# The TAU Performance Technology for Complex Parallel Systems

*(Performance Analysis Bring Your Own Code Workshop, NRL Washington D.C.)*

Sameer Shende, Allen D. Malony, Robert Bell
University of Oregon
*{sameer, malony, bertie}@cs.uoregon.edu*

Tuning and Analysis Utilities

UNIVERSITY OF OREGON

Los Alamos NATIONAL LABORATORY

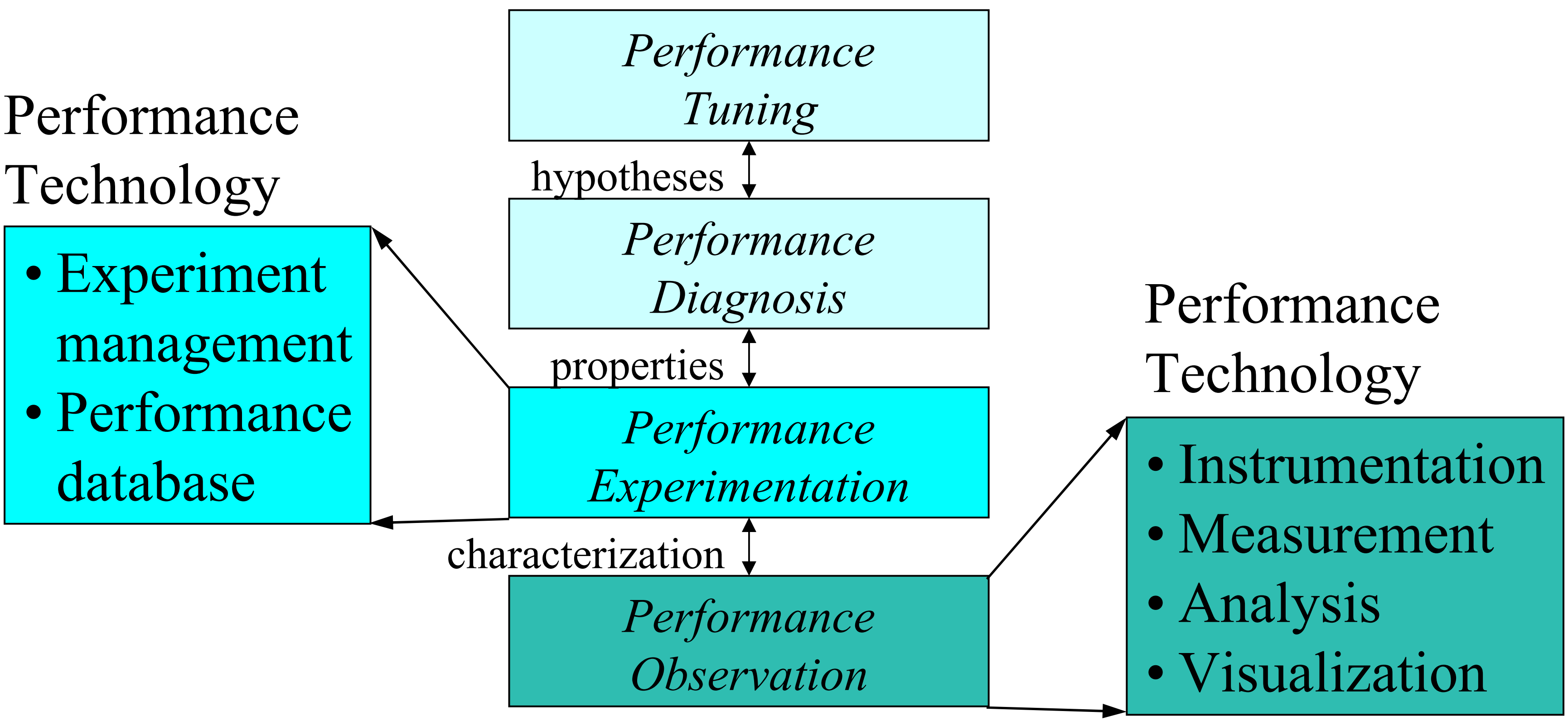
John von Neumann - Institut für Computing NIC
Zentralinstitut für Angewandte Mathematik

# Outline

- Motivation
- Part I: Instrumentation
- Part II: Measurement
- Part III: Analysis Tools
- Conclusion

# Research Motivation

- Tools for performance problem solving
  - Empirical-based performance optimization process
  - Performance technology concerns



# TAU Performance System

- Tuning and Analysis Utilities (11+ year project effort)
- *Performance system framework* for scalable parallel and distributed high-performance computing
- Targets a general complex system computation model
  - nodes / contexts / threads
  - Multi-level: system / software / parallelism
  - Measurement and analysis abstraction
- *Integrated toolkit* for performance instrumentation, measurement, analysis, and visualization
  - Portable performance profiling and tracing facility
  - Open software approach with technology integration
- University of Oregon , Forschungszentrum Jülich, LANL

# TAU Performance Systems Goals

- 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
- Support for performance mapping
- Support for object-oriented and generic programming
- Integration in complex software systems and applications

# Definitions – Profiling

- Profiling
  - Recording of summary information during execution
    - inclusive, exclusive time, # calls, hardware statistics, …
  - Reflects performance behavior of program entities
    - functions, loops, basic blocks
    - user-defined "semantic" entities
  - Very good for low-cost performance assessment
  - Helps to expose performance bottlenecks and hotspots
  - Implemented through
    - sampling: periodic OS interrupts or hardware counter traps
    - instrumentation: direct insertion of measurement code

# *Definitions – Tracing*

- Tracing
  - Recording of information about significant points (events) during program execution
    - entering/exiting code region (function, loop, block, …)
    - thread/process interactions (e.g., send/receive message)
  - Save information in event record
    - timestamp
    - CPU identifier, thread identifier
    - Event type and event-specific information
  - Event trace is a time-sequenced stream of event records
  - Can be used to reconstruct dynamic program behavior
  - Typically requires code instrumentation

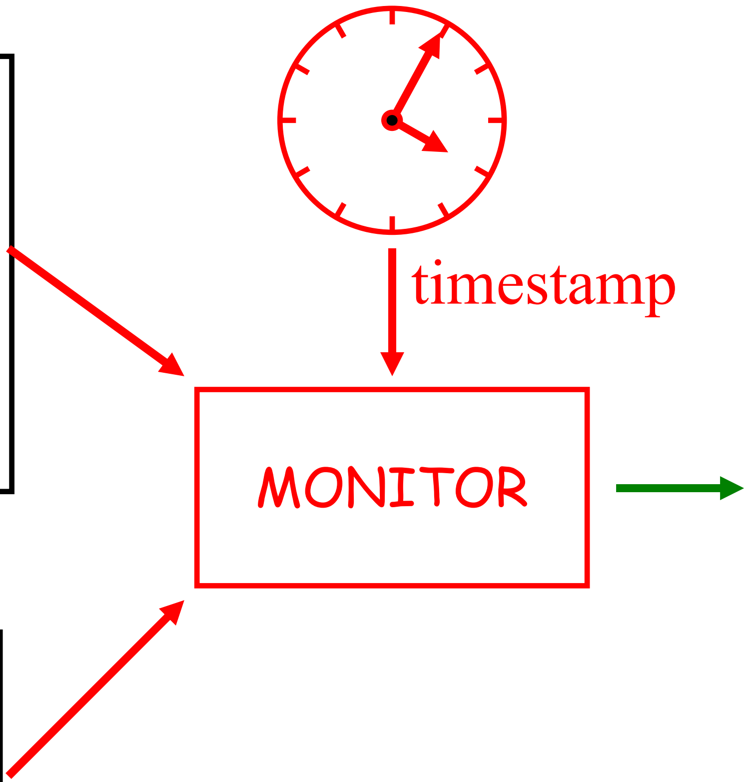
# Event Tracing: Instrumentation, Monitor, Trace

CPU A:

```
void master {
  trace(ENTER, 1);
  ...
  trace(SEND, B);
  send(B, tag, buf);
  ...
  trace(EXIT, 1);
}
```

CPU B:

```
void slave {
  trace(ENTER, 2);
  ...
  recv(A, tag, buf);
  trace(RECV, A);
  ...
  trace(EXIT, 2);
}
```




Event definition

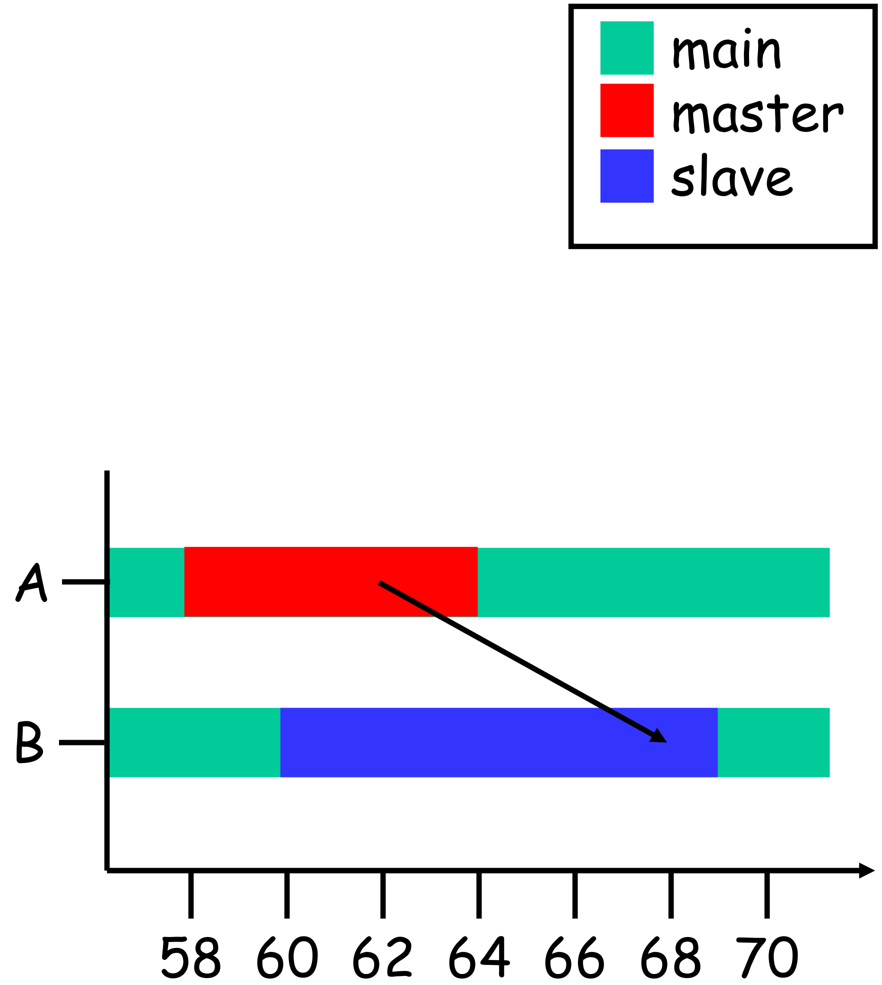
| | |
|---|---|
| 1 | master |
| 2 | slave |
| 3 | ... |

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

# *Event Tracing: "Timeline" Visualization*

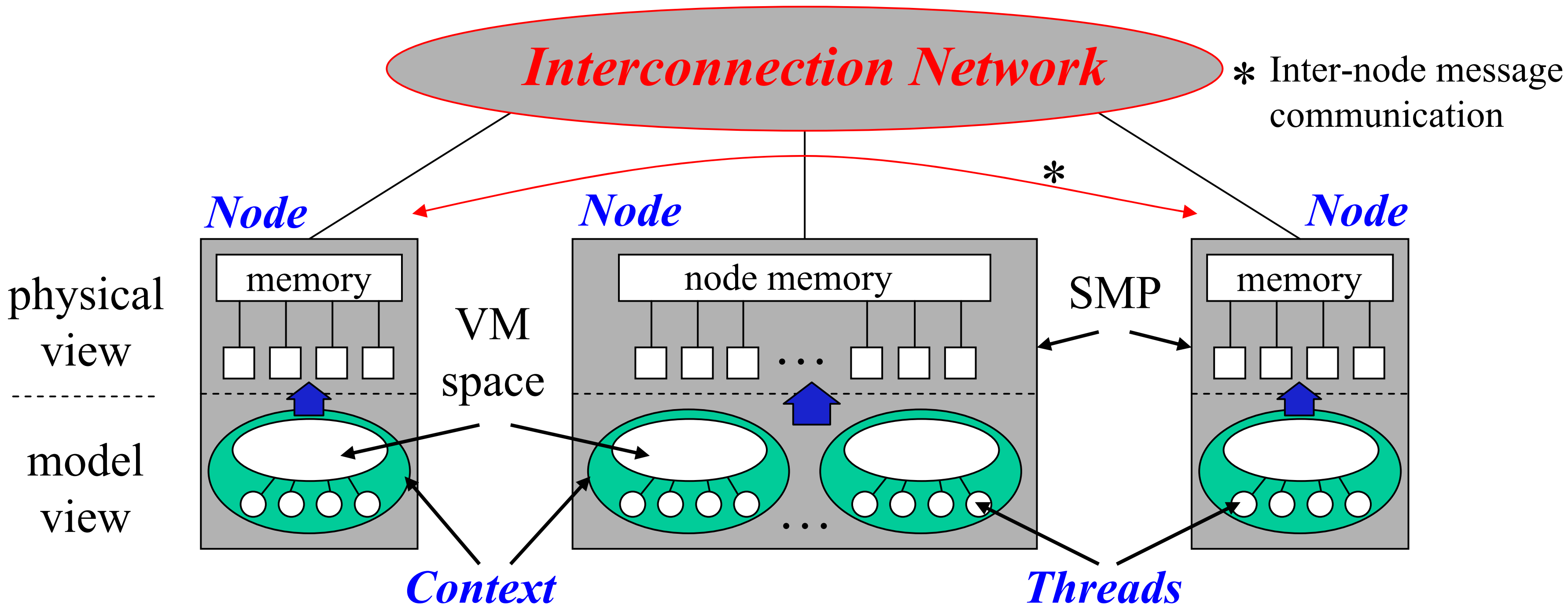
| | |
|---|---|
| 1 | master |
| 2 | slave |
| 3 | ... |

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

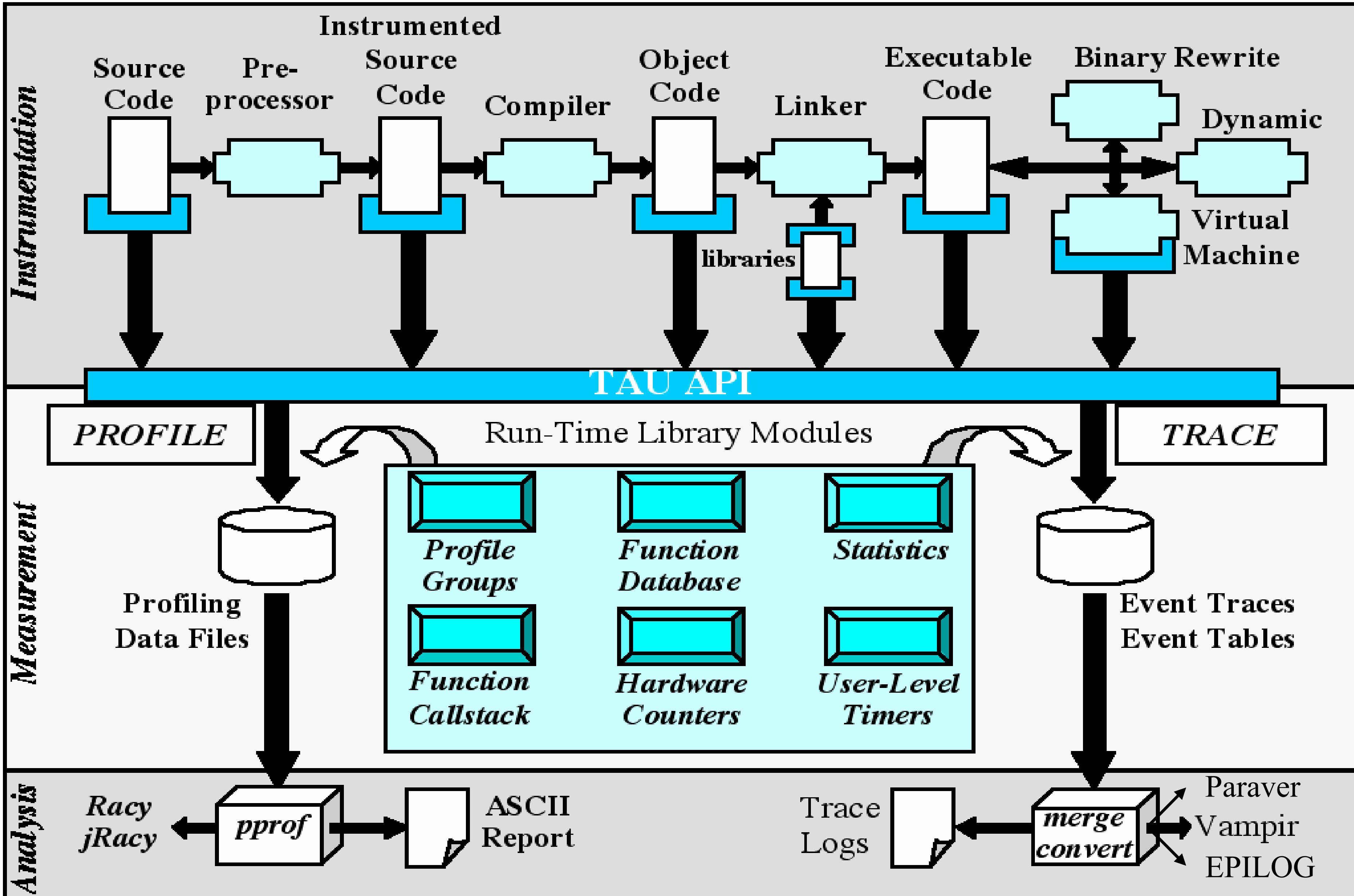


# General Complex System Computation Model

- ***Node***: physically distinct shared memory machine
  - Message passing *node interconnection network*
- ***Context***: distinct virtual memory space within node
- ***Thread***: execution threads (user/system) in context



# TAU Performance System Architecture



# Strategies for Empirical Performance Evaluation

- Empirical performance evaluation as a series of performance experiments
  - Experiment trials describing instrumentation and measurement requirements
  - Where/When/How axes of empirical performance space
    - where are performance measurements made in program
      - routines, loops, statements…
    - when is performance instrumentation done
      - compile-time, while pre-processing, runtime…
    - how are performance measurement/instrumentation chosen
      - profiling with hw counters, tracing, callpath profiling…

# TAU Instrumentation Approach

- Support for standard program events
  - Routines
  - Classes and templates
  - Statement-level blocks
- Support for user-defined events
  - Begin/End events (“user-defined timers”)
  - Atomic events (e.g., size of memory allocated/freed)
  - Selection of event statistics
- Support definition of “semantic” entities for mapping
- Support for event groups
- Instrumentation optimization

# *TAU Instrumentation*

- Flexible instrumentation mechanisms at multiple levels
  - Source code
    - manual
    - automatic
      - C, C++, F77/90/95 (Program Database Toolkit (*PDT*))
      - OpenMP (directive rewriting (*Opari*), *POMP spec*)
  - Object code
    - pre-instrumented libraries (e.g., MPI using *PMPI*)
    - statically-linked and dynamically-linked
  - Executable code
    - dynamic instrumentation (pre-execution) (*DynInstAPI*)
    - virtual machine instrumentation (e.g., Java using *JVMPI*)

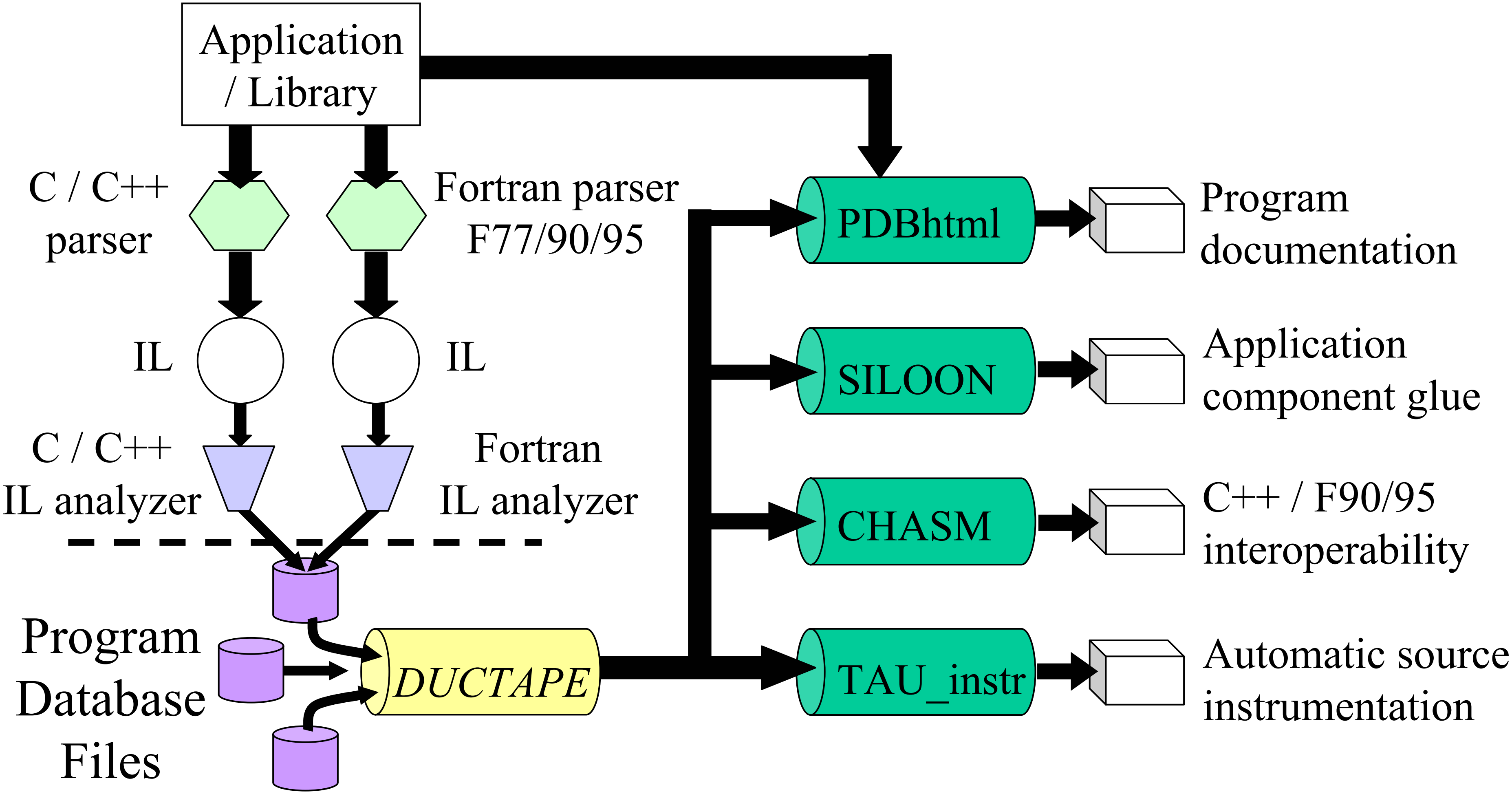
# *Multi-Level Instrumentation*

- Targets common measurement interface
  - *TAU API*
- Multiple instrumentation interfaces
  - Simultaneously active
- Information sharing between interfaces
  - Utilizes instrumentation knowledge between levels
- Selective instrumentation
  - Available at each level
  - Cross-level selection
- Targets a common performance model
- Presents a unified view of execution
  - Consistent performance events

# *Program Database Toolkit (PDT)*

- Program code analysis framework
  - develop source-based tools
- *High-level interface* to source code information
- *Integrated toolkit* for source code parsing, database creation, and database query
  - Commercial grade front-end parsers
  - Portable IL analyzer, database format, and access API
  - Open software approach for tool development
- Multiple source languages
- Implement automatic performance instrumentation tools
  - *tau_instrumentor*

# *Program Database Toolkit (PDT)*



# PDT 3.2 Functionality

- C++ statement-level information implementation
  - for, while loops, declarations, initialization, assignment…
  - PDB records defined for most constructs
- DUCTAPE
  - Processes PDB 1.x, 2.x, 3.x uniformly
- PDT applications
  - XMLgen
    - PDB to XML converter
    - Used for CHASM and CCA tools
  - PDBstmt
    - Statement callgraph display tool

# PDT 3.2 Functionality (continued)

- Cleanscape Flint parser fully integrated for F90/95
  - Flint parser (f95parse) is very robust
  - Produces PDB records for TAU instrumentation (stage 1)
    - Linux (x86, IA-64, Opteron, Power4), HP Tru64, IBM AIX, Cray X1,T3E, Solaris, SGI, Apple, Windows, Power4 Linux (IBM Blue Gene/L compatible)
  - Full PDB 2.0 specification (stage 2) [SC'04]
  - Statement level support (stage 3) [SC'04]
- URL: http://www.cs.uoregon.edu/research/paracomp/pdtoolkit

# TAU Performance Measurement

- TAU supports profiling and tracing measurement
- Robust timing and hardware performance support using PAPI
- Support for online performance monitoring
  - Profile and trace performance data export to file system
  - Selective exporting
- Extension of TAU measurement for multiple counters
  - Creation of user-defined TAU counters
  - Access to system-level metrics
- Support for callpath measurement
- Integration with system-level performance data
  - Linux MAGNET/MUSE (Wu Feng, LANL)

# *TAU Measurement*

- Performance information
  - Performance events
  - High-resolution timer library (real-time / virtual clocks)
  - General software counter library (user-defined events)
  - Hardware performance counters
    - *PAPI* (Performance API) (UTK, Ptools Consortium)
    - consistent, portable API
- Organization
  - Node, context, thread levels
  - Profile groups for collective events (runtime selective)
  - Performance data mapping between software levels

# TAU Measurement Options

- Parallel profiling
  - Function-level, block-level, statement-level
  - Supports user-defined events
  - TAU parallel profile data stored during execution
  - Hardware counts values
  - Support for multiple counters
  - Support for callgraph and callpath profiling
- Tracing
  - All profile-level events
  - Inter-process communication events
  - Trace merging and format conversion

# Grouping Performance Data in TAU

- Profile Groups
  - A group of related routines forms a profile group
  - Statically defined
    - TAU_DEFAULT, TAU_USER[1-5], TAU_MESSAGE, TAU_IO, …
  - Dynamically defined
    - group name based on string, such as "adlib" or "particles"
    - runtime lookup in a map to get unique group identifier
    - uses *tau_instrumentor* to instrument
  - Ability to change group names at runtime
  - Group-based instrumentation and measurement control

# *TAU Analysis*

- Parallel profile analysis
  - *Pprof*
    - parallel profiler with text-based display
  - *ParaProf*
    - Graphical, scalable, parallel profile analysis and display
- Trace analysis and visualization
  - Trace merging and clock adjustment (if necessary)
  - Trace format conversion (ALOG, SDDF, VTF, Paraver)
  - Trace visualization using *Vampir* (Pallas/Intel)

# *Pprof Output (NAS Parallel Benchmark – LU)*

- Intel Quad PIII Xeon
- F90 + MPICH
- Profile
  - Node
  - Context
  - Thread
- Events
  - code
  - MPI

emacs@neutron.cs.uoregon.edu

Buffers Files Tools Edit Search Mule Help

Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:

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

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

# Terminology – Example

- For routine "int main( )":
- Exclusive time
  - 100-20-50-20=10 secs
- Inclusive time
  - 100 secs
- Calls
  - 1 call
- Subrs (no. of child routines called)
  - 3
- Inclusive time/call
  - 100secs

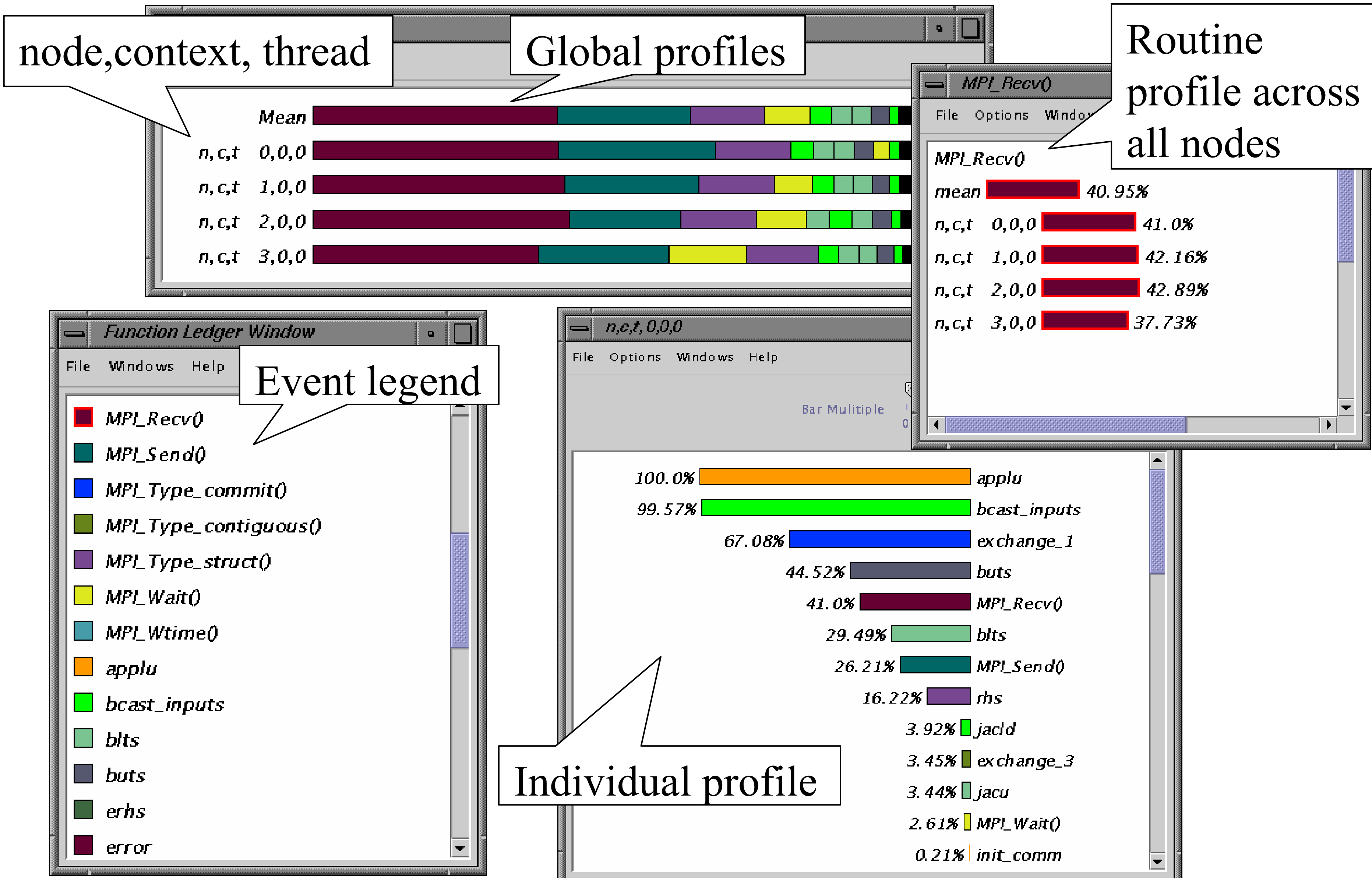
```
int main( )
{ /* takes 100 secs */

  f1(); /* takes 20 secs */
  f2(); /* takes 50 secs */
  f1(); /* takes 20 secs */

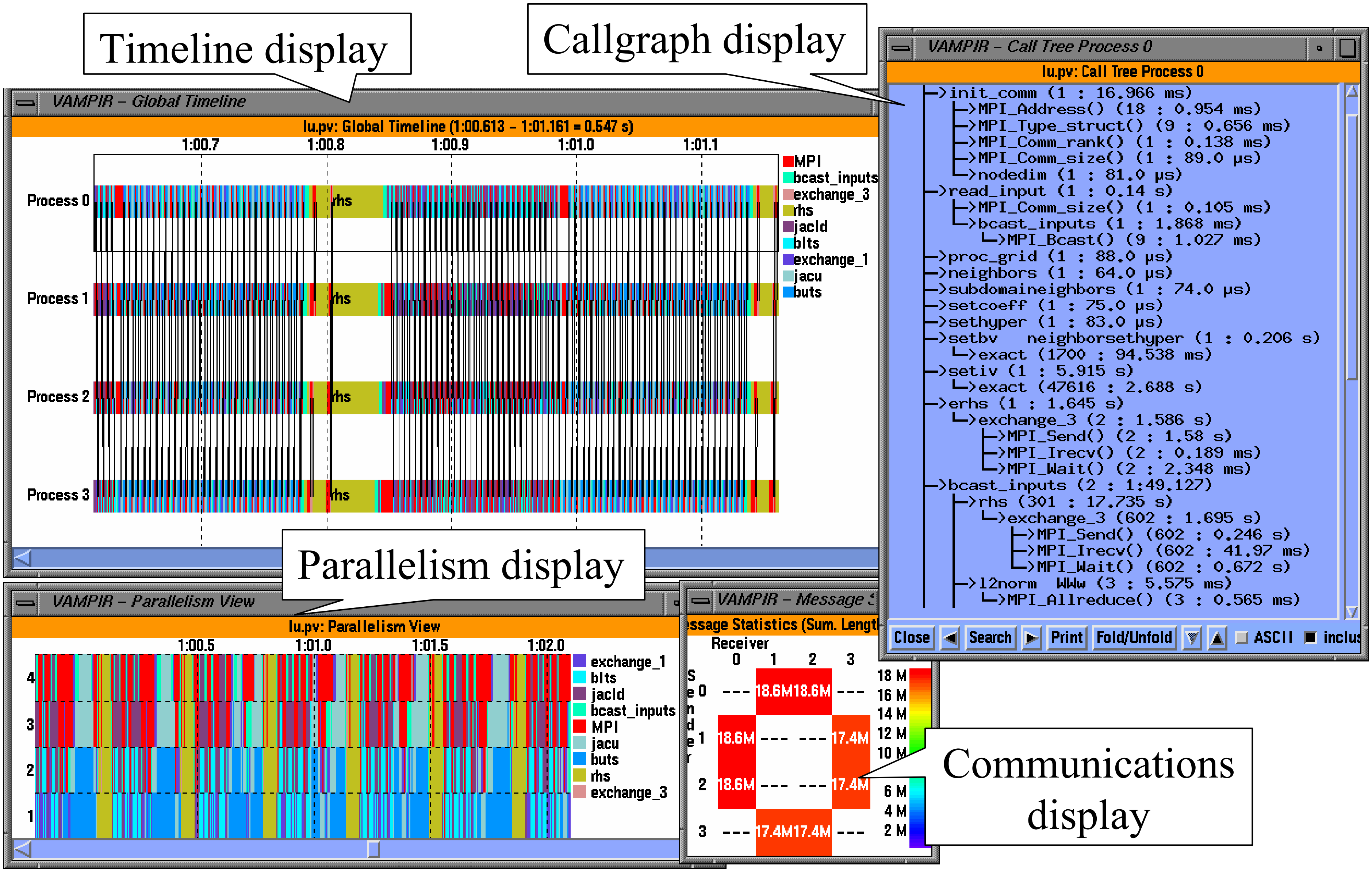
  /* other work */
}

/*
Time can be replaced by  counts
from PAPI e.g., PAPI_FP_INS. */
```

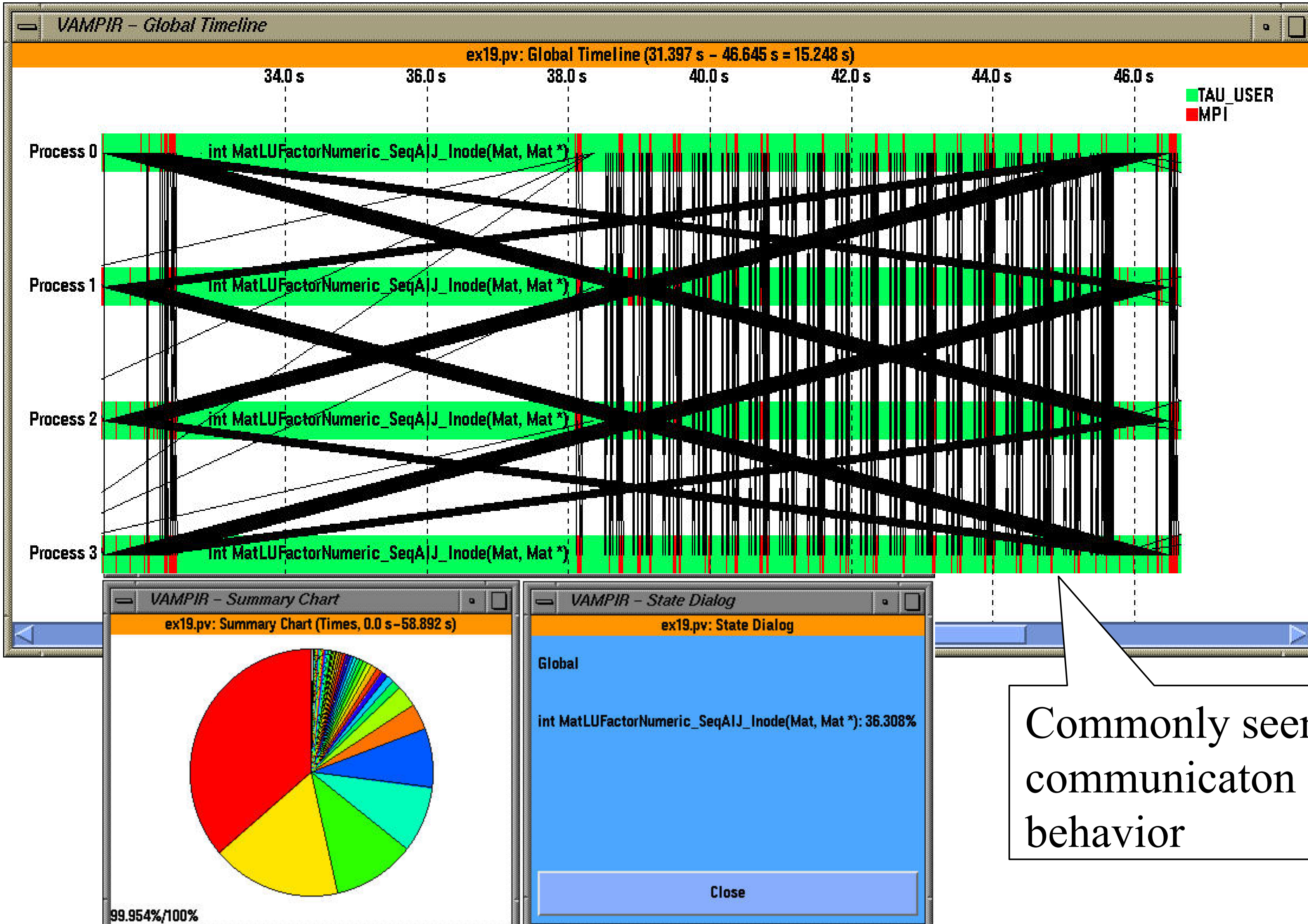
# ParaProf (NAS Parallel Benchmark – LU)



# *TAU + Vampir (NAS Parallel Benchmark – LU)*

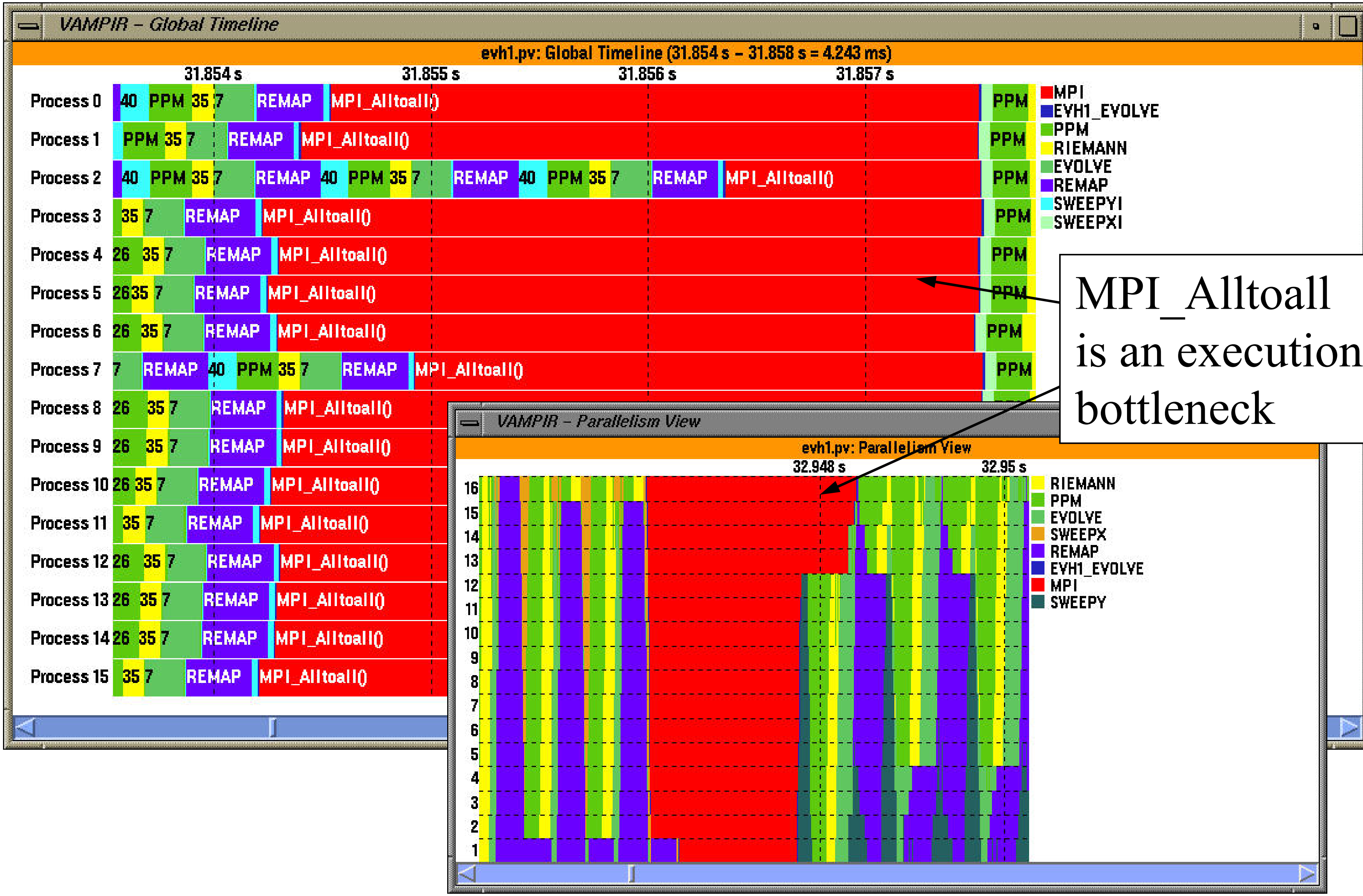


# PETSc ex19 (Tracing)




Commonly seen communicaton behavior

# TAU's EVH1 Execution Trace in Vampir



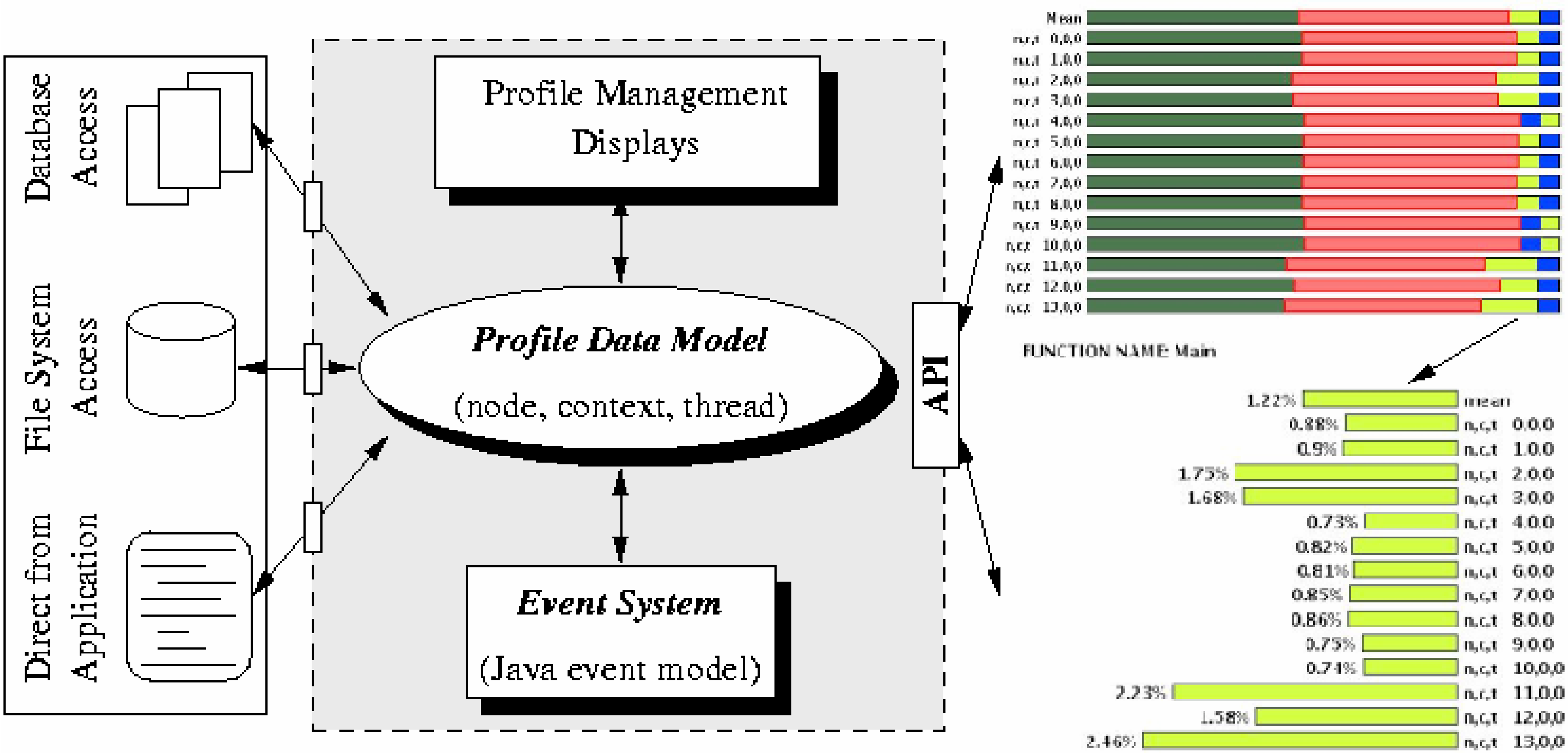

MPI_Alltoall is an execution bottleneck

# Performance Analysis and Visualization

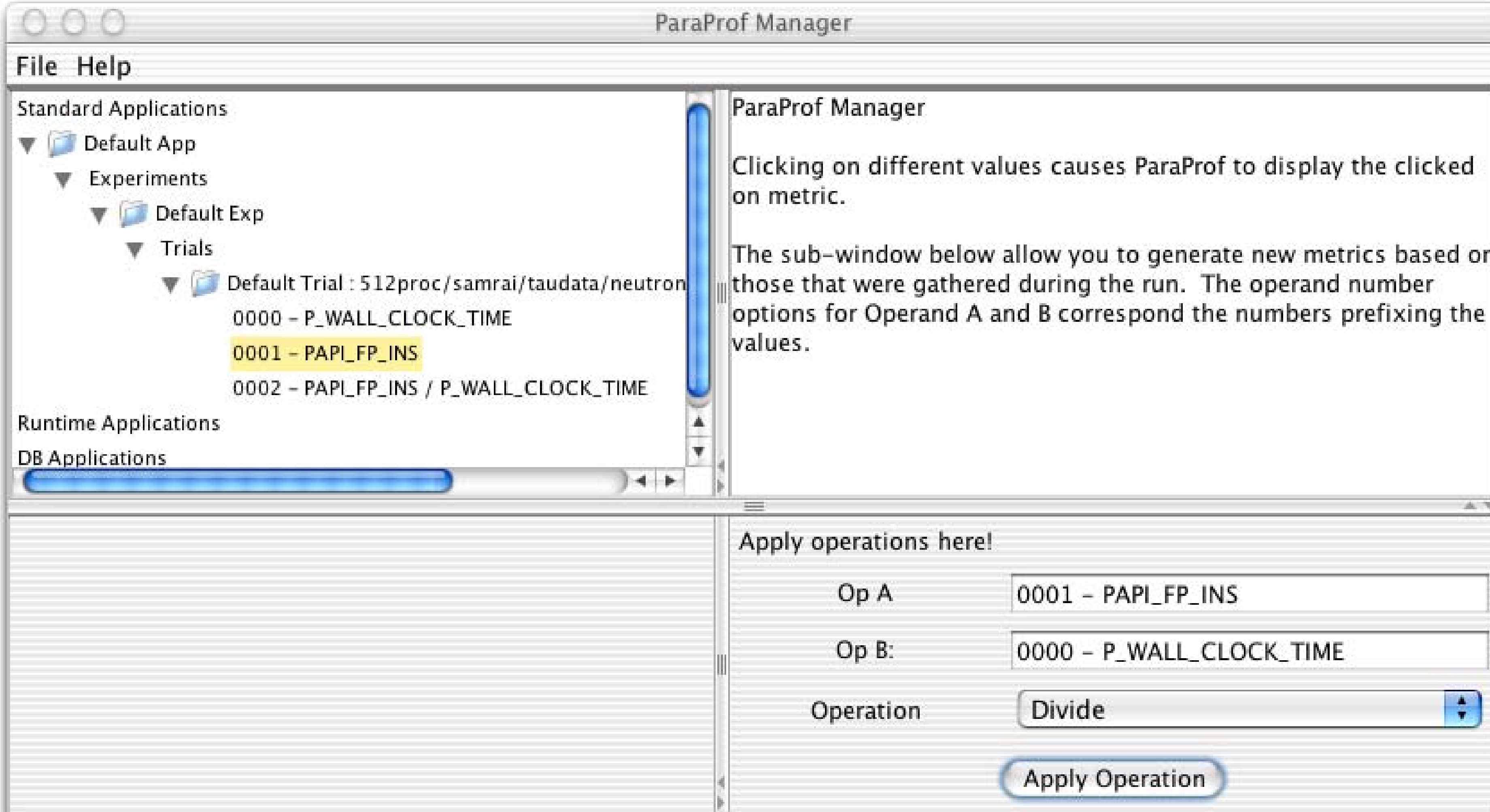
- Analysis of parallel profile and trace measurement
- Parallel profile analysis
  - ParaProf
  - Profile generation from trace data
- Performance database framework (PerfDBF)
- Parallel trace analysis
  - Translation to VTF 3.0 and EPILOG
  - Integration with VNG (Technical University of Dresden)
- Online parallel analysis and visualization

# ParaProf Framework Architecture

- Portable, extensible, and scalable tool for profile analysis
- Try to offer “best of breed” capabilities to analysts
- Build as profile analysis framework for extensibility

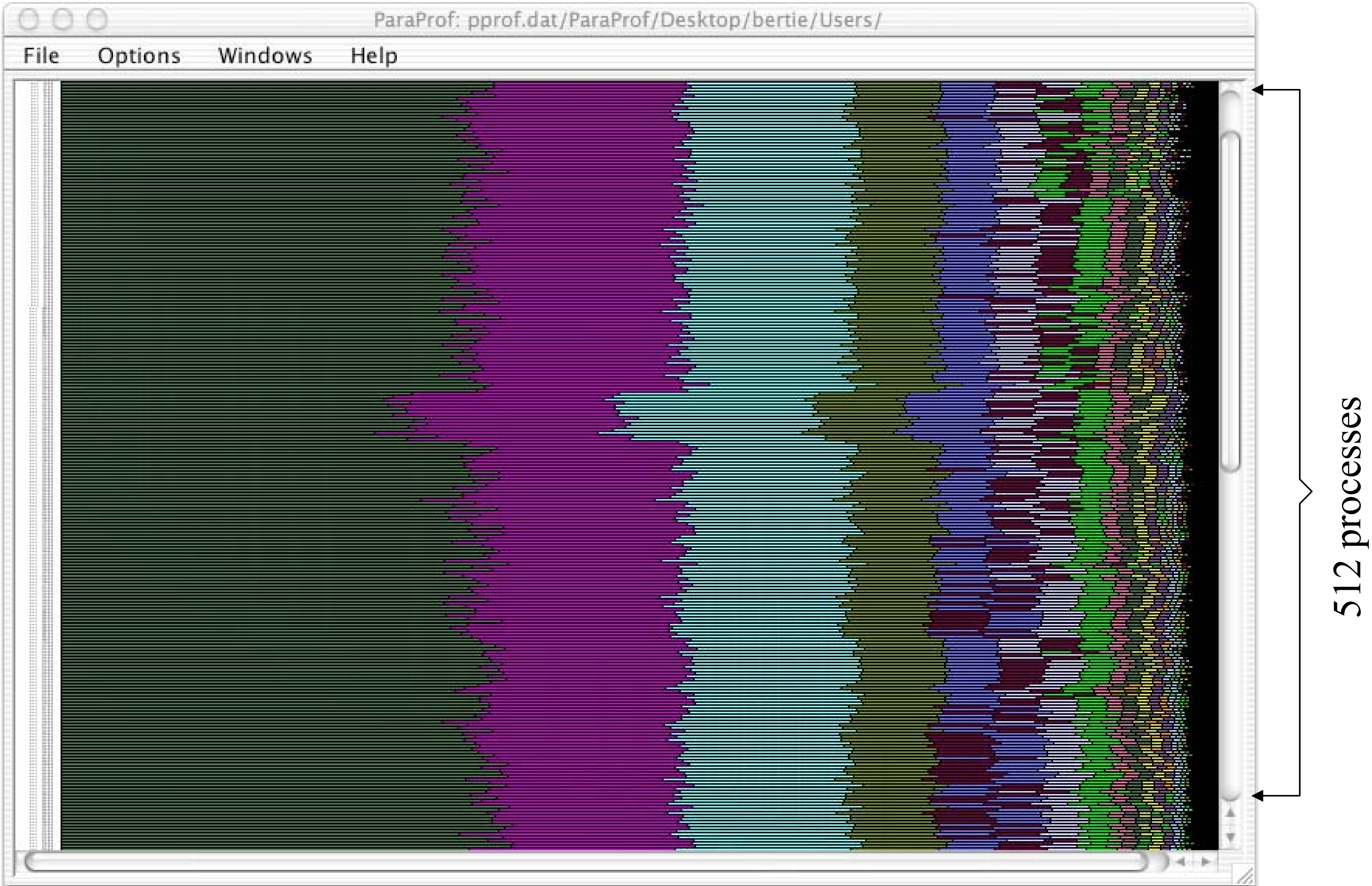


# Profile Manager Window

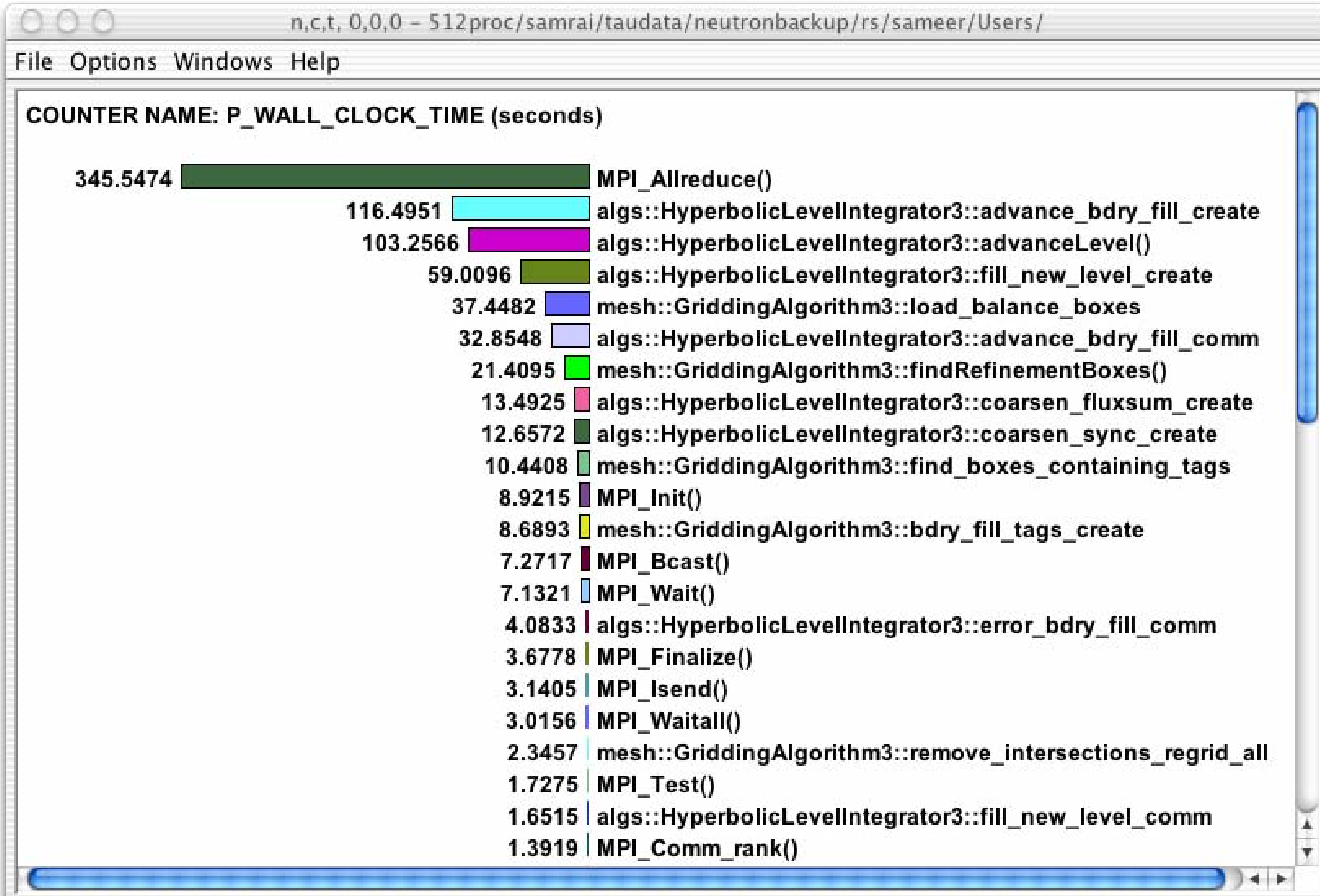



- Structured AMR toolkit (SAMRAI++), LLNL

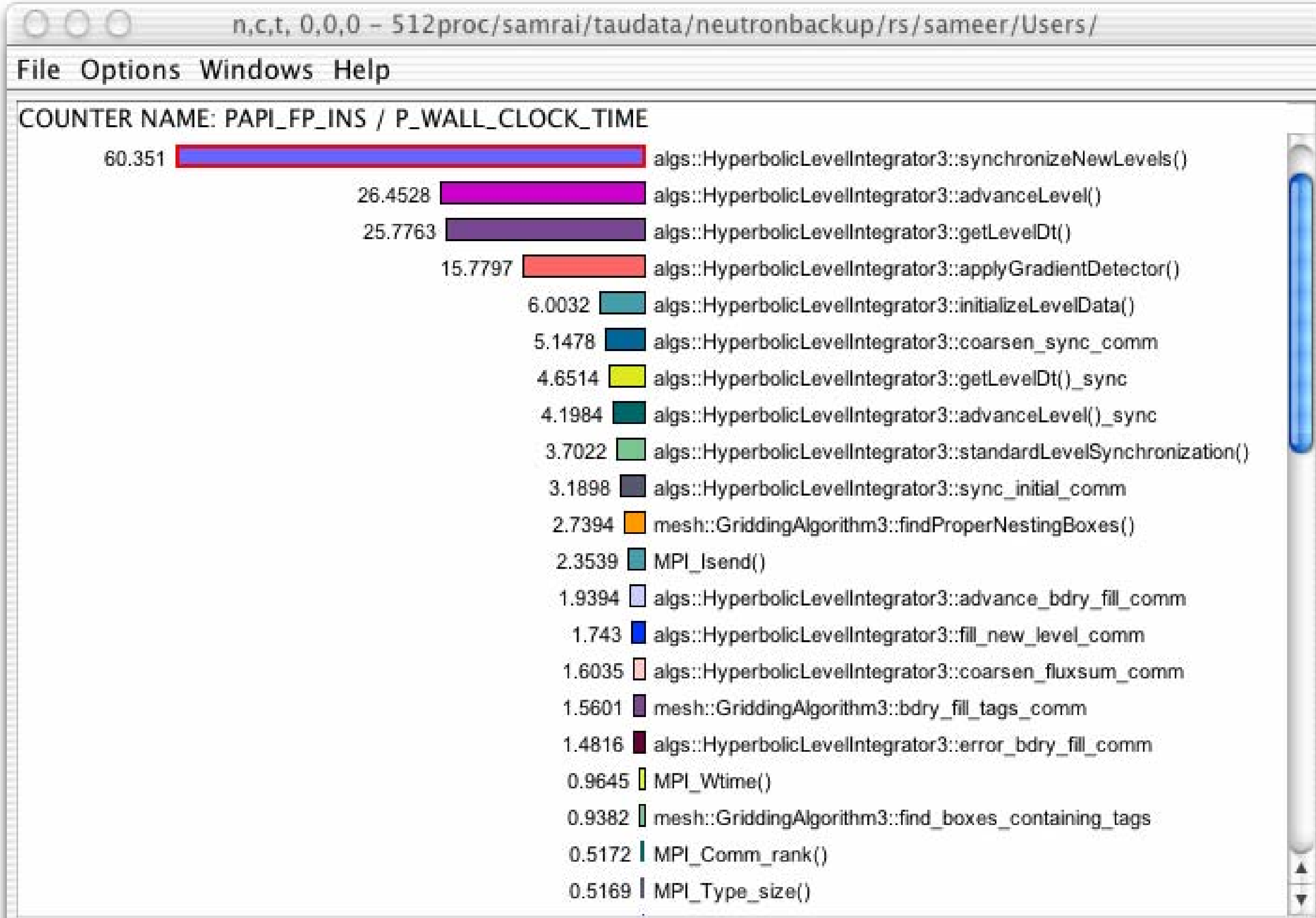
# Full Profile Window (Exclusive Time)



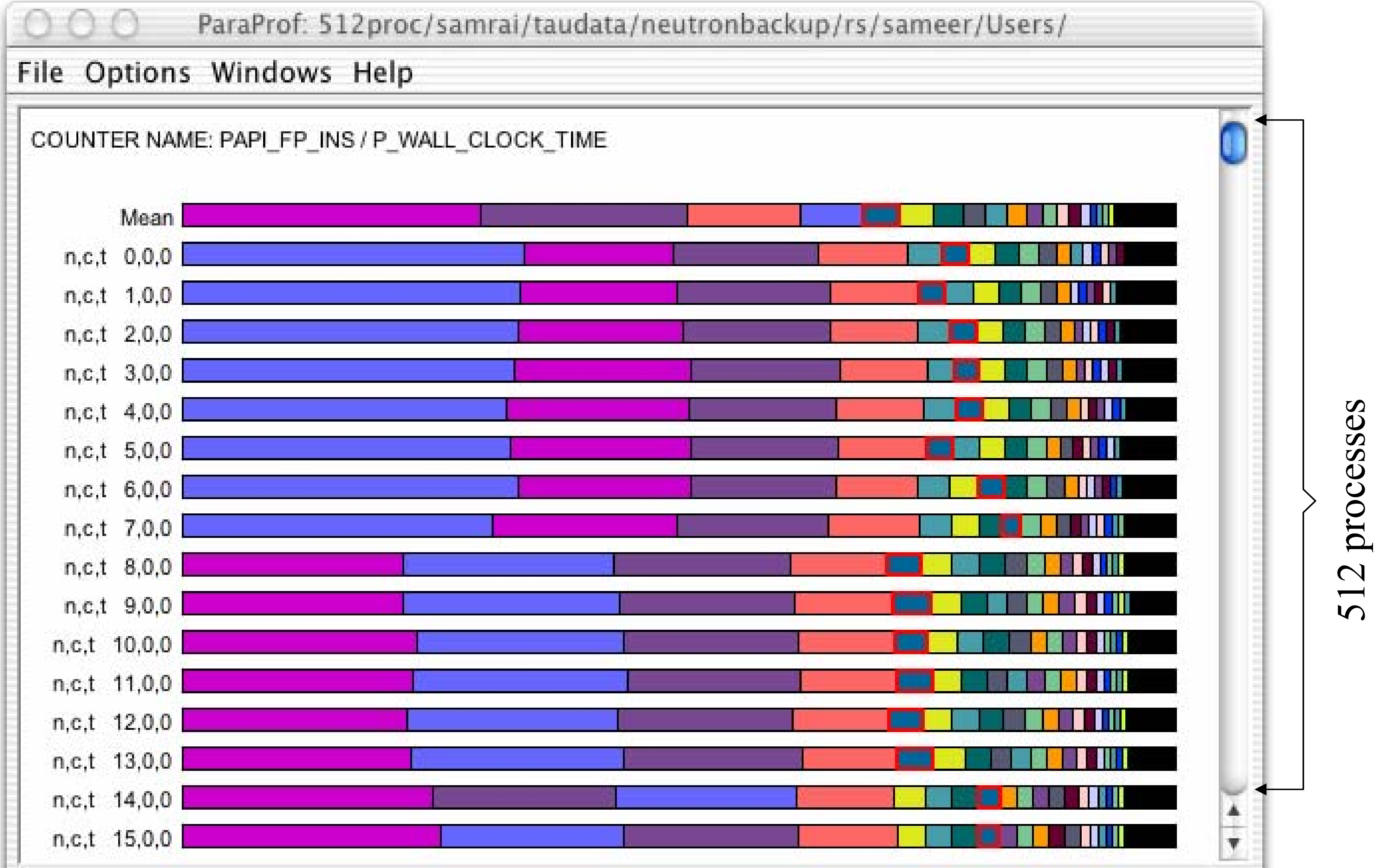
# *Node / Context / Thread Profile Window*



# *Derived Metrics*



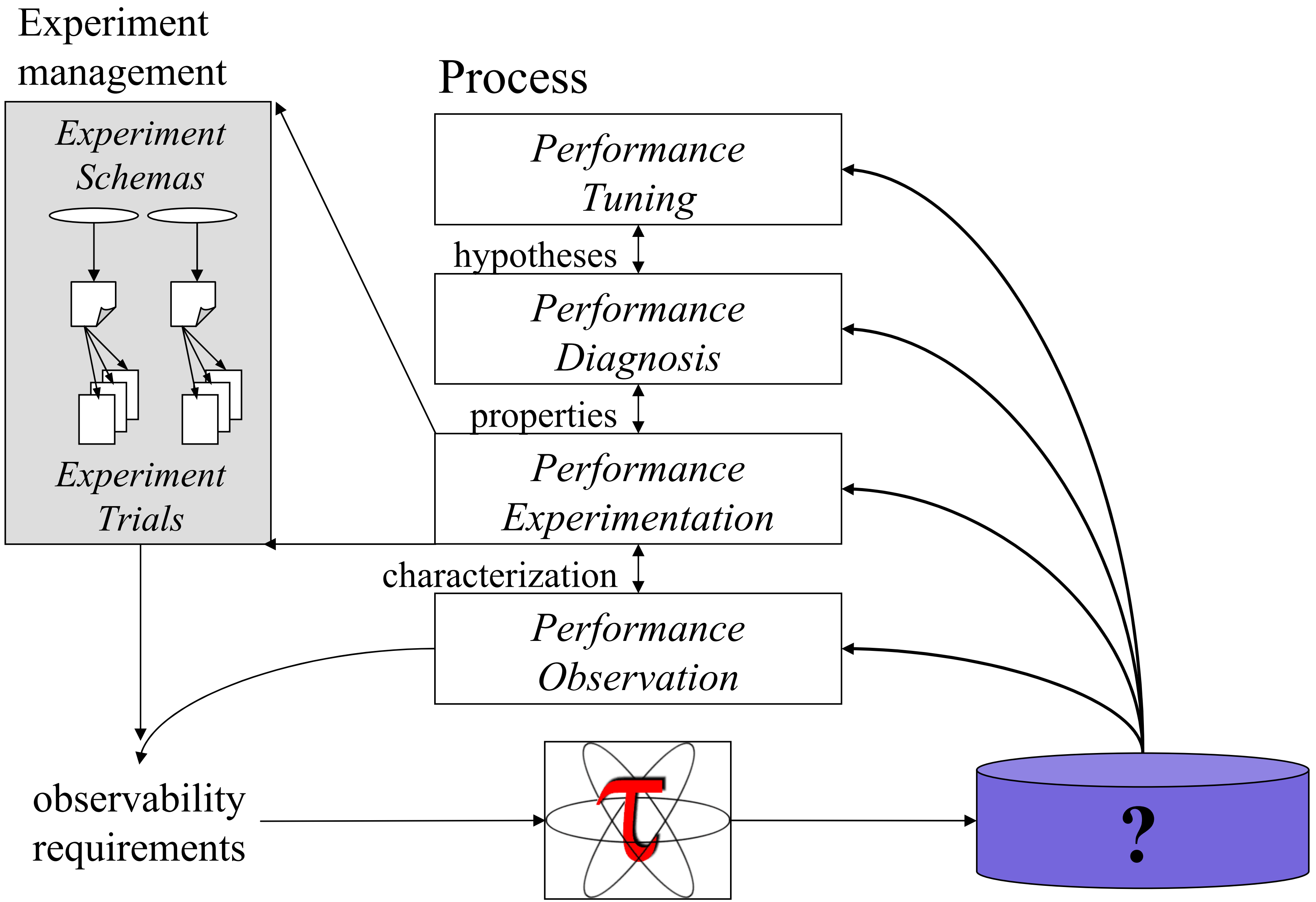
# Full Profile Window (Metric-specific)



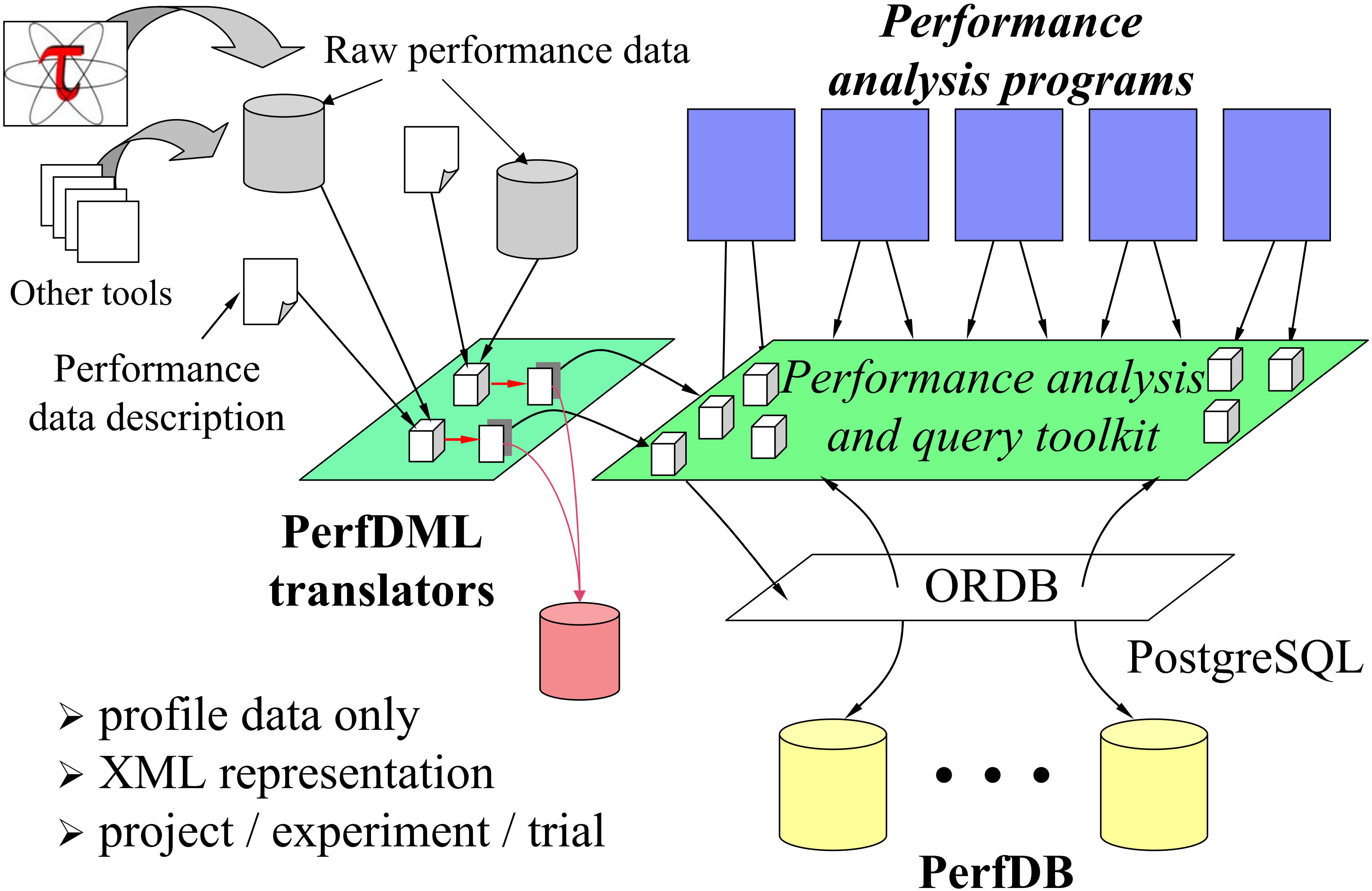
# *ParaProf Enhancements*

- Readers completely separated from the GUI
- Access to performance profile database
- Profile translators
  - mpiP, papiprof, dynaprof
- Callgraph display
  - prof/gprof style with hyperlinks
- Integration of 3D performance plotting library
- Scalable profile analysis
  - Statistical histograms, cluster analysis, …
- Generalized programmable analysis engine
- Cross-experiment analysis

# Empirical-Based Performance Optimization

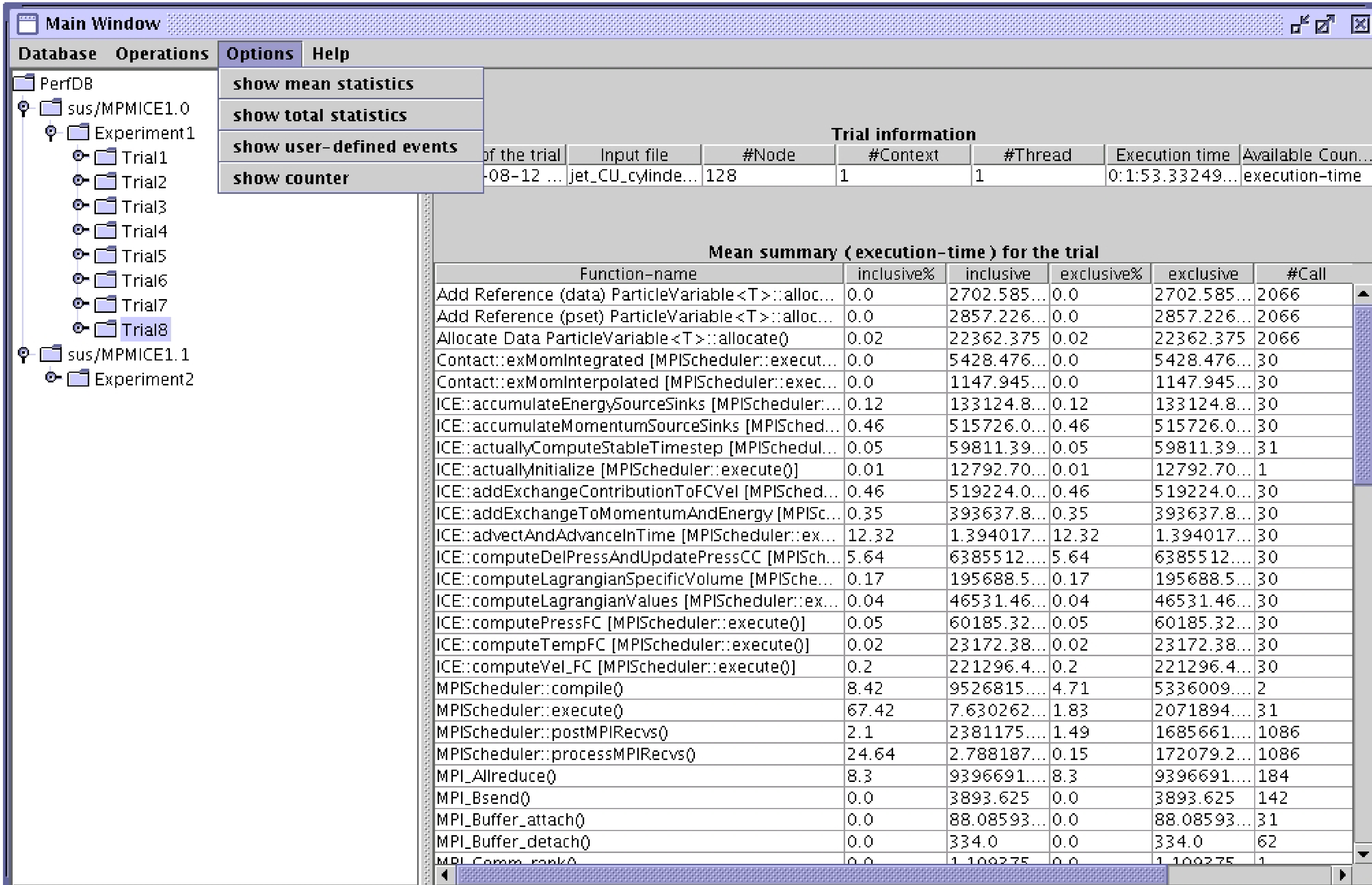


# TAU Performance Database Framework

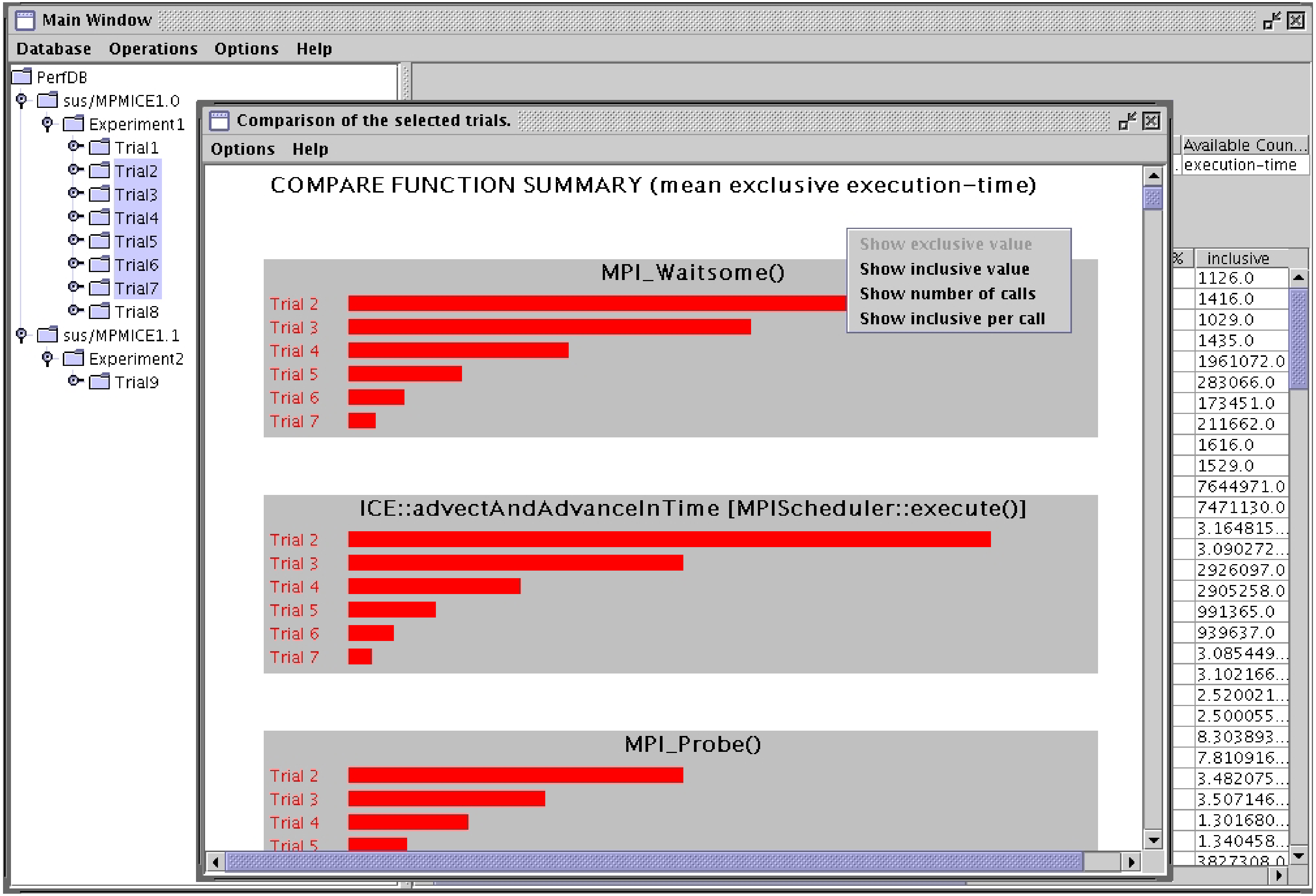



- profile data only
- XML representation
- project / experiment / trial

# *PerfDBF Browser*



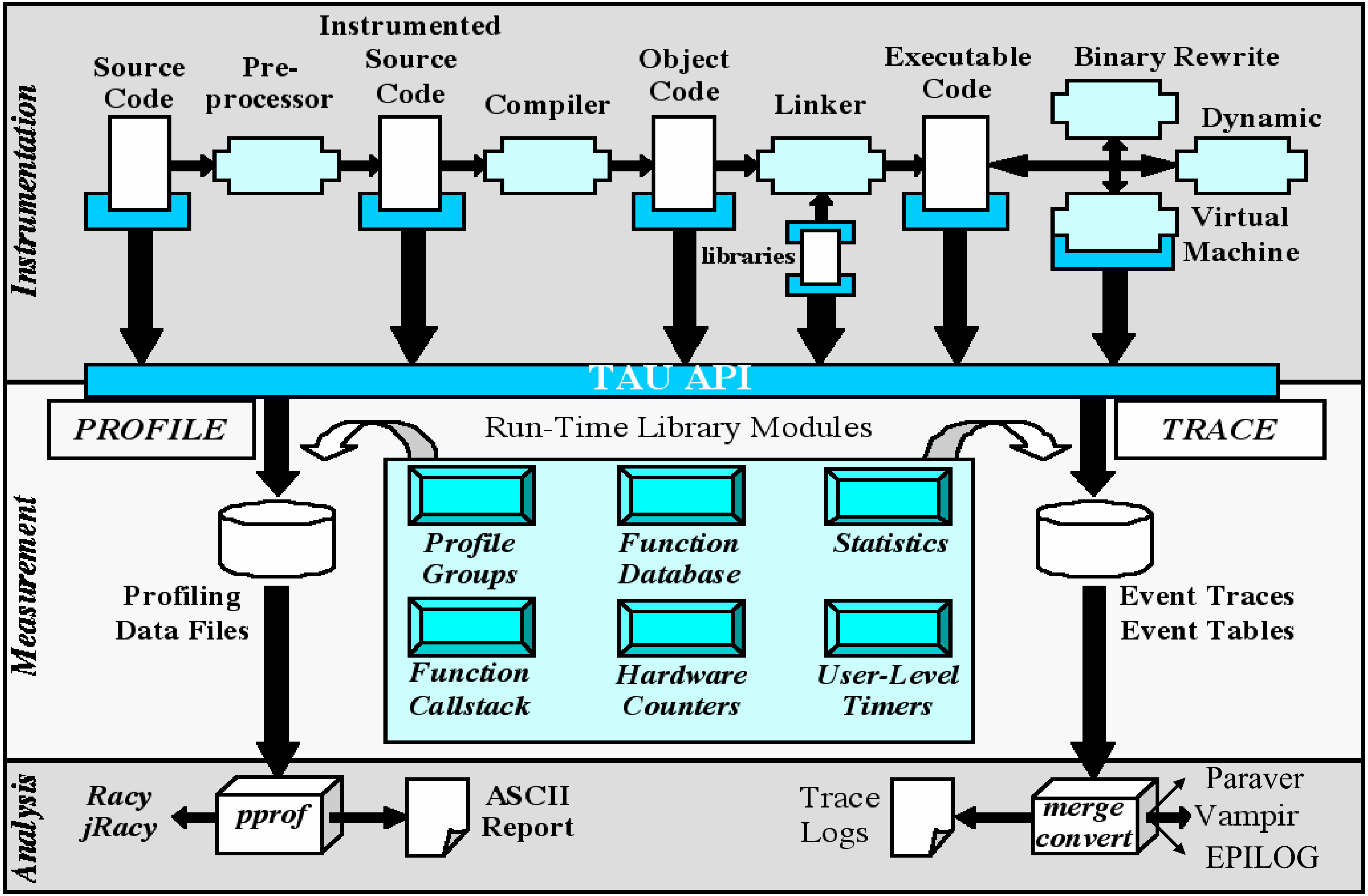
# PerfDBF Cross-Trial Analysis



# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# TAU Performance System Architecture



# *Using TAU*

- Install TAU
  % configure ; make clean install
- Instrument application
  - TAU Profiling API
- Typically modify application makefile
  - include TAU's stub makefile, modify variables
- Set environment variables
  - directory where profiles/traces are to be stored
- Execute application
  % mpirun –np <procs> a.out;
- Analyze performance data
  - paraprof, vampir, pprof, paraver …

# Using TAU with Vampir

- Configure TAU with -TRACE option

```
% configure -TRACE -SGITIMERS …
```

- Execute application

```
% mpirun -np 4 a.out
```

- This generates TAU traces and event descriptors
- Merge all traces using tau_merge

```
% tau_merge *.trc app.trc
```

- Convert traces to Vampir Trace format using tau_convert

```
% tau_convert -pv app.trc tau.edf app.pv
```

Note: Use -vampir instead of -pv for multi-threaded traces

- Load generated trace file in Vampir

```
% vampir app.pv
```

# Description of Optional Packages

- PAPI – Measures hardware performance data e.g., floating point instructions, L1 data cache misses etc.
- DyninstAPI – Helps instrument an application binary at runtime or rewrites the binary
- EPILOG – Trace library. Epilog traces can be analyzed by EXPERT [FZJ], an automated bottleneck detection tool.
- Opari – Tool that instruments OpenMP programs
- Vampir – Commercial trace visualization tool [Pallas]
- Paraver – Trace visualization tool [CEPBA]

# TAU Measurement System Configuration

- configure [OPTIONS]

| | |
|---|---|
| {-c++=<CC>, -cc=<cc>} | Specify C++ and C compilers |
| {-pthread, -sproc} | Use pthread or SGI sproc threads |
| -openmp | Use OpenMP threads |
| -jdk=<dir> | Specify Java instrumentation (JDK) |
| -opari=<dir> | Specify location of Opari OpenMP tool |
| -papi=<dir> | Specify location of PAPI |
| -pdt=<dir> | Specify location of PDT |
| -dyninst=<dir> | Specify location of DynInst Package |
| -mpi[inc/lib]=<dir> | Specify MPI library instrumentation |
| -python[inc/lib]=<dir> | Specify Python instrumentation |
| -epilog=<dir> | Specify location of EPILOG |

# TAU Measurement System Configuration

- configure [OPTIONS]
  - -TRACE — Generate binary TAU traces
  - -PROFILE (default) — Generate profiles (summary)
  - -PROFILECALLPATH — Generate call path profiles
  - -PROFILEMEMORY — Track heap memory for each routine
  - -MULTIPLECOUNTERS — Use hardware counters + time
  - -COMPENSATE — Compensate timer overhead
  - -CPUTIME — Use usertime+system time
  - -PAPIWALLCLOCK — Use PAPI's wallclock time
  - -PAPIVIRTUAL — Use PAPI's process virtual time
  - -SGITIMERS — Use fast IRIX timers
  - -LINUXTIMERS — Use fast x86 Linux timers

# TAU Measurement Configuration – Examples

- ./configure -c++=xlC_r –pthread
  - Use TAU with xlC_r and pthread library under AIX
  - Enable TAU profiling (default)
- ./configure -TRACE –PROFILE
  - Enable both TAU profiling and tracing
- ./configure -c++=xlC_r -cc=xlc_r
  -papi=/usr/local/packages/papi
  -pdt=/usr/local/pdtoolkit-3.1 –arch=ibm64
  -mpiinc=/usr/lpp/ppe.poe/include
  -mpilib=/usr/lpp/ppe.poe/lib -MULTIPLECOUNTERS
  - Use IBM's xlC_r and xlc_r compilers with PAPI, PDT, MPI packages and multiple counters for measurements
- Typically configure multiple measurement libraries

# TAU Manual Instrumentation API for C/C++

- Initialization and runtime configuration
  - TAU_PROFILE_INIT(argc, argv);
    TAU_PROFILE_SET_NODE(myNode);
    TAU_PROFILE_SET_CONTEXT(myContext);
    TAU_PROFILE_EXIT(message);
    TAU_REGISTER_THREAD();
- Function and class methods for C++ only:
  - TAU_PROFILE(name, type, group);
- Template
  - TAU_TYPE_STRING(variable, type);
    TAU_PROFILE(name, type, group);
    CT(variable);
- User-defined timing
  - TAU_PROFILE_TIMER(timer, name, type, group);
    TAU_PROFILE_START(timer);
    TAU_PROFILE_STOP(timer);

# *TAU Measurement API (continued)*

- User-defined events
  - TAU_REGISTER_EVENT(variable, event_name);
    TAU_EVENT(variable, value);
    TAU_PROFILE_STMT(statement);
- Heap Memory Tracking:
  - TAU_TRACK_MEMORY();
  - TAU_SET_INTERRUPT_INTERVAL(seconds);
  - TAU_DISABLE_TRACKING_MEMORY();
  - TAU_ENABLE_TRACKING_MEMORY();
- Reporting
  - TAU_REPORT_STATISTICS();
  - TAU_REPORT_THREAD_STATISTICS();

# Manual Instrumentation – C++ Example

```
#include <TAU.h>
int main(int argc, char **argv)
{
  TAU_PROFILE("int main(int, char **)", " ", TAU_DEFAULT);
  TAU_PROFILE_INIT(argc, argv);
  TAU_PROFILE_SET_NODE(0); /* for sequential programs */
  foo();
  return 0;
}

int foo(void)
{
  TAU_PROFILE("int foo(void)", " ", TAU_DEFAULT); // measures entire foo()
  TAU_PROFILE_TIMER(t, "foo(): for loop", "[23:45 file.cpp]", TAU_USER);
  TAU_PROFILE_START(t);
  for(int i = 0; i < N ; i++){
    work(i);
  }
  TAU_PROFILE_STOP(t);
  // other statements in foo …
}
```

# Manual Instrumentation – C Example

```
#include <TAU.h>
int main(int argc, char **argv)
{
  TAU_PROFILE_TIMER(tmain, "int main(int, char **)", " ", TAU_DEFAULT);
  TAU_PROFILE_INIT(argc, argv);
  TAU_PROFILE_SET_NODE(0); /* for sequential programs */
  TAU_PROFILE_START(tmain);
  foo();
  …
  TAU_PROFILE_STOP(tmain);
  return 0;
}
int foo(void)
{
  TAU_PROFILE_TIMER(t, "foo()", " ", TAU_USER);
  TAU_PROFILE_START(t);
  for(int i = 0; i < N ; i++){
    work(i);
  }
  TAU_PROFILE_STOP(t);
}
```

# Manual Instrumentation – F90 Example

```
cc34567 Cubes program – comment line
      PROGRAM SUM_OF_CUBES
       integer profiler(2)
       save profiler
      INTEGER :: H, T, U
        call TAU_PROFILE_INIT()
        call TAU_PROFILE_TIMER(profiler, 'PROGRAM SUM_OF_CUBES')
        call TAU_PROFILE_START(profiler)
        call TAU_PROFILE_SET_NODE(0)
      ! This program prints all 3-digit numbers that
      ! equal the sum of the cubes of their digits.
      DO H = 1, 9
        DO T = 0, 9
          DO U = 0, 9
          IF (100*H + 10*T + U == H**3 + T**3 + U**3) THEN
             PRINT "(3I1)", H, T, U
          ENDIF
          END DO
        END DO
      END DO
      call TAU_PROFILE_STOP(profiler)
      END PROGRAM SUM_OF_CUBES
```

# *Compiling*

```
% configure [options]
% make clean install
```

Creates <arch>/lib/Makefile.tau<options> stub Makefile

and <arch>/lib/libTau<options>.a [.so] libraries which defines a single configuration of TAU

# Compiling: TAU Makefiles

- Include TAU Stub Makefile (<arch>/lib) in the user's Makefile.
- Variables:
  - TAU_CXX — Specify the C++ compiler used by TAU
  - TAU_CC, TAU_F90 — Specify the C, F90 compilers
  - TAU_DEFS — Defines used by TAU. Add to CFLAGS
  - TAU_LDFLAGS — Linker options. Add to LDFLAGS
  - TAU_INCLUDE — Header files include path. Add to CFLAGS
  - TAU_LIBS — Statically linked TAU library. Add to LIBS
  - TAU_SHLIBS — Dynamically linked TAU library
  - TAU_MPI_LIBS — TAU's MPI wrapper library for C/C++
  - TAU_MPI_FLIBS — TAU's MPI wrapper library for F90
  - TAU_FORTRANLIBS — Must be linked in with C++ linker for F90
  - TAU_CXXLIBS — Must be linked in with F90 linker
  - TAU_INCLUDE_MEMORY — Use TAU's malloc/free wrapper lib
  - TAU_DISABLE — TAU's dummy F90 stub library
- Note: Not including TAU_DEFS in CFLAGS disables instrumentation in C/C++ programs (TAU_DISABLE for f90).

# Including TAU Makefile - C++ Example

```
include $PET_HOME/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-pdt
F90 = $(TAU_CXX)
CC  = $(TAU_CC)
CFLAGS = $(TAU_DEFS) $(TAU_INCLUDE)
LIBS = $(TAU_LIBS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
	$(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.cpp.o:
	$(CC) $(CFLAGS) -c $< -o $@
```

# *Including TAU Makefile - F90 Example*

```
include $PET_HOME/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-pdt
F90 = $(TAU_F90)
FFLAGS = -I<dir>
LIBS = $(TAU_LIBS) $(TAU_CXXLIBS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
	$(F90) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.f.o:
	$(F90) $(FFLAGS) -c $< -o $@
```

# *Including TAU Makefile - F90 Example*

```
include $PET_HOME/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-pdt
F90 = $(TAU_F90)
FFLAGS = -I<dir>
LIBS = $(TAU_LIBS) $(TAU_CXXLIBS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
	$(F90) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.f.o:
	$(F90) $(FFLAGS) -c $< -o $@
```

# *Using TAU's Malloc Wrapper Library for C/C++*

```
include $PET_HOME/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-pdt
CC=$(TAU_CC)
CFLAGS=$(TAU_DEFS) $(TAU_INCLUDE) $(TAU_MEMORY_INCLUDE)
LIBS = $(TAU_LIBS)
OBJS = f1.o f2.o ...
TARGET= a.out
TARGET: $(OBJS)
	$(F90) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.c.o:
	$(CC) $(CFLAGS) -c $< -o $@
```

# TAU's malloc/free wrapper

```
#include <TAU.h>
#include <malloc.h>
int main(int argc, char **argv)
{
  TAU_PROFILE("int main(int, char **)", " ", TAU_DEFAULT);

  int *ary = (int *) malloc(sizeof(int) * 4096);

  // TAU's malloc wrapper library replaces this call automatically
  // when $(TAU_MEMORY_INCLUDE) is used in the Makefile.
  …
  free(ary);
  // other statements in foo …
}
```

# Using TAU's Malloc Wrapper Library for C/C++

| NumSamples | MaxValue | MinValue | MeanValue | name |
|---|---|---|---|---|
| 1 | 40016.0 | 40016.0 | 40016.0 | malloc size <file=main.cpp, line=252> |
| 1 | 40016.0 | 40016.0 | 40016.0 | free size <file=main.cpp, line=298> |
| 12 | 30000.0 | 240.0 | 5590.0 | malloc size <file=select.cpp, line=80> |
| 12 | 30000.0 | 240.0 | 5590.0 | malloc size <file=select.cpp, line=81> |
| 3 | 30000.0 | 6000.0 | 17000.0 | free size <file=select.cpp, line=107> |
| 3 | 30000.0 | 6000.0 | 17000.0 | free size <file=select.cpp, line=109> |
| 1 | 8000.0 | 8000.0 | 8000.0 | malloc size <file=main.cpp, line=258> |
| 1 | 8000.0 | 8000.0 | 8000.0 | free size <file=main.cpp, line=299> |
| 7 | 6000.0 | 600.0 | 2228.5714 | free size <file=select.cpp, line=118> |
| 7 | 6000.0 | 600.0 | 2228.5714 | free size <file=select.cpp, line=119> |
| 2 | 240.0 | 240.0 | 240.0 | free size <file=select.cpp, line=126> |
| 2 | 240.0 | 240.0 | 240.0 | free size <file=select.cpp, line=128> |

# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# Using Program Database Toolkit (PDT)

**Step I: Configure PDT:**

```
% configure -arch=ibm64 -XLC
% make clean; make install
```

**Builds <pdtdir>/<arch>/bin/cxxparse, cparse, f90parse and f95parse**

**Builds <pdtdir>/<arch>/lib/libpdb.a. See <pdtdir>/README file.**

**Step II: Configure TAU with PDT for auto-instrumentation of source code:**

```
% configure -arch=ibm64 -c++=xlC -cc=xlc
  -pdt=/usr/contrib/TAU/pdtoolkit-3.1
% make clean; make install
```

**Builds <taudir>/<arch>/bin/tau_instrumentor,**

**<taudir>/<arch>/lib/Makefile.tau<options> and libTau<options>.a**

**See <taudir>/INSTALL file.**

# *Using Program Database Toolkit (PDT) (contd.)*

1. **Parse the Program to create foo.pdb:**

```
% cxxparse foo.cpp -I/usr/local/mydir -DMYFLAGS …
```

**or**

```
% cparse foo.c -I/usr/local/mydir -DMYFLAGS …
```

**or**

```
% f95parse foo.f90 -I/usr/local/mydir …
```

2. **Instrument the program:**

```
% tau_instrumentor foo.pdb   foo.f90 -o foo.inst.f90
```

3. **Compile the instrumented program:**

```
% ifort foo.inst.f90 -c -I/usr/local/mpi/include -o foo.o
```

# TAU Makefile for PDT (C++)

```
include /usr/tau/include/Makefile
CXX = $(TAU_CXX)
CC  = $(TAU_CC)
PDTPARSE = $(PDTDIR)/$(PDTARCHDIR)/bin/cxxparse
TAUINSTR = $(TAUROOT)/$(CONFIG_ARCH)/bin/tau_instrumentor
CFLAGS = $(TAU_DEFS) $(TAU_INCLUDE)
LIBS = $(TAU_LIBS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
      $(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.cpp.o:
      $(PDTPARSE) $<
      $(TAUINSTR) $*.pdb $< -o $*.inst.cpp -f select.dat
      $(CC) $(CFLAGS) -c $*.inst.cpp -o $@
```

# TAU Makefile for PDT (F90)

```
include $PET_HOME/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-pdt
F90 = $(TAU_F90)
CC  = $(TAU_CC)
PDTPARSE = $(PDTDIR)/$(PDTARCHDIR)/bin/f95parse
TAUINSTR = $(TAUROOT)/$(CONFIG_ARCH)/bin/tau_instrumentor
LIBS = $(TAU_LIBS) $(TAU_CXXLIBS)
OBJS = ...
TARGET= f1.o f2.o f3.o
PDB=merged.pdb
TARGET:$(PDB) $(OBJS)
      $(F90) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
$(PDB): $(OBJS:.o=.f)
      $(PDTF95PARSE) $(OBJS:.o=.f) -o$(PDB) -R free
# This expands to f95parse *.f -omerged.pdb -R free
.f.o:
      $(TAU_INSTR) $(PDB) $< -o $*.inst.f -f sel.dat;\
      $(FCOMPILE) $*.inst.f -o $@;
```

# *Using PDT: tau_instrumentor*

```
% 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
```

# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# *Using MPI Wrapper Interposition Library*

**Step I: Configure TAU with MPI:**

```
% configure -mpiinc=/usr/lpp/ppe.poe/include
  -mpilib=/usr/lpp/ppe.poe/lib -arch=ibm64 -c++=CC -cc=cc
  -pdt=$PET_HOME/PTOOLS/pdtoolkit-3.2.1
% make clean; make install
```

**Builds <taudir>/<arch>/lib/libTauMpi<options>,**

**<taudir>/<arch>/lib/Makefile.tau<options> and libTau<options>.a**

# *TAU's MPI Wrapper Interposition Library*

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

# *Including TAU's stub Makefile*

```
include $PET_HOME/PTOOLS/tau-2.13.6/rs6000/lib/Makefile.tau-mpi-pdt
F90 = $(TAU_F90)
CC  = $(TAU_CC)
LIBS = $(TAU_MPI_LIBS) $(TAU_LIBS) $(TAU_CXXLIBS)
LD_FLAGS = $(TAU_LDFLAGS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
     $(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.f.o:
     $(F90) $(FFLAGS) -c $< -o $@
```

# *Including TAU's stub Makefile with PAPI*

```
include $PET_HOME/PTOOLS/tau-2.13.6/rs6000/lib/Makefile.tau-papiwallclock-multiplecounters-papivirtual-mpi-papi-pdt
CC   = $(TAU_CC)
LIBS = $(TAU_MPI_LIBS) $(TAU_LIBS) $(TAU_CXXLIBS)
LD_FLAGS = $(TAU_LDFLAGS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
	$(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.f.o:
	$(F90) $(FFLAGS) -c $< -o $@
```

# Setup: Running Applications

```
% set path=($path <taudir>/<arch>/bin)
% set path=($path $PET_HOME/PTOOLS/tau-2.13.5/src/rs6000/bin)
% setenv LD_LIBRARY_PATH $LD_LIBRARY_PATH\:<taudir>/<arch>/lib

For PAPI (1 counter, if multiplecounters is not used):
% setenv PAPI_EVENT PAPI_L1_DCM (PAPI's Level 1 Data cache misses)
For PAPI (multiplecounters):
% setenv COUNTER1 PAPI_FP_INS    (PAPI's Floating point ins)
% setenv COUNTER2 PAPI_TOT_CYC   (PAPI's Total cycles)
% setenv COUNTER3 P_VIRTUAL_TIME   (PAPI's virtual time)
% setenv COUNTER4 PAPI_NATIVE_<arch_specific_event>
(NOTE: PAPI_FP_INS and PAPI_L1_DCM cannot be used together on Power4. Other restrictions may apply to no. of counters used.)
% mpirun -np <n> <application>
% llsubmit job.sh
% paraprof   (for performance analysis)
```

# Using TAU with Vampir

```
include $PET_HOME/PTOOLS/tau-
2.13.5/rs6000/lib/Makefile.tau-mpi-pdt-trace
F90 = $(TAU_F90)
LIBS = $(TAU_MPI_LIBS) $(TAU_LIBS) $(TAU_CXXLIBS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
	$(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.f.o:
	$(F90) $(FFLAGS) -c $< -o $@
```

# Using TAU with Vampir

```
% llsubmit job.sh
% ls *.trc *.edf
```

*Merging Trace Files*

```
% tau_merge tau*.trc app.trc
```

*Converting TAU Trace Files to Vampir and Paraver Trace formats*

```
% tau_convert -pv app.trc tau.edf app.pv
  (use -vampir if application is multi-threaded)
% vampir app.pv
% tau_convert -paraver app.trc tau.edf app.par
  (use -paraver -t if application is multi-threaded)
% paraver app.par
```

# TAU Makefile for PDT with MPI and F90

```
include $PET/PTOOLS/tau-2.13.5/rs6000/lib/Makefile.tau-mpi-pdt
FCOMPILE = $(TAU_F90) $(TAU_MPI_INCLUDE)
PDTF95PARSE = $(PDTDIR)/$(PDTARCHDIR)/bin/f95parse
TAUINSTR = $(TAUROOT)/$(CONFIG_ARCH)/bin/tau_instrumentor
PDB=merged.pdb
COMPILE_RULE= $(TAU_INSTR) $(PDB) $< -o $*.inst.f -f sel.dat;\
      $(FCOMPILE) $*.inst.f -o $@;
LIBS = $(TAU_MPI_FLIBS) $(TAU_LIBS) $(TAU_CXXLIBS)
OBJS = f1.o f2.o f3.o …
TARGET= a.out
TARGET: $(PDB) $(OBJS)
      $(TAU_F90) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
$(PDB): $(OBJS:.o=.f)
      $(PDTF95PARSE) $(OBJS:.o=.f) $(TAU_MPI_INCLUDE) -o$(PDB)
# This expands to f95parse *.f -I…/mpi/include -omerged.pdb
.f.o:
      $(COMPILE_RULE)
```

# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# Using Opari with TAU

**Step I: Configure KOJAK/opari [Download from http://www.fz-juelich.de/zam/kojak/]**

```
% cd kojak-1.0; cp mf/Makefile.defs.ibm Makefile.defs;
  edit Makefile
% make
```

**Builds opari**

**Step II: Configure TAU with Opari (used here with MPI and PDT)**

```
% configure -opari=/usr/contrib/TAU/kojak-1.0/opari
  -mpiinc=/usr/lpp/ppe.poe/include
  -mpilib=/usr/lpp/ppe.poe/lib
  -pdt=/usr/contrib/TAU/pdtoolkit-3.2.1
% make clean; make install
```

# Instrumentation of OpenMP Constructs

- **O**penMP **P**ragma **A**nd **R**egion **I**nstrumentor
- 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`***)
- Work in Progress:
  Investigating standardization through OpenMP Forum

# *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

- OpenMP directive instrumentation

```
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);
#line 261 "stommel.c"
```

# OPARI: Basic Usage (f90)

- Reset OPARI state information
  - ```
    rm -f opari.rc
    ```
- Call OPARI for each input source file
  - ```
    opari file1.f90
    ...
    opari fileN.f90
    ```
- Generate OPARI runtime table, compile it with ANSI C
  - ```
    opari -table opari.tab.c
    cc -c opari.tab.c
    ```
- Compile modified files `*.mod.f90` using OpenMP
- Link the resulting object files, the OPARI runtime table `opari.tab.o` and the TAU POMP RTL
    ```

# OPARI: Makefile Template (C/C++)

```
OMPCC  = ...          # insert C OpenMP compiler here
OMPCXX = ...          # insert C++ OpenMP compiler here

.c.o:
        opari $<
        $(OMPCC) $(CFLAGS) -c $*.mod.c
.cc.o:
        opari $<
        $(OMPCXX) $(CXXFLAGS) -c $*.mod.cc

opari.init:
        rm -rf opari.rc

opari.tab.o:
        opari -table opari.tab.c
        $(CC) -c opari.tab.c

myprog: opari.init myfile*.o ... opari.tab.o
        $(OMPCC) -o myprog myfile*.o opari.tab.o -lpomp

myfile1.o: myfile1.c myheader.h
myfile2.o: ...
```

# OPARI: Makefile Template (Fortran)

```
OMPF77 = ...          # insert f77 OpenMP compiler here
OMPF90 = ...          # insert f90 OpenMP compiler here

.f.o:
	opari $<
	$(OMPF77) $(CFLAGS) -c $*.mod.F
.f90.o:
	opari $<
	$(OMPF90) $(CXXFLAGS) -c $*.mod.F90

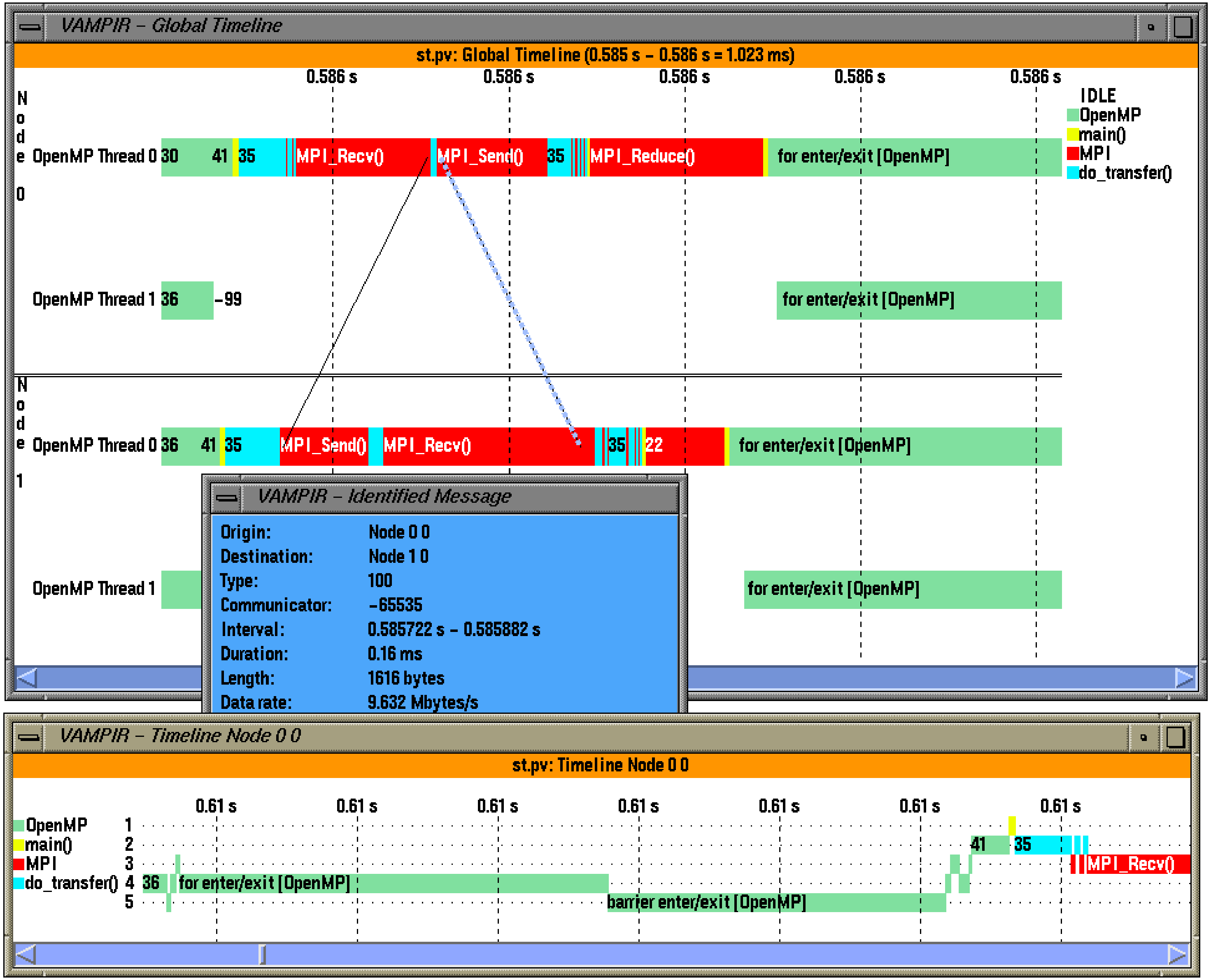
opari.init:
	rm -rf opari.rc

opari.tab.o:
	opari -table opari.tab.c
	$(CC) -c opari.tab.c

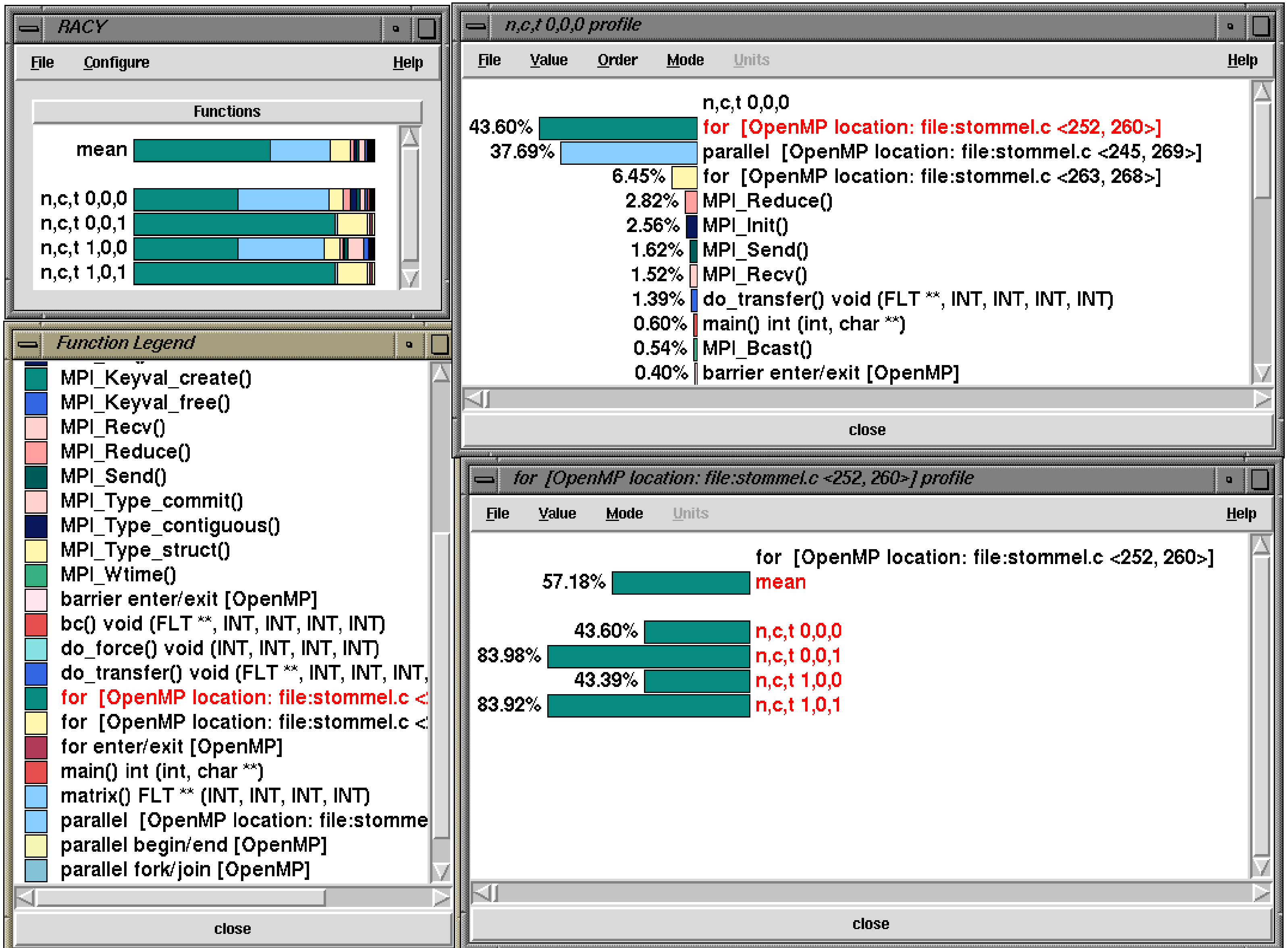
myprog: opari.init myfile*.o ... opari.tab.o
	$(OMPF90) -o myprog myfile*.o opari.tab.o -lpomp

myfile1.o: myfile1.f90
myfile2.o: ...
```

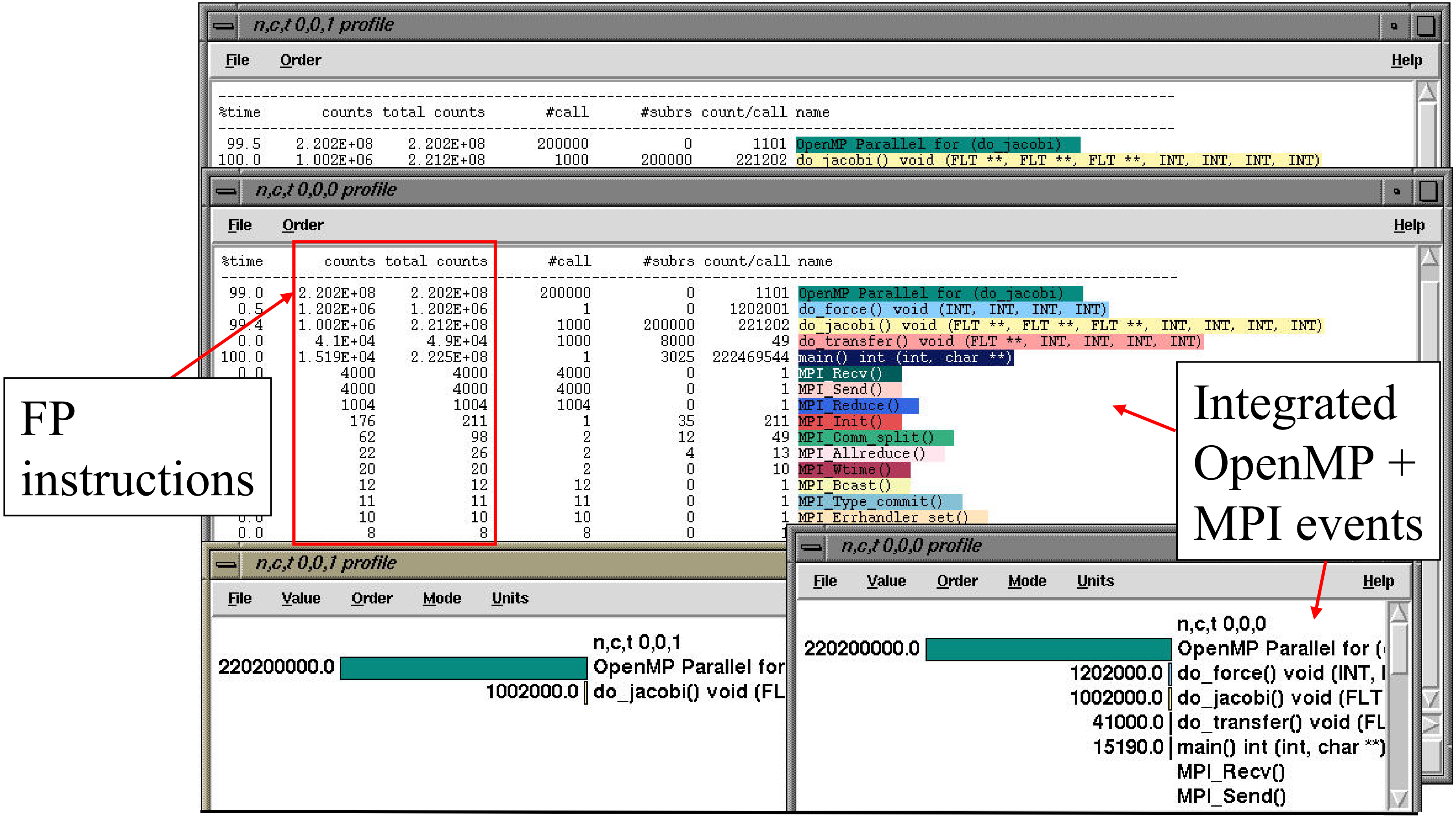
# Tracing Hybrid Executions – TAU and Vampir



# Profiling Hybrid Executions



# OpenMP + MPI Ocean Modeling (HW Profile)




% configure -papi=../packages/papi -openmp -c++=pgCC -cc=pgcc -mpiinc=../packages/mpich/include -mpilib=../packages/mpich/lib

# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# *Dynamic Instrumentation*

- TAU uses DyninstAPI for runtime code patching
- ***tau_run*** (mutator) loads measurement library
- Instruments mutatee
- MPI issues:
  - one mutator per executable image [TAU, DynaProf]
  - one mutator for several executables [Paradyn, DPCL]

# Using DyninstAPI with TAU

**Step I: Install DyninstAPI[Download from http://www.dyninst.org]**

```
% cd dyninstAPI-4.0.2/core; make
```

**Set DyninstAPI environment variables (including LD_LIBRARY_PATH)**

**Step II: Configure TAU with Dyninst**

```
% configure -dyninst=/usr/local/dyninstAPI-4.0.2
% make clean; make install
```

**Builds <taudir>/<arch>/bin/tau_run**

```
% tau_run [<-o outfile>] [-Xrun<libname>]
  [-f <select_inst_file>] [-v] <infile>
% tau_run -o a.inst.out a.out
```

**Rewrites a.out**

```
% tau_run klargest
```

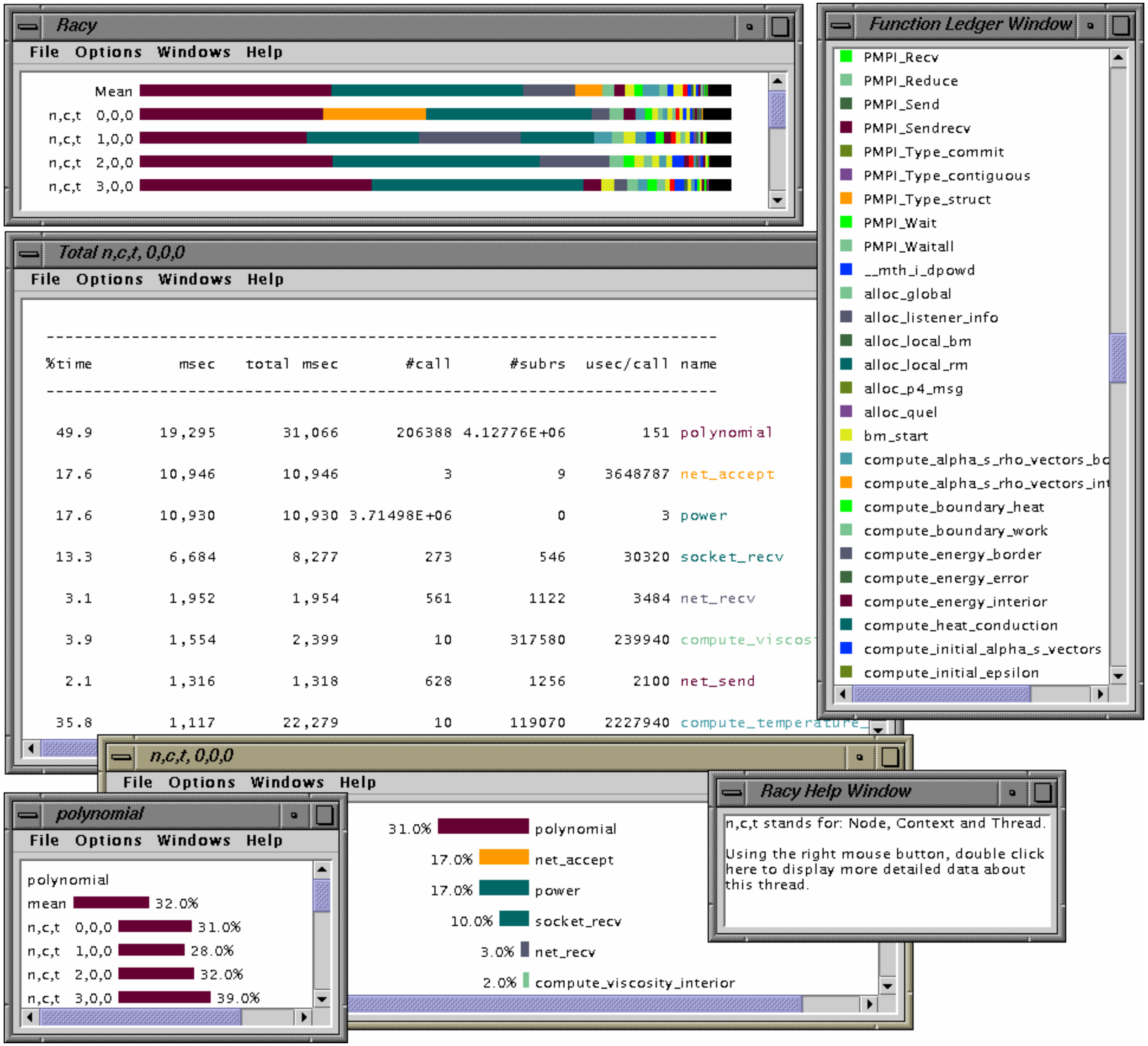
**Instruments klargest with TAU calls and executes it**

```
% tau_run -XrunTAUsh-papi a.out
```

**Loads libTAUsh-papi.so instead of libTAU.so for measurements**

*NOTE: All compilers and platforms are not yet supported (work in progress)*

# SIMPLE Hydrodynamics Benchmark



# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# Multi-Threading Performance Measurement

- General issues
  - Thread identity and per-thread data storage
  - Performance measurement support and synchronization
  - Fine-grained parallelism
    - different forms and levels of threading
    - greater need for efficient instrumentation
- TAU general threading and measurement model
  - Common thread layer and measurement support
  - Interface to system specific libraries (reg, id, sync)
- Target different thread systems with core functionality
  - Pthreads, Windows, Java, SMARTS, Tulip, OpenMP

# *Virtual Machine Performance Instrumentation*

- Integrate performance system with VM
  - Captures robust performance data (e.g., thread events)
  - Maintain features of environment
    - portability, concurrency, extensibility, interoperation
  - Allow use in optimization methods
- JVM Profiling Interface (JVMPI)
  - Generation of JVM events and hooks into JVM
  - Profiler agent (TAU) loaded as shared object
    - registers events of interest and address of callback routine
  - Access to information on dynamically loaded classes
  - No need to modify Java source, bytecode, or JVM

# *Using TAU with Java Applications*

**Step I: Sun JDK 1.2+ [download from www.javasoft.com]**

**Step II: Configure TAU with JDK (v 1.2 or better)**

```
% configure -jdk=/usr/java2 -TRACE -PROFILE
% make clean; make install
```

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

**For Java (without instrumentation):**

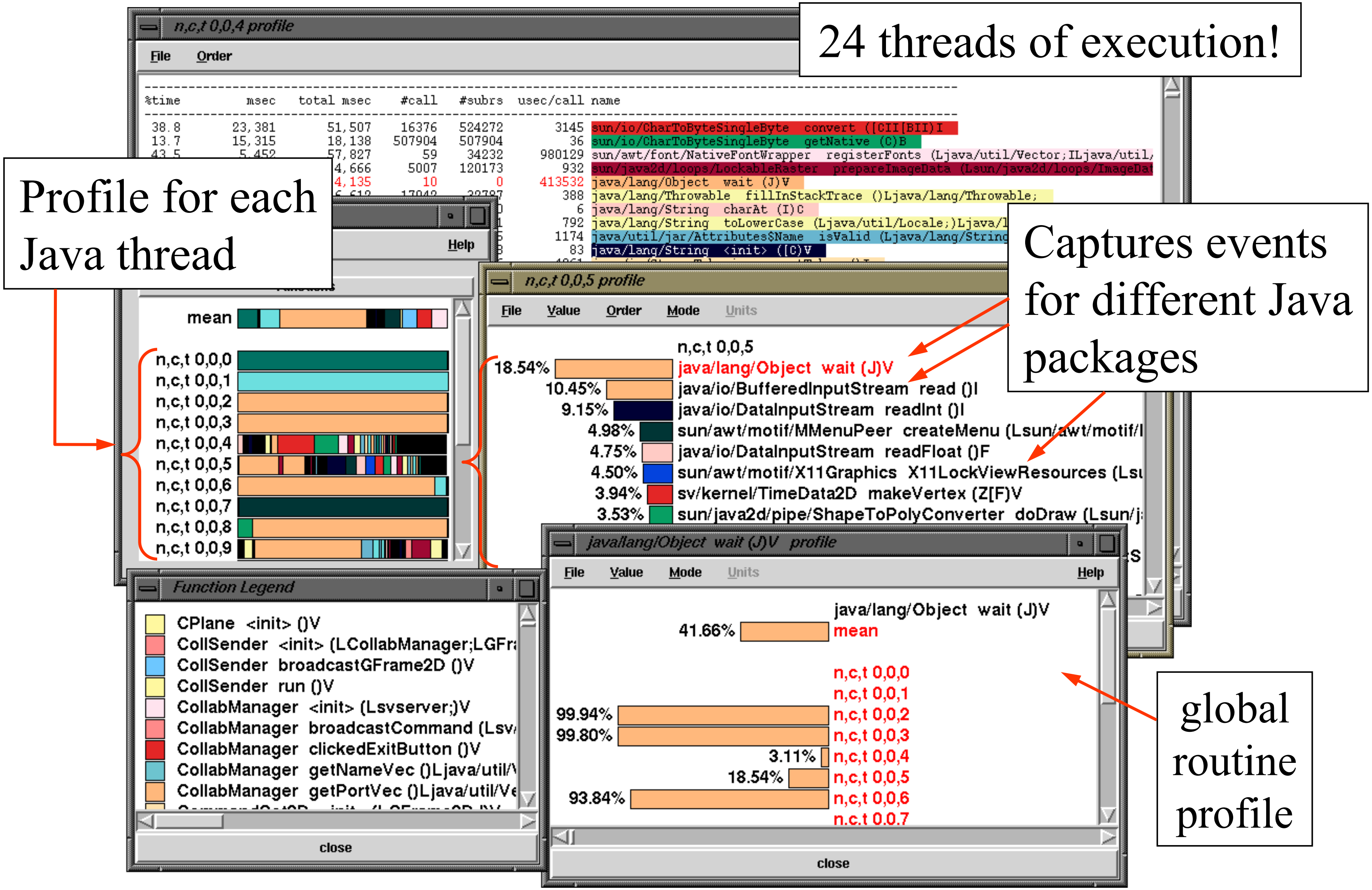
```
% java application
```

**With instrumentation:**

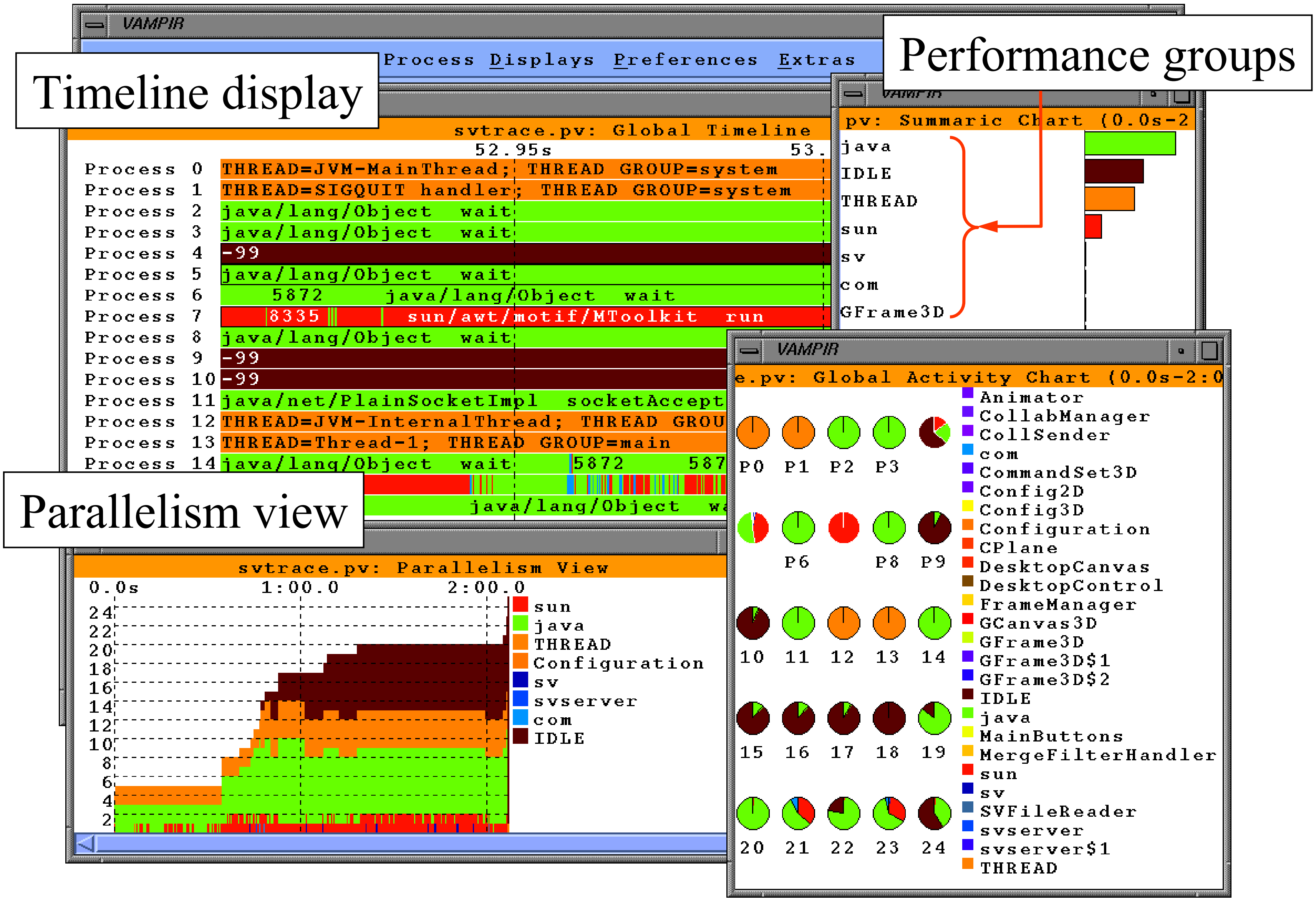
```
% java -XrunTAU application
% java -XrunTAU:exclude=sun/io,java application
```

**Excludes sun/io/* and java/* classes**

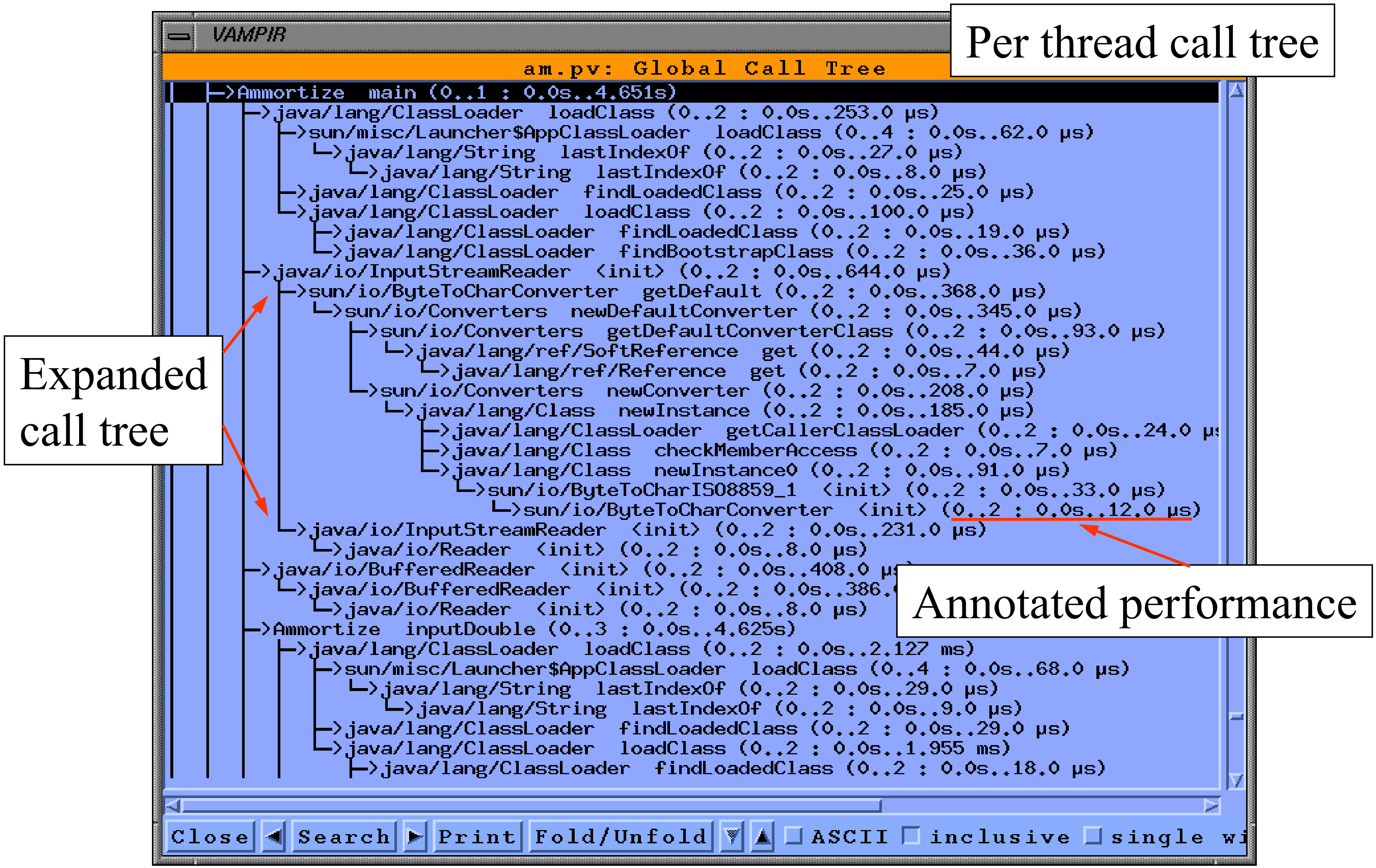
# *TAU Profiling of Java Application (SciVis)*



# TAU Tracing of Java Application (SciVis)



# *Vampir Dynamic Call Tree View (SciVis)*



# Using TAU – A tutorial

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

# Using TAU with Python Applications

**Step I: Configure TAU with Python**

```
% configure -pythoninc=/usr/include/python2.2/include
% make clean; make install
```

**Builds <taudir>/<arch>/lib/<bindings>/pytau.py and tau.py packages for manual and automatic instrumentation respectively**

```
% setenv PYTHONPATH $PYTHONPATH\:<taudir>/<arch>/lib/[<dir>]
```

# Python Automatic Instrumentation Example

```
#!/usr/bin/env/python

import tau
from time import sleep

def f2():
    print " In f2: Sleeping for 2 seconds "
    sleep(2)
def f1():
    print " In f1: Sleeping for 3 seconds "
    sleep(3)

def OurMain():
    f1()
tau.run('OurMain()')
```

**Running:**

```
% setenv PYTHONPATH <tau>/<arch>/lib
% ./auto.py
Instruments OurMain, f1, f2, print…
```

# *Using TAU – A tutorial*

- Configuration
- Instrumentation
  - Manual
  - PDT- Source rewriting for C,C++, F77/90/95
  - MPI – Wrapper interposition library
  - OpenMP – Directive rewriting
  - Binary Instrumentation
    - DyninstAPI – Runtime/Rewriting binary
    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

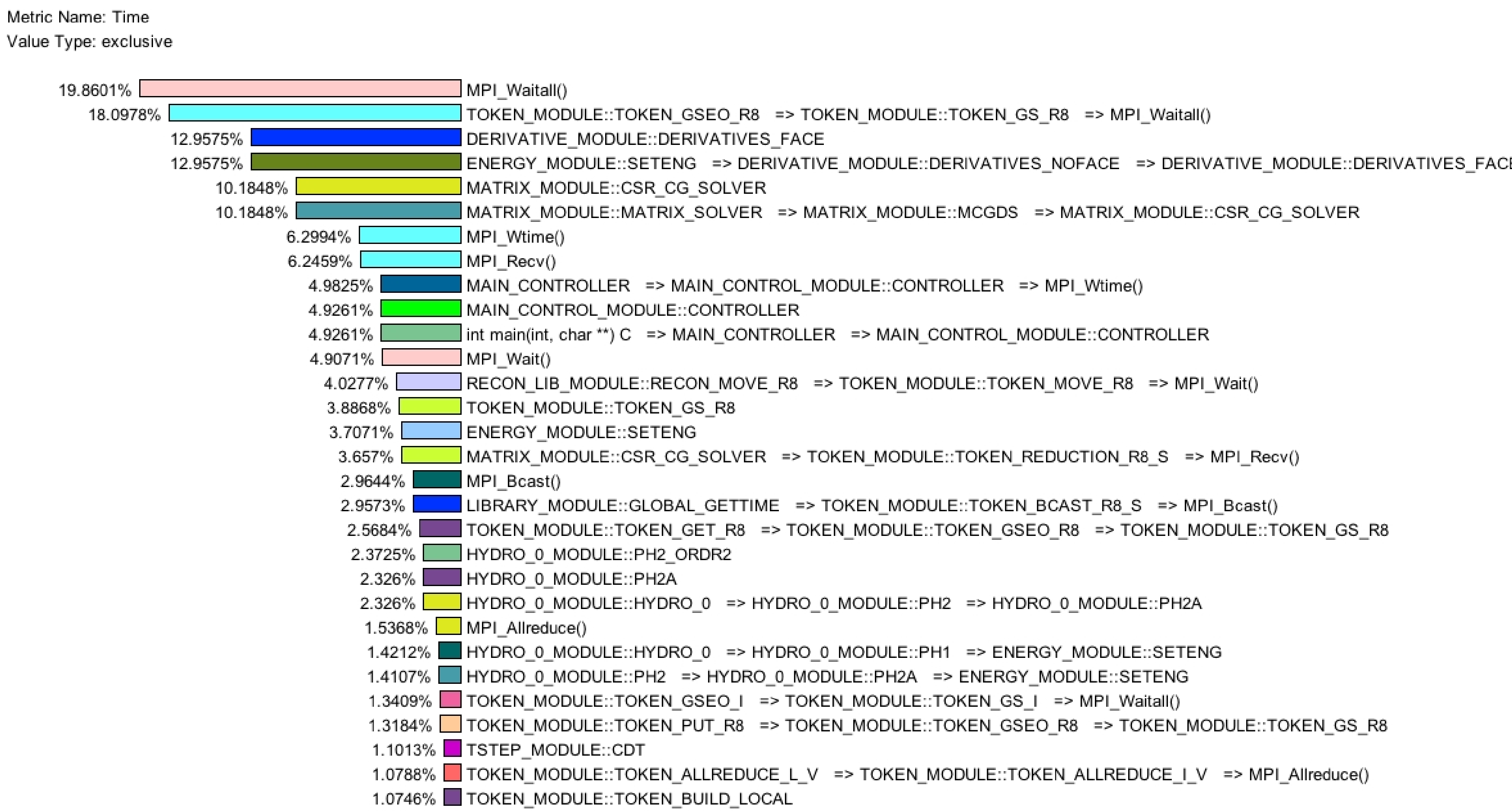
# Performance Mapping

- Associate performance with "significant" entities (events)
- Source code points are important
  - Functions, regions, control flow events, user events
- Execution process and thread entities are important
- Some entities are more abstract,  harder to measure
- Consider callgraph (callpath) profiling
  - Measure time (metric) along an edge (path) of callgraph
    - Incident edge gives parent / child view
    - Edge sequence (path) gives parent / descendant view
- Problem: Callpath profiling when callgraph is unknown
  - Determine callgraph dynamically at runtime
  - Map performance measurement to dynamic call path state

# *k-Level Callpath Implementation in TAU*

- TAU maintains a performance event (routine) callstack
- Profiled routine (child) looks in callstack for parent
  - Previous profiled performance event is the parent
  - A *callpath profile structure* created first time parent calls
  - TAU records parent in a *callgraph map* for child
  - String representing k-level callpath used as its key
    - "**a( )=>b( )=>c()**" : name for time spent in "c" when called by "b" when "b" is called by "a"
- Map returns pointer to callpath profile structure
  - k-level callpath is profiled using this profiling data
  - Set environment variable TAU_CALLPATH_DEPTH to depth
- Build upon TAU's performance mapping technology
- Measurement is independent of instrumentation
- Use –PROFILECALLPATH to configure TAU

# k-Level Callpath Implementation in TAU



# Gprof Style Callpath View in Paraprof

```
Metric Name: Time
Sorted By: exclusive
Units: seconds

     Exclusive     Inclusive     Calls/Tot.Calls                  Name[id]
     ---------------------------------------------------------------------------------

     1.8584        1.8584        1196/13188                       TOKEN_MODULE::TOKEN_GS_I  [521]
     0.584         0.584         234/13188                        TOKEN_MODULE::TOKEN_GS_L  [544]
     25.0819       25.0819       11758/13188                      TOKEN_MODULE::TOKEN_GS_R8  [734]
 --> 27.5242       27.5242       13188                            MPI_Waitall()  [525]


     17.9579       39.1657       156/156                          DERIVATIVE_MODULE::DERIVATIVES_NOFACE  [841]
 --> 17.9579       39.1657       156                              DERIVATIVE_MODULE::DERIVATIVES_FACE  [843]
     0.0156        0.0195        312/312                          TIMER_MODULE::TIMERSET  [77]
     0.1133        9.1269        2340/2340                        MESSAGE_MODULE::CLONE_GET_R8  [808]
     0.1602        11.4608       4056/4056                        MESSAGE_MODULE::CLONE_PUT_R8  [850]
     0.0059        0.6006        117/117                          MESSAGE_MODULE::CLONE_PUT_I  [856]

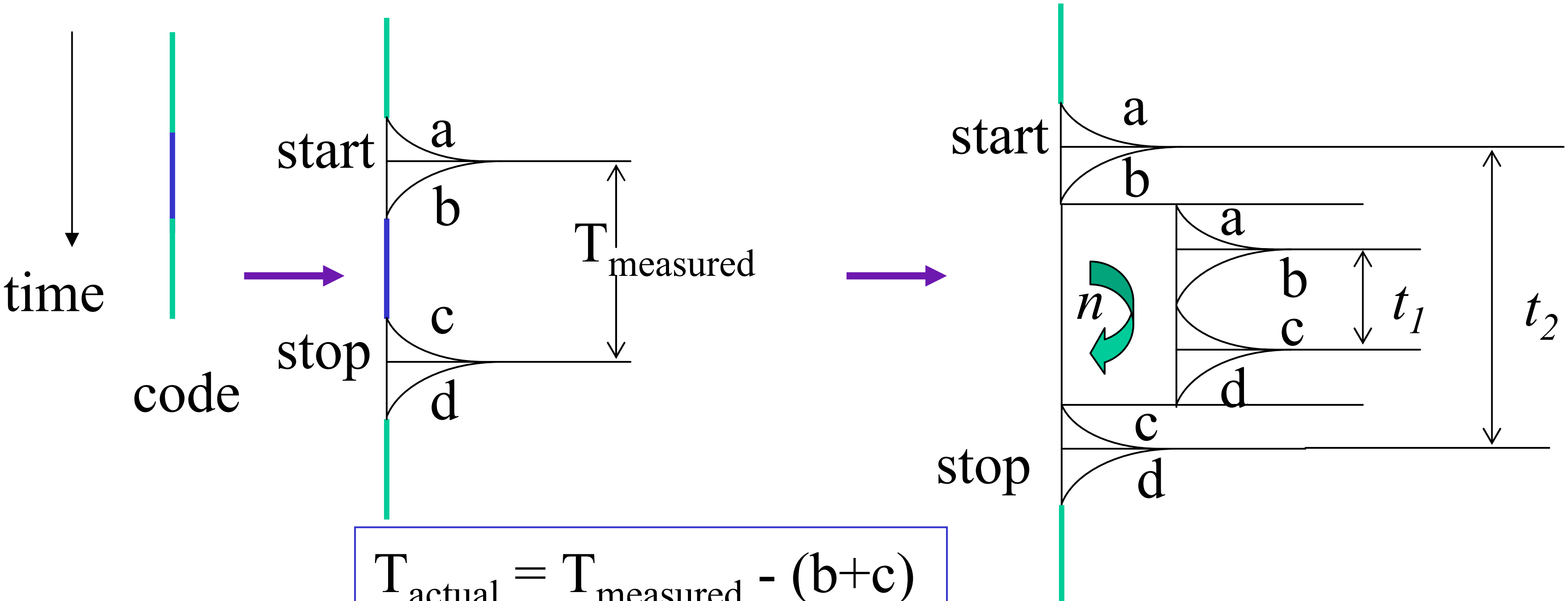

     14.1151       21.6209       5/5                              MATRIX_MODULE::MCGDS  [1443]
 --> 14.1151       21.6209       5                                MATRIX_MODULE::CSR_CG_SOLVER  [1470]
     0.0654        1.2617        1005/1005                        TOKEN_MODULE::TOKEN_GET_R8  [769]
     0.0557        5.2714        1005/1005                        TOKEN_MODULE::TOKEN_REDUCTION_R8_S  [1475]
     0.0703        0.9726        1000/1000                        TOKEN_MODULE::TOKEN_REDUCTION_R8_V  [208]
```

# Compensation of Instrumentation Overhead

- Runtime estimation of a single timer overhead
- Evaluation of number of timer calls along a calling path
- Compensation by subtracting timer overhead
- Recalculation of performance metrics to improve the accuracy of measurements
- Configure TAU with –COMPENSATE configuration option

# *Estimating Timer Overheads*

- Introduce a pair of timer calls (start/stop)




$T_{actual} = T_{measured} - (b+c)$

$t_1 = n * (b+c)$

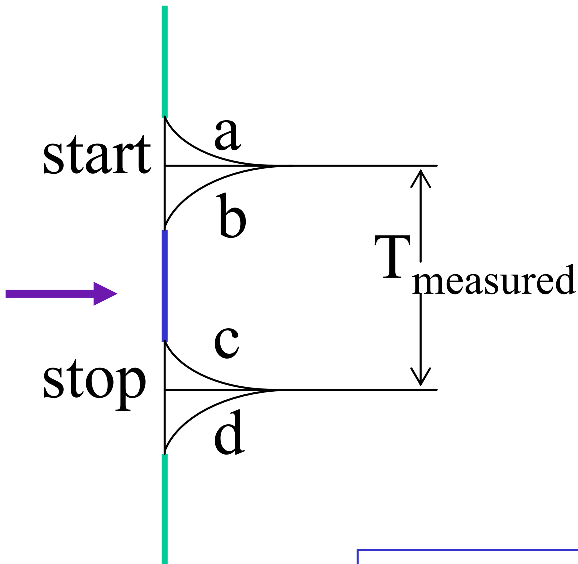
$t_2 = b+n*(a+b+c+d)+c$

$T_{overhead} = a+b+c+d = (t_2 - (t_1/n))/n$

$T_{null} = b+c = t_1/n$

# *Recalculating Inclusive Time*

- Number of children/grandchildren… nodes
- Traverse callstack




main
=>
f1
=> f2
…
f3
=> f4

$$T_{actual} = T_{measured} - (b+c) - n_{descendants} * T_{overhead}$$

# *Getting Started with TAU*

- Step 1: Profile F90 application with MPI level instrumentation.
  - Include <TAU-stub-mpi-makefile> in your application
  - Modify Link Rule (if using F90 as the linker), add

  $(TAU_MPI_FLIBS) $(TAU_LIBS) $(TAU_CXLIBS)
  - Generate Profiles, view using pprof and paraprof
- Step 2: Modify compilation rule for .cpp.o, .f90.o using cxxparse/f95parse and tau_instrumentor (refer to slide #78)
- Step 3: Use callpath profiling stub Makefile (-callpath…)

  % setenv TAU_CALLPATH_DEPTH <n>
- Step 4: Use trace generation stub Makefile (-trace)

# *TAU Performance System Status*

- Computing platforms (selected)
  - IBM SP / pSeries, SGI Origin 2K/3K, Cray T3E / SV-1 / X1, HP (Compaq) SC (Tru64), Sun, Hitachi SR8000, NEC SX-5/6, Linux clusters (IA-32/64, Alpha, PPC, PA-RISC, Power, Opteron), Apple (G4/5, OS X), Windows
- Programming languages
  - C, C++, Fortran 77/90/95, HPF, Java, OpenMP, Python
- Thread libraries
  - pthreads, SGI sproc, Java,Windows, OpenMP
- Compilers (selected)
  - Intel KAI (KCC, KAP/Pro), PGI, GNU, Fujitsu, Sun, Microsoft, SGI, Cray, IBM (xlc, xlf), Compaq, NEC, Intel

# Concluding Remarks

- Complex parallel systems and software pose challenging performance analysis problems that require robust methodologies and tools
- To build more sophisticated performance tools, existing proven performance technology must be utilized
- Performance tools must be integrated with software and systems models and technology
  - Performance engineered software
  - Function consistently and coherently in software and system environments
- TAU performance system offers robust performance technology that can be broadly integrated

# *Support Acknowledgements*

- Department of Energy (DOE)
  - Office of Science contracts
  - University of Utah DOE ASCI Level 1 sub-contract
  - DOE ASCI Level 3 (LANL, LLNL)
- NSF National Young Investigator (NYI) award
- Research Centre Juelich
  - John von Neumann Institute for Computing
  - Dr. Bernd Mohr
- Los Alamos National Laboratory