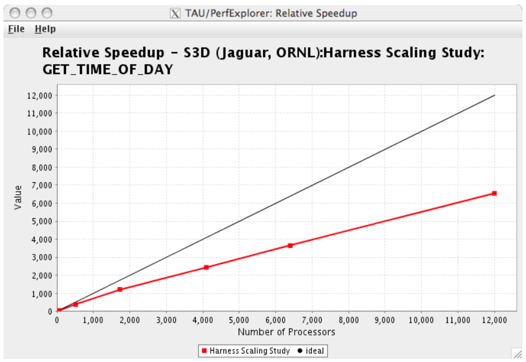


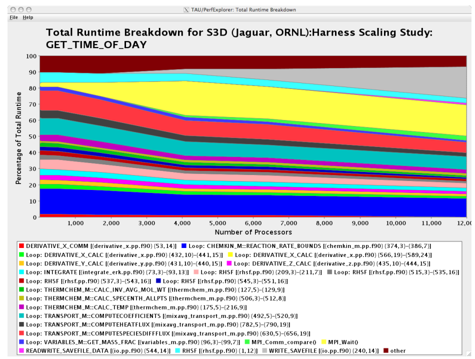
PerfExplorer - Timesteps Per Second



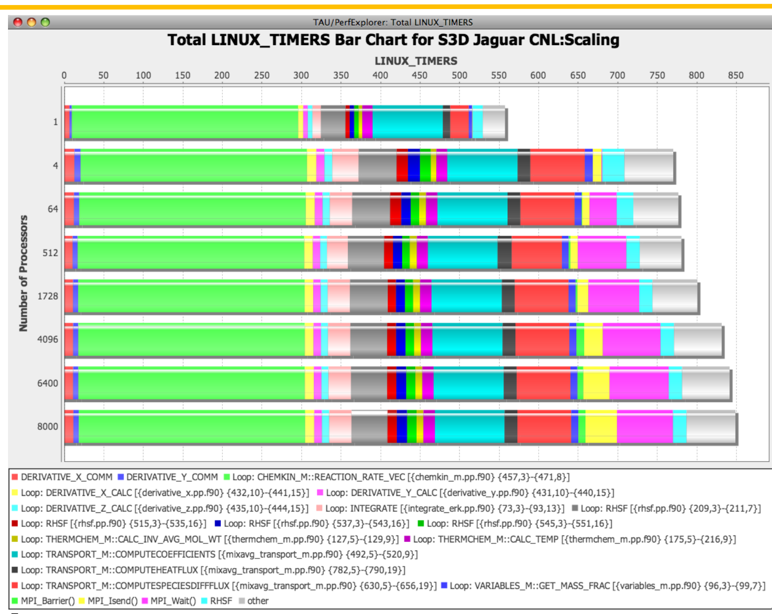
Usage Scenarios: Evaluate Scalability

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

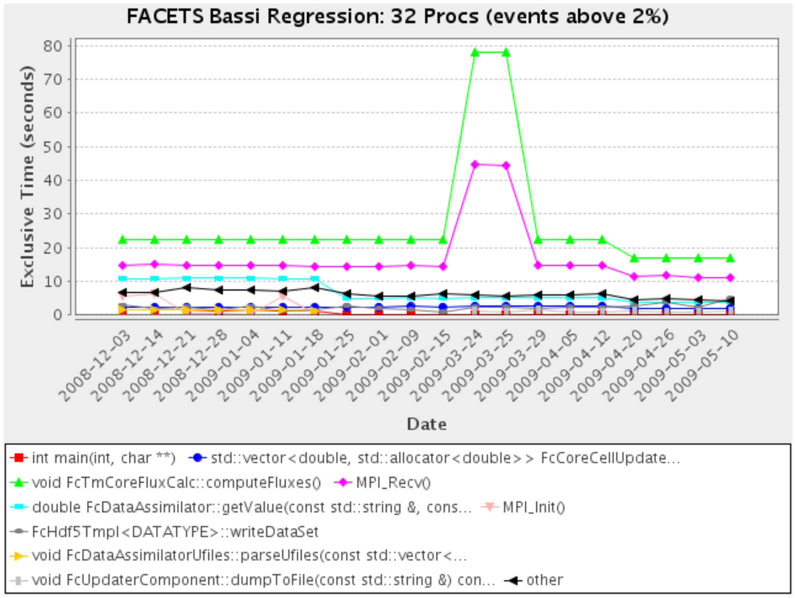




Usage Scenarios: Evaluate Scalability



Performance Regression Testing



Evaluate Scalability using PerfExplorer Charts

```
% export TAU_MAKEFILE=$TAU_ROOT/lib/Makefile.tau-mpi-pdt
% export PATH=$TAU_ROOT/bin:$PATH
% make F90=tau_f90.sh
(Or edit Makefile and change F90=tau_f90.sh)
% aprun -n 1 ./a.out
% paraprof --pack 1p.ppk
% aprun -n 2 ./a.out …
% paraprof --pack 2p.ppk … and so on.
On your client:
% perfdmf_configure --create-default
(Chooses 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 -a "app" -x "experiment" -n "name" file.ppk
Then,
% perfexplorer
(Select experiment, Menu: Charts -> Speedup)
```

Hands-on training with sample codes

Labs!

Lab: PAPI, and TAU

Lab Instructions

Get workshop.tar.gz using:

```
% wget
  http://www.paratools.com/ornl11/workshop.tar.gz
```

Or

```
% cp /ccs/proj/perc/TOOLS/tau/tar/workshop.tar.gz;
  tar zxf workshop.tar.gz
```

And follow the instructions in the README file.
http://tau.uoregon.edu/point.iso LiveDVD

For LiveDVD, see ~/workshop-point/README and follow.

Use /ccs/proj/perc/TOOLS/tau_latest as the TAU directory on Jaguar, ORNL and craycnl as the architecture directory. For Lens, please use x86_64 as the architecture directory.

Lab Instructions

To profile a code using TAU:

1. Choose TAU stub makefile
   % source /ccs/proj/perc/TOOLS/tau/tau.bashrc [or .cshrc]
   % export TAU_MAKEFILE=
   $TAU_ROOT/lib/Makefile.tau-[options]
2. Change the compiler name to tau_cxx.sh, tau_f90.sh, tau_cc.sh:
   % make CC=tau_cc.sh CXX=tau_cxx.sh F90=tau_f90.sh
3. Allocate nodes to run jobs:
   % qsub -I -q debug -A TRN001 -l size=12 -l walltime=0:59:00 -l gres=widow2
4. If stub makefile has -papi in its name, set the TAU_METRICS environment variable:
   % export TAU_METRICS=TIME:PAPI_L2_DCM:PAPI_TOT_CYC...
5. Execute the application:
   % aprun -n 8 ./a.out
6. Build and run workshop examples, then run pprof/paraprof

Support Acknowledgements

- Department of Energy (DOE)
  - Office of Science contracts
  - ANL, ORNL, PNNL contracts
  - LLNL-LANL-SNL ASC/NNSA Level 3 contract
- Department of Defense (DoD)
  - HPCMO, PETTT, HPTi
- National Science Foundation (NSF)
  - POINT, SI2
- University of Oregon
  - Dr. A. Malony, W. Spear,
    S. Biersdorff, S. Millstein, Dr. C. Lee
- University of Tennessee, Knoxville
  - Dr. Shirley Moore
- T.U. Dresden, GWT
  - Dr. Wolfgang Nagel and Dr. Andreas Knupfer
- Research Centre Juelich
  - Dr. Bernd Mohr, Dr. Felix Wolf