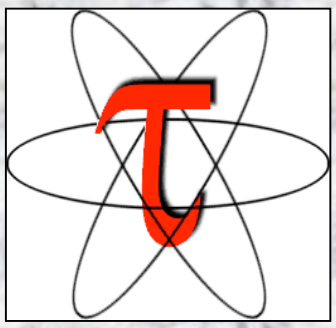
TAU Parallel Performance System

DOD UGC 2004 Tutorial



Part 2: TAU Components and Usage

Tutorial Outline – Part 2

TAU Components and Usage

- Configuration
- Instrumentation
  - Source, library, dynamic, multi-level
- Measurement
  - Profiling and tracing
- Analysis
  - ParaProf
  - Vampir
- Examples of use

How To Use TAU?

- Instrumentation
  - Application code and libraries
  - Selective instrumentation
- Install, compile, and link with TAU measurement library
  - Configure TAU system
  - Multiple configurations for different measurements options
  - Does not require change in instrumentation – just relink
  - Selective measurement control
- Execute “experiments” to produce performance data
  - Performance data generated at end or during execution
- Use analysis tools to look at performance results

Using TAU in Practice

- 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 …

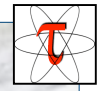
TAU System Configuration

- 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> Location of Opari OpenMP tool
  - -papi=<dir> Location of PAPI
  - -pdt=<dir> Location of PDT
  - -dyninst=<dir> 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 Configuration

- configure [OPTIONS]
  - -TRACE — Generate binary TAU traces
  - -PROFILE (default) — Generate profiles (summary)
  - -PROFILECALLPATH — Generate call path profiles
  - -PROFILESTATS — Generate std. dev. statistics
  - -MULTIPLECOUNTERS — Use hardware counters + time
  - -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

Configuring TAU



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

- Creates <arch>/lib/Makefile.tau<options> stub Makefile
- Creates <arch>/lib/libTau<options.a [.so] libraries
- Defines a single configuration of TAU
- Attempts to automatically detect architecture

Examples: TAU Configuration

- Use TAU with xlC_r and pthread library under AIX
  Enable TAU profiling (default)
  - ./configure -c++=xlC_r –pthread
- Enable both TAU profiling and tracing
  - ./configure -TRACE –PROFILE
- Use IBM's xlC_r and xlc_r compilers with PAPI, PDT, MPI packages and multiple counters for measurements
  - ./configure -c++=xlC_r -cc=xlc_r
    -papi=/usr/local/packages/papi
    -pdt=/usr/local/pdtoolkit-3.0 –arch=ibm64
    -mpiinc=/usr/lpp/ppe.poe/include
    -mpilib=/usr/lpp/ppe.poe/lib -MULTIPLECOUNTERS
- Typically configure multiple measurement libraries

Instrumentation Alternatives

- Manual instrumentation at the source
  - Use TAU API appropriate for source language
- Automatic source-level instrumentation
  - Source rewriting
  - Directive rewriting (e.g., for OpenMP)
- Library instrumentation
  - Typically done at source level
  - Wrapper interposition library (e.g., PMPI)
- Binary Instrumentation
  - Pre-execution or runtime binary rewriting
- Dynamic runtime instrumentation

TAU Measurement 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
  - 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 for C/C++ (continued)

- User-defined events
  - TAU_REGISTER_EVENT(variable, event_name);
    TAU_EVENT(variable, value);
    TAU_PROFILE_STMT(statement);
- Mapping
  - TAU_MAPPING(statement, key);
    TAU_MAPPING_OBJECT(funcIdVar);
    TAU_MAPPING_LINK(funcIdVar, key);
  - TAU_MAPPING_PROFILE (funcIdVar);
    TAU_MAPPING_PROFILE_TIMER(timer, funcIdVar);
    TAU_MAPPING_PROFILE_START(timer);
    TAU_MAPPING_PROFILE_STOP(timer);
- Reporting
  - TAU_REPORT_STATISTICS();
    TAU_REPORT_THREAD_STATISTICS();

Example: Manual Instrumentation (C++)

```
#include <TAU.h>
int main(int argc, char **argv)
{
  TAU_PROFILE("int main(int, char **)", " ", TAU_DEFAULT); /* name,type,group */
  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 …
}
```

Example: Manual Instrumentation (C)

```
#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);
}
```

Example: Manual Instrumentation (F90)

```
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
```

Instrumenting Multithreaded Applications

```
#include <TAU.h>
void * threaded_function(void *data)
{
  TAU_REGISTER_THREAD();  // Before any other TAU calls
  TAU_PROFILE("void * threaded_function", " ", TAU_DEFAULT);
  work();
}
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 */
  pthread_attr_t attr;
  pthread_t tid;

  pthread_attr_init(&attr);
  pthread_create(&tid, NULL, threaded_function, NULL);
  return 0;
}
```

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_DISABLE — TAU's dummy F90 stub library
- Note: Not including TAU_DEFS in CFLAGS disables instrumentation in C/C++ programs (TAU_DISABLE for f90)

Example: Including TAU Makefile

```
include /usr/tau/sgi64/lib/Makefile.tau-pthread-kcc
CXX = $(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 $@
```

Example: Including TAU Makefile (F90)

```
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 $@
```

Example: Using TAU's malloc Wrapper Library

```
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

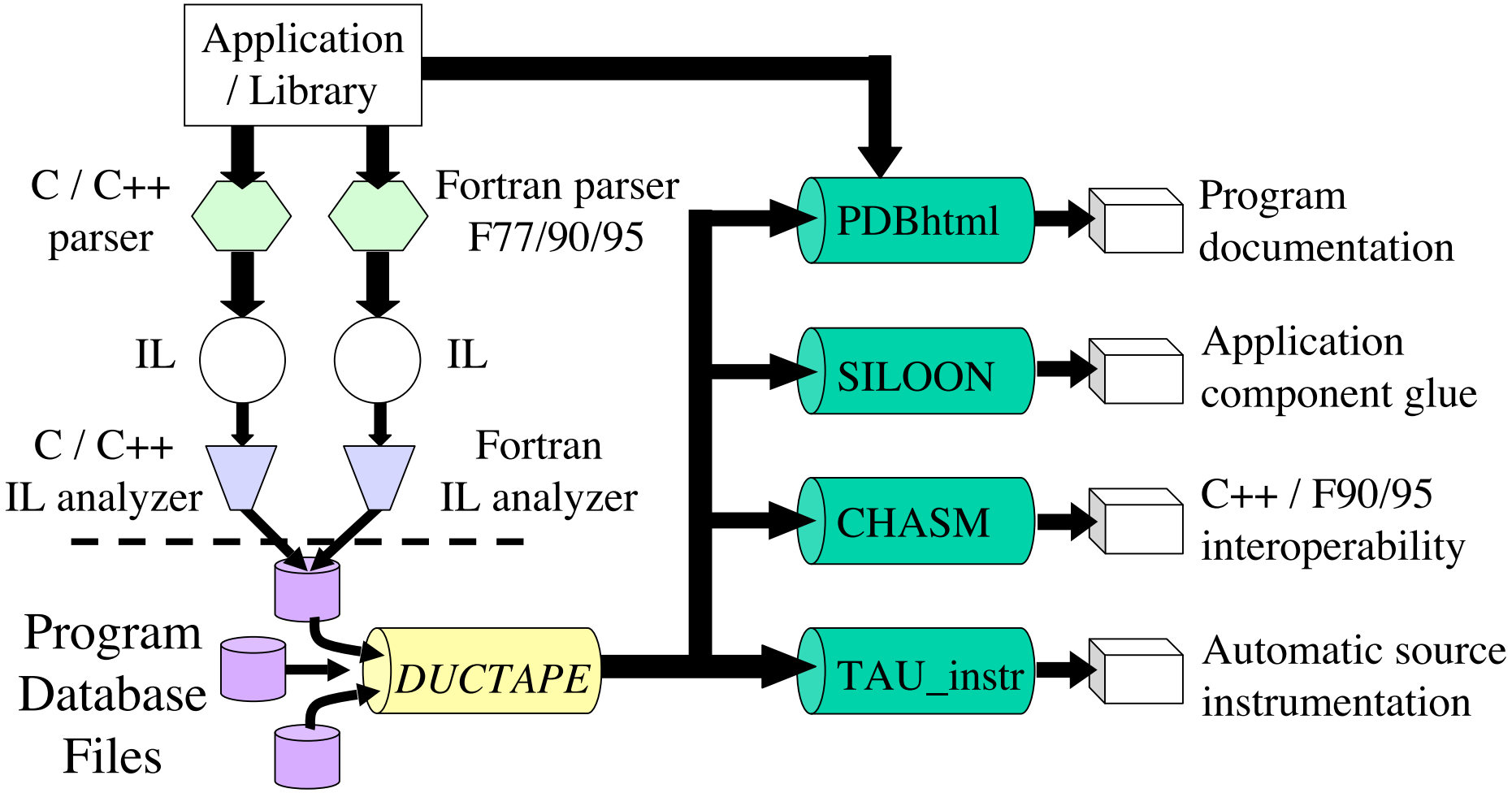
- Used to capture measurements of memory usage

```
#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 …
}
```

Program Database Toolkit (PDT)

- Program code analysis framework
  - develop source-based analysis 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 for automatic source instrumentation*

Program Database Toolkit (PDT)



PDT Components

- Language front end
  - Edison Design Group (EDG): C, C++, Java
  - Mutek Solutions Ltd.: F77, F90
  - Cleanscape FortranLint F95 parser/analyzer
  - Creates an intermediate-language (IL) tree
- IL Analyzer
  - Processes the intermediate language (IL) tree
  - Creates “program database” (PDB) formatted file
- DUCTAPE (Bernd Mohr, ZAM, Germany)
  - C++ program Database Utilities and Conversion Tools APplication Environment
  - C++ library to process the PDB for PDT applications
- Intel/KAI C++ headers for std. C++ library

Contents of PDB files

- Source file names
- Routines, Classes, Methods, Templates, Macros, Modules
- Parameters, signature
- Entry and exit point information (return)
- Location information for all of the above
- Static callgraph
- Header file inclusion tree
- Statement-level information
  - Loops, if-then-else, switch …

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]
- PDT 3.2 released in June 3, 2004
  - Important bug fixes
- http://www.cs.uoregon.edu/research/paracomp/pdtoolkit

Configuring PDT

Step I: Configure PDT:

```
% configure -arch=IRIX64 -CC
% 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=IRIX64 -c++=CC -cc=cc
  -pdt=/usr/contrib/TAU/pdtoolkit-3.0
% make clean; make install
```

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

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

See <taudir>/INSTALL file

TAU Makefile for PDT

```
include /usr/tau/include/Makefile
CXX = $(TAU_CXX)
CC  = $(TAU_CC)
PDTPARSE = $(PDTDIR)/$(CONFIG_ARCH)/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_instrumentor: A PDT Instrumentation Tool

```
% 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
```

tau_reduce: Rule-Based Overhead Analysis

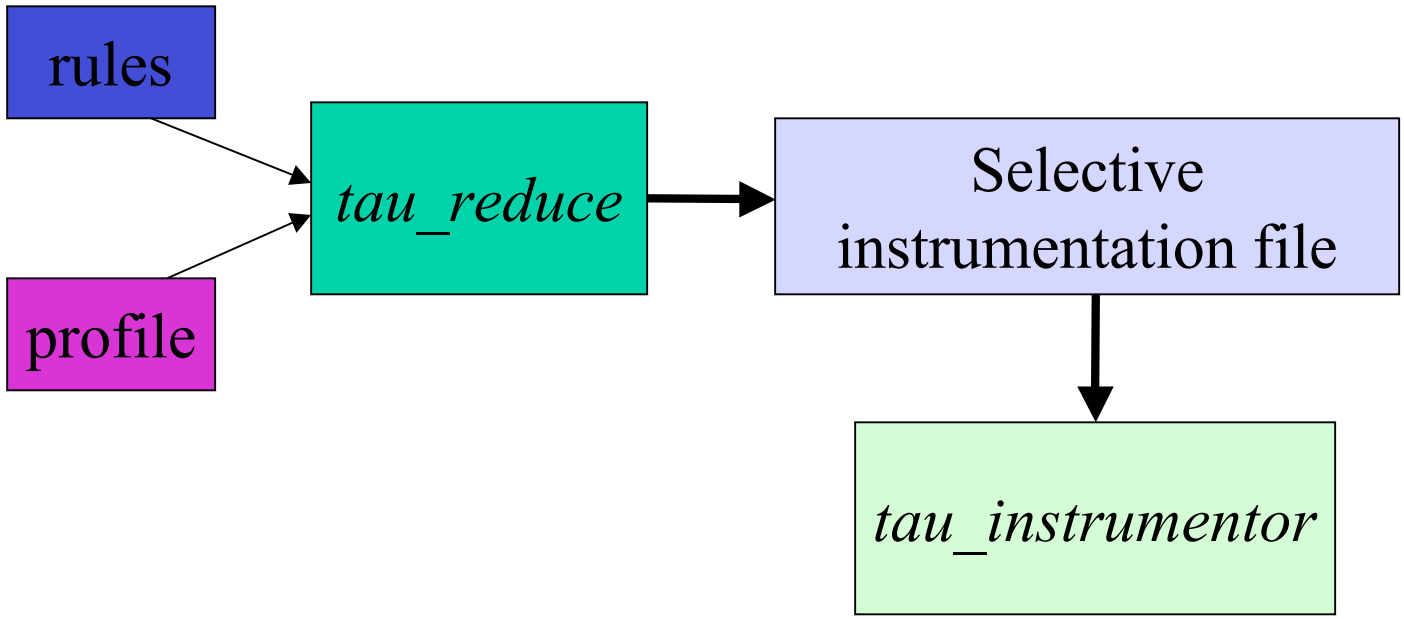
- Analyze the performance data to determine events with high (relative) overhead performance measurements
- Create a select list for excluding those events
- Rule grammar (used in *tau_reduce* tool)

  [GroupName:] Field Operator Number

  - *GroupName* indicates rule applies to events in group
  - *Field* is a event metric attribute (from profile statistics)
    - numcalls, numsubs, percent, usec, cumusec, count [PAPI], totalcount, stdev, usecs/call, counts/call
  - *Operator* is one of >, <, or =
  - *Number* is any number
  - Compound rules possible using & between simple rules

Iterative Instrumentation Process

- Reads profile files and rules
- Creates selective instrumentation file
  - Specifies which routines should be excluded
  - Input to *tau_instrumentor*



Examples: Instrumentation Rules

- #Exclude all events that are members of TAU_USER
  #and use less than 1000 microseconds
  - TAU_USER:usec < 1000
- #Exclude all events that have less than 100
  #microseconds and are called only once
  - usec < 1000 & numcalls = 1
- #Exclude all events that have less than 1000 usecs per
  #call OR have a (total inclusive) percent less than 5
  - usecs/call < 1000
    percent < 5
- Scientific notation can be used
  - usec>1000 & numcalls>400000 & usecs/call<30 & percent>25

Instrumentation Control

- Selection of which performance events to observe
  - Could depend on scope, type, level of interest
  - Could depend on instrumentation overhead
- How is selection supported in instrumentation system?
  - No choice
  - Include / exclude routine and file lists (TAU)
  - Environment variables
  - Static vs. dynamic
- Problem: Controlling instrumentation of small routines
  - High relative measurement overhead
  - Significant intrusion and possible perturbation

Example: tau_reduce

- *tau_reduce* implements overhead reduction in TAU
- Consider *klargest* example
  - Find *k*th largest element in a *N* elements
  - Compare two methods: *quicksort*, *select_kth_largest*
- *i* = 2324, *N* = 1000000 (uninstrumented)
  - *quicksort*: (wall clock) = 0.188511 secs
  - *select_kth_largest*: (wall clock) = 0.149594 secs
  - Total: (P3/1.2GHz, *time*) = 0.340u 0.020s 0:00.37
- Execution with all routines instrumented
- Execution with rule-based selective instrumentation
  - usec>1000 & numcalls>400000 & usecs/call<30 & percent>25

Reducing Instrumentation on One Processor

Before selective instrumentation reduction

NODE 0;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	13	4,982	1	4	4982030	int main
93.5	3,223	4,659	4.20241E+06	1.40268E+07	1	void quicksort
62.9	0.00481	3,134	5	5	626839	int kth_largest_qs
36.4	137	1,813	28	450057	64769	int select_kth_largest
33.6	150	1,675	449978	449978	4	void sort_5elements
28.8	1,435	1,435	1.02744E+07	0	0	void interchange
0.4	20	20	1	0	20668	void setup
0.0	0.0118	0.0118	49	0	0	int ceil

After selective instrumentation reduction

NODE 0;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	14	383	1	4	383333	int main
50.9	195	195	5	0	39017	int kth_largest_qs
40.0	153	153	28	79	5478	int select_kth_largest
5.4	20	20	1	0	20611	void setup
0.0	0.02	0.02	49	0	0	int ceil

TAU's MPI Wrapper Interposition Library

- Uses standard MPI Profiling Interface
  - Provides name shifted interface
    - *MPI_Send* ⇔ *PMPI_Send*
    - weak bindings
- Instrument MPI wrapper library
  - Use TAU measurement API
- Interpose TAU's MPI wrapper library
  - Replace -lmpi by -lTauMpi -lpmpi -lmpi
- No change to the source code!
  - Just re-link the application to generate performance data

Using MPI Wrapper Interposition Library

Step I: Configure TAU with MPI:

```
% configure -mpiinc=/usr/include -mpilib=/usr/lib64
  -arch=sgi64 -c++=CC -cc=cc
  -pdt=/usr/contrib/TAU/pdtoolkit-3.0
% make clean; make install
```

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

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

MPI Library Instrumentation (MPI_Send)

```
int  MPI_Send(…) /* TAU redefines MPI_Send */
...
{
  int  returnVal, typesize;
  TAU_PROFILE_TIMER(tautimer, "MPI_Send()", " ", TAU_MESSAGE);
  TAU_PROFILE_START(tautimer);
  if (dest != MPI_PROC_NULL) {
    PMPI_Type_size(datatype, &typesize);
    TAU_TRACE_SENDMSG(tag, dest, typesize*count);
  }
  /* Wrapper calls PMPI_Send */
  returnVal = PMPI_Send(buf, count, datatype, dest, tag, comm);
  TAU_PROFILE_STOP(tautimer);
  return returnVal;
}
```

Including TAU's Stub Makefile (C, C++)

```
include /usr/tau/sgi64/lib/Makefile.tau-mpi
CXX = $(TAU_CXX)
CC  = $(TAU_CC)
CFLAGS = $(TAU_DEFS) $(TAU_INCLUDE) $(TAU_MPI_INCLUDE)
LIBS = $(TAU_MPI_LIBS) $(TAU_LIBS)
LD_FLAGS = $(TAU_LDFLAGS)
OBJS = ...
TARGET= a.out
TARGET: $(OBJS)
     $(CXX) $(LDFLAGS) $(OBJS) -o $@ $(LIBS)
.cpp.o:
     $(CC) $(CFLAGS) -c $< -o $@
```

Including TAU's Stub Makefile (Fortran)

```
include $PET_HOME/PTOOLS/tau-2.13.5/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 $@
```

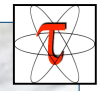
Including TAU's Stub Makefile with PAPI

```
include $PET_HOME/PTOOLS/tau-2.13.5/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 $@
```

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)
```

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
- Supports
  - Fortran77 and Fortran90, OpenMP 2.0
  - C and C++, OpenMP 1.0
  - ***POMP*** Extensions
  - Preserves source information (**`#line line file`**)
  - Measurement library implementations
    - EPILOG, TAU POMP, DPOMP (IBM)
- Work in Progress
  - Investigating standardization through OpenMP Forum

POMP OpenMP Performance Tool Interface

- OpenMP Instrumentation
  - OpenMP Directive Instrumentation
  - OpenMP Runtime Library Routine Instrumentation

- POMP Extensions
  - Runtime Library Control (**`init`**, **`finalize`**, **`on`**, **`off`**)
  - (Manual) User Code Instrumentation (**`begin`**, **`end`**)
  - Conditional Compilation (**`#ifdef _POMP`**, **`!$P`**)
  - Conditional / Selective Transformations (**`[no]instrument`**)

Example: !$OMP PARALLEL DO

```
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)
```

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: Opari 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"
```

Example: TAU POMP Implementation

```
TAU_GLOBAL_TIMER(tfor, "for enter/exit",
                 "[OpenMP]", OpenMP);
void pomp_for_enter(OMPRegDescr* r) {
  #ifdef TAU_AGGREGATE_OPENMP_TIMINGS
    TAU_GLOBAL_TIMER_START(tfor)
  #endif
  #ifdef TAU_OPENMP_REGION_VIEW
    TauStartOpenMPRegionTimer(r);
  #endif
}
void pomp_for_exit(OMPRegDescr* r) {
  #ifdef TAU_AGGREGATE_OPENMP_TIMINGS
    TAU_GLOBAL_TIMER_STOP(tfor)
  #endif
  #ifdef TAU_OPENMP_REGION_VIEW
    TauStopOpenMPRegionTimer(r);
  #endif
}
```

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: ...
```

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

Using Opari with TAU

Step I: Configure KOJAK/opari

[Download from http://www.fz-juelich.de/zam/kojak/]

```
% cd kojak-0.99; cp mf/Makefile.defs.sgi 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-0.99/opari
  -mpiinc=/usr/include -mpilib=/usr/lib64
  -arch=sgi64 -c++=CC -cc=cc
  -pdt=/usr/contrib/TAU/pdtoolkit-3.0
% make clean; make install
```

Dynamic Instrumentation

- TAU uses DyninstAPI for runtime code patching
- *tau_run* (mutator) loads measurement library
- Instruments mutatee
  - Application binary
  - Uses TAU-developed instrumentation specification
- 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)

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>]
```

Example: Python Manual Instrumentation

- Python measurement API and dynamic library

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

import pytau
From time import sleep

x = pytau.profileTimer(``Timer A'')
pytau.start(x)

print " Sleeping for 5 seconds "
sleep(5)

pytau.stop(x)
```

Running:

```
% setenv PYTHONPATH <tau>/<arch>/lib
% ./application.py
```

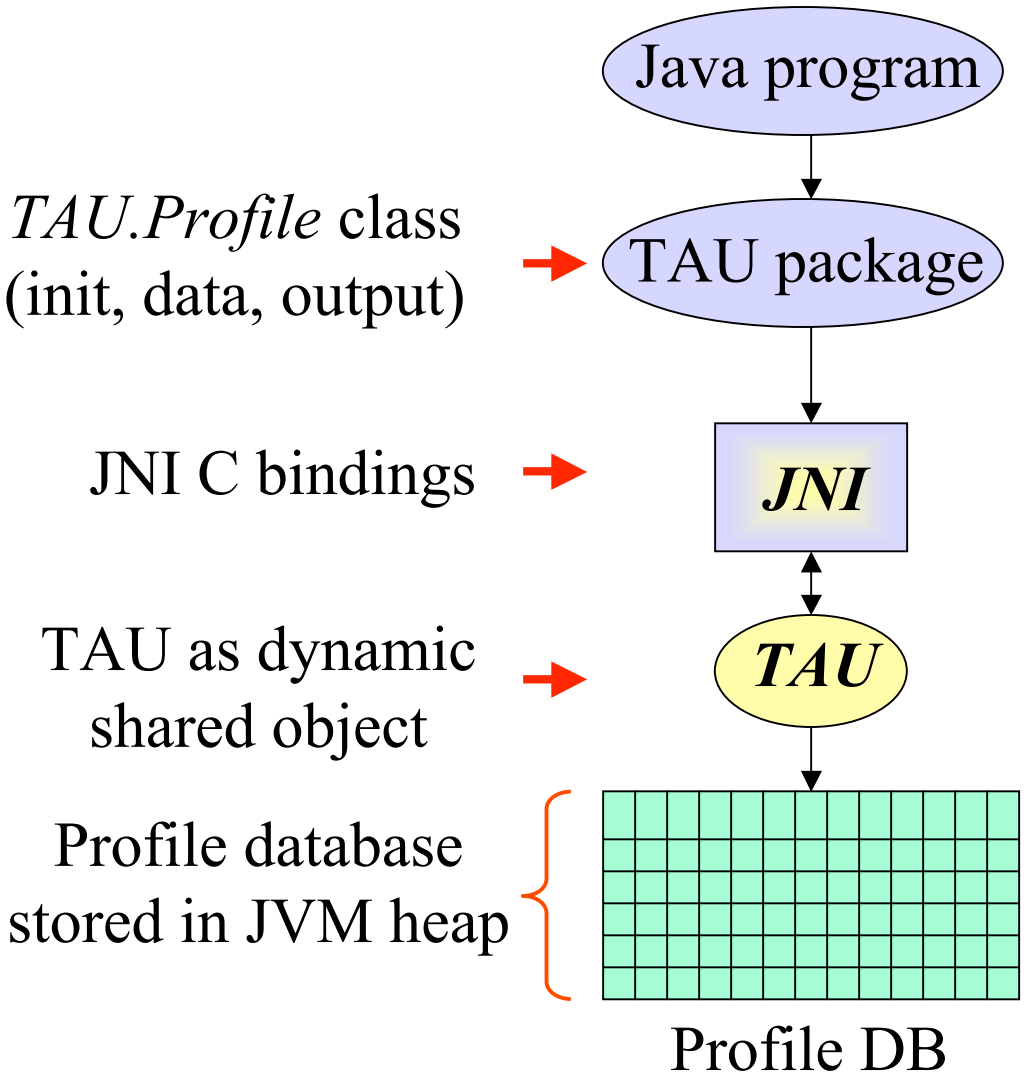
Example: Python Automatic Instrumentation

```
#!/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…
```

TAU Java Source Instrumentation Architecture



- Any code section can be measured
- Portability
- Measurement options
  - Profiling, tracing
- Limitations
  - Source access only
  - Lack of thread information
  - Lack of node information

Java Source-Level Instrumentation

- TAU Java package
- User-defined events
- *TAU.Profile* class for new "timers"
  - Start/Stop
- Performance data output at end

emacs@neutron.cs.uoregon.edu

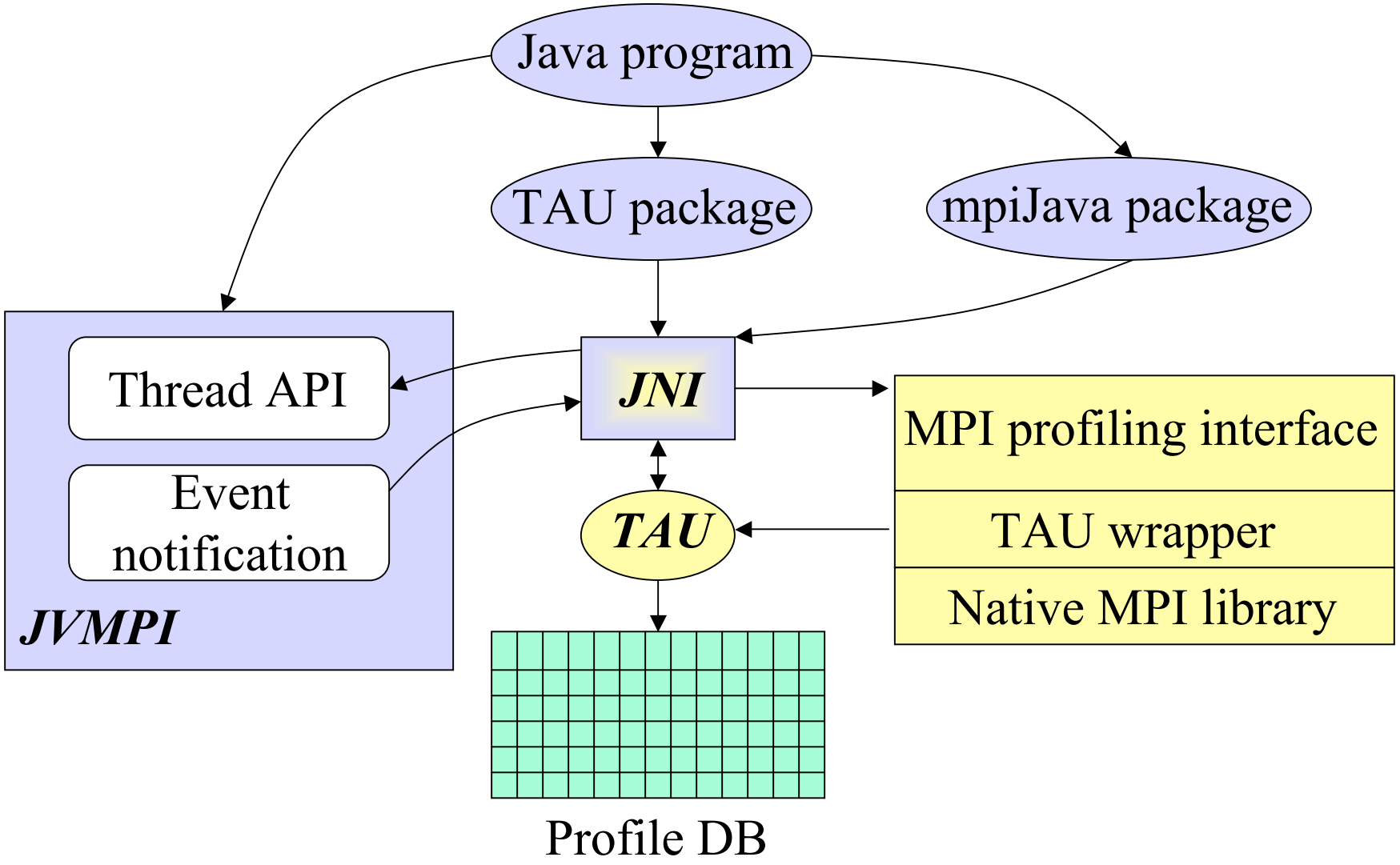
Buffers Files Tools Edit Search Mule Java Help

```
import TAU.*;
import mpi.*;

public class Life {

  static TAU.Profile blocktimer= new TAU.Profile("Life compute local block info",\
 "", "TAU_DEFAULT", TAU.Profile.TAU_DEFAULT);

  static TAU.Profile updatetimer = new TAU.Profile("Life main update loop", "", "\
TAU_DEFAULT", TAU.Profile.TAU_DEFAULT);

    // .. other static data
  static public void main(String [] args) throws MPIException {
    MPI.Init(args) ;

     Cartcomm p = MPI.COMM_WORLD.Create_cart(dims, periods, false) ;

    /* Compute local `blockSizeX', `blockBaseX', `blockSizeY', `blockBaseY'. */

    blocktimer.Start();
    {
        // Code to compute blockSizeX, blockBaseX, blockSizeY, blockBaseY
    }
    blocktimer.Stop();

    updatetimer.Start();
    for(int iter = 0 ; iter < NITER ; iter++) {
      // Shift this block's upper x edge into next neighbour's lower ghost edge
      p.Sendrecv(block, blockSizeX * sY, 1, edgeXType, dstX[0], 0,
                 block, 0,               1, edgeXType, srcX[0], 0) ;

      // other synchronization operations and loops
      dumpBoard() ;
    }
    updatetimer.Stop();

    MPI.Finalize();
  }
--:**  LifeBenchmark.java      (Java)--L8--Top----------------------------------
```

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

TAU Java Instrumentation Architecture



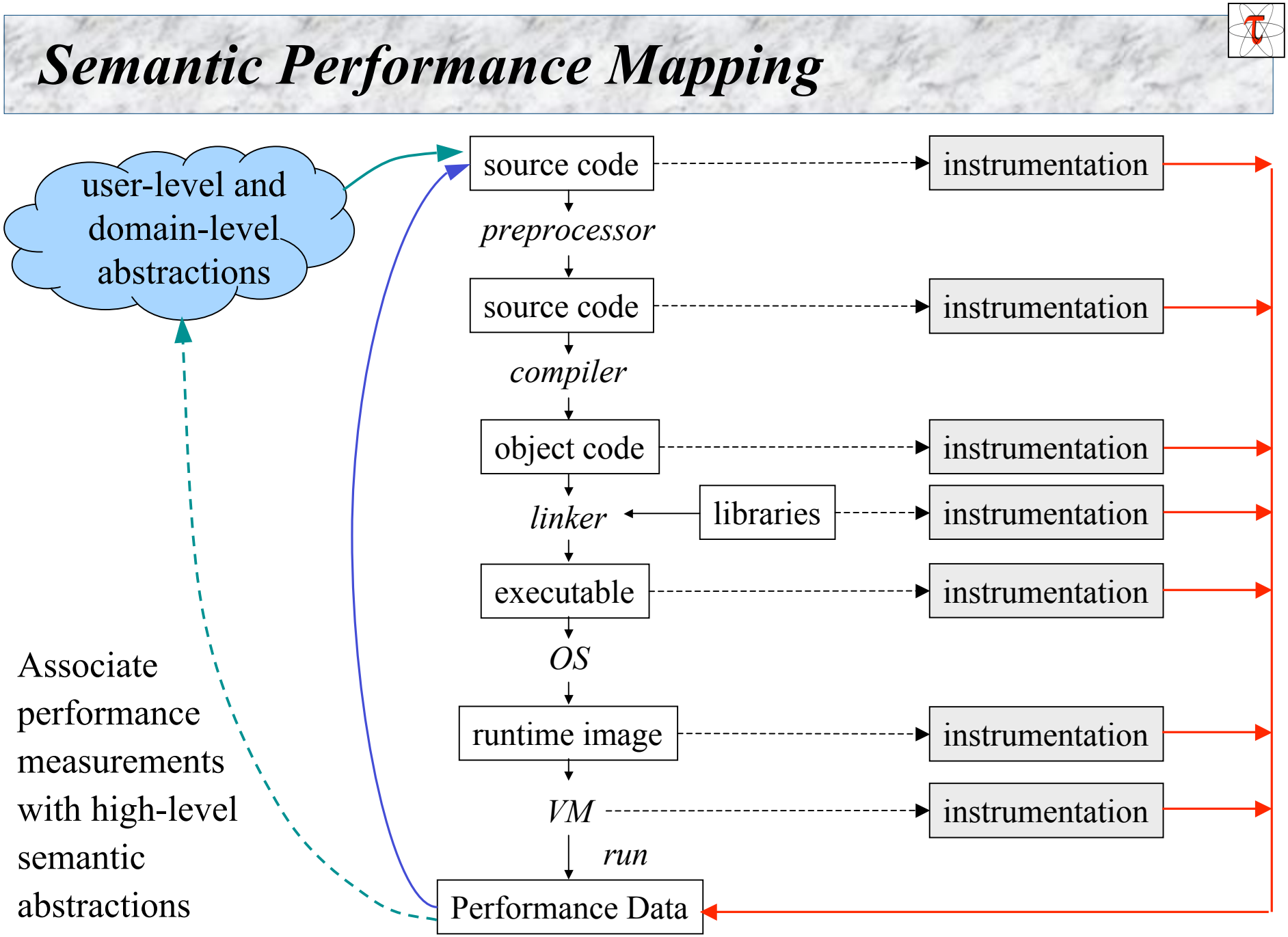
TAU Measurement

- Performance information
  - 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
- Measurement types
  - Parallel profiling
    - includes multiple counters, callpaths, performance mapping
  - Parallel tracing
- Support for online performance data access

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, OpenMP

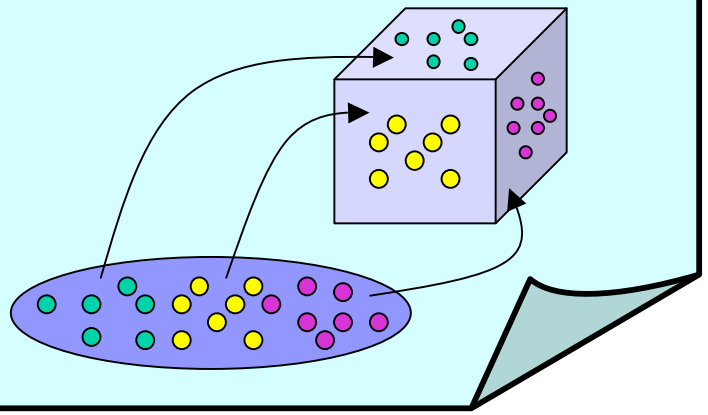
Semantic Performance Mapping



Hypothetical Mapping Example

- Particles distributed on surfaces of a cube

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



Hypothetical Mapping Example (continued)

```
int ProcessParticle(Particle *p) {
  /* perform some computation on p */
}
int main() {
  GenerateParticles();
  /* create a list of particles */
  for (int i = 0; i < N; i++)
    /* iterates over the list */
    ProcessParticle(P[i]);
}
```

- How much time is spent processing *face i* particles?
- What is the distribution of performance among faces?
- How is this determined if execution is parallel?

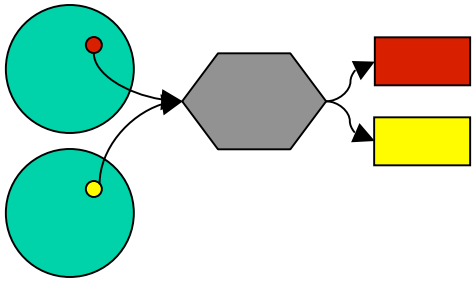
Semantic Entities/Attributes/Associations (SEAA)

- New dynamic mapping scheme
  - Entities defined at any level of abstraction
  - Attribute entity with semantic information
  - Entity-to-entity associations
- Two association types (implemented in TAU API)
  - Embedded
  - External
- "The Role of Performance Mapping"
  - Dr. Sameer Shende
  - Ph.D. thesis

Mapping Associations

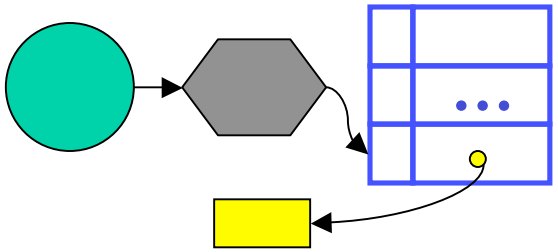
- Embedded association
  - Embedded

    extends associated object to store performance measurement entity



- External association
  - External

    creates an external look-up table using address of object as key to locate performance measurement entity

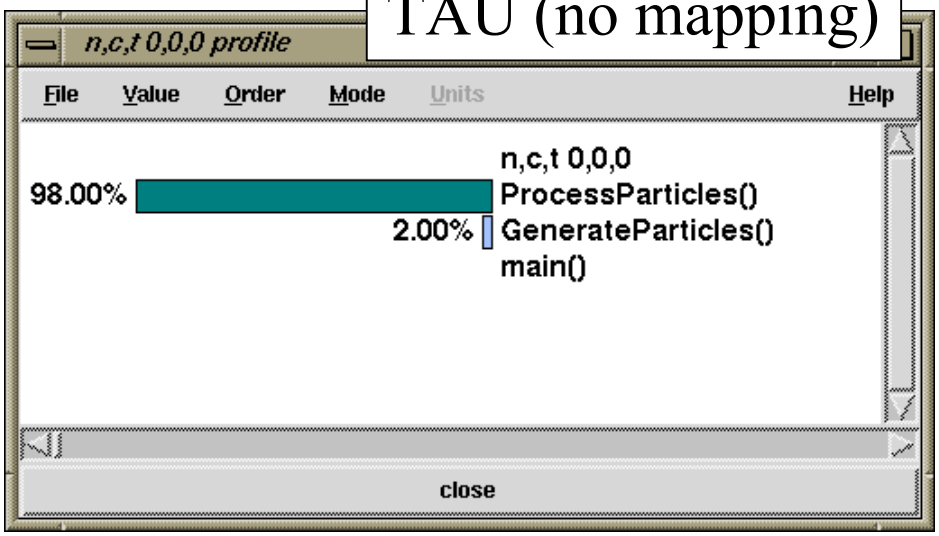


No Performance Mapping versus Mapping

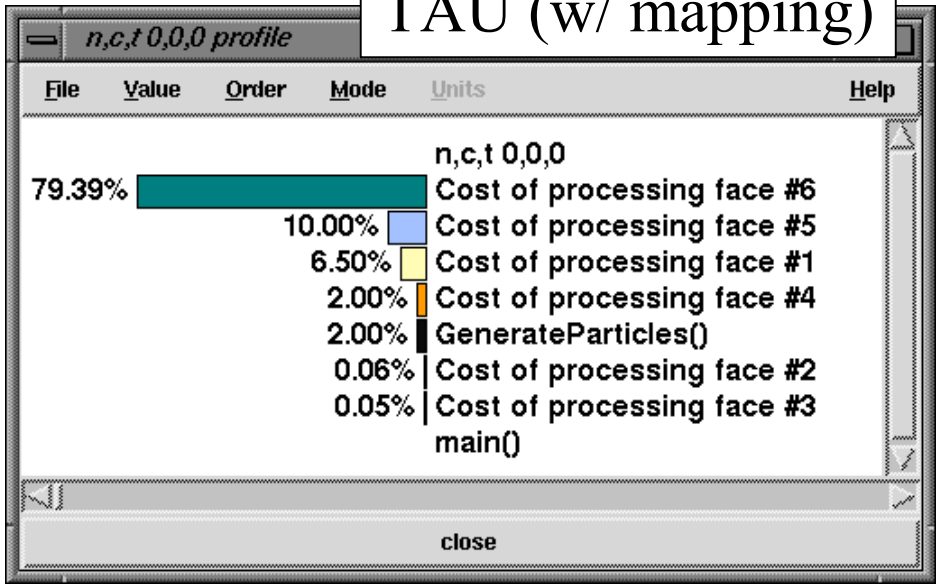
- Typical performance tools report performance with respect to routines
- Does not provide support for mapping

- Performance tools with SEAA mapping can observe performance with respect to scientist's programming and problem abstractions

TAU (no mapping)



TAU (w/ mapping)

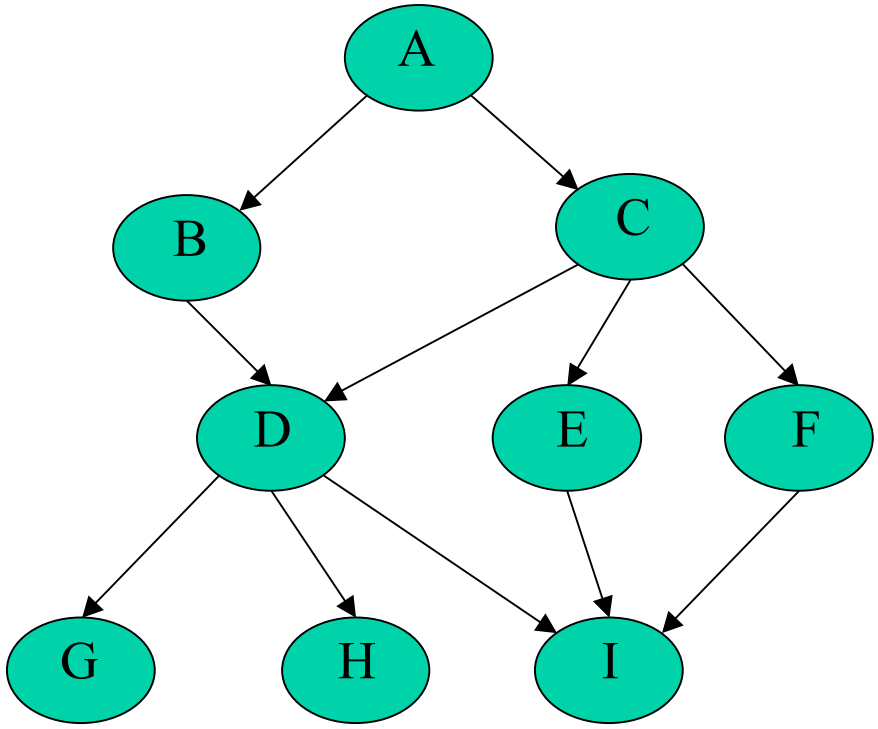


Performance Mapping and Callpath Profiling

- 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

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



- 1-level callpath
  - Immediate descendant
  - A→B, E→I, D→H
  - C→H ?
- *k*-level callpath
  - *k* call descendant
  - 2-level: A→D, C→I
  - 2-level: A→I ?
  - 3-level: A→H

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

Running Applications

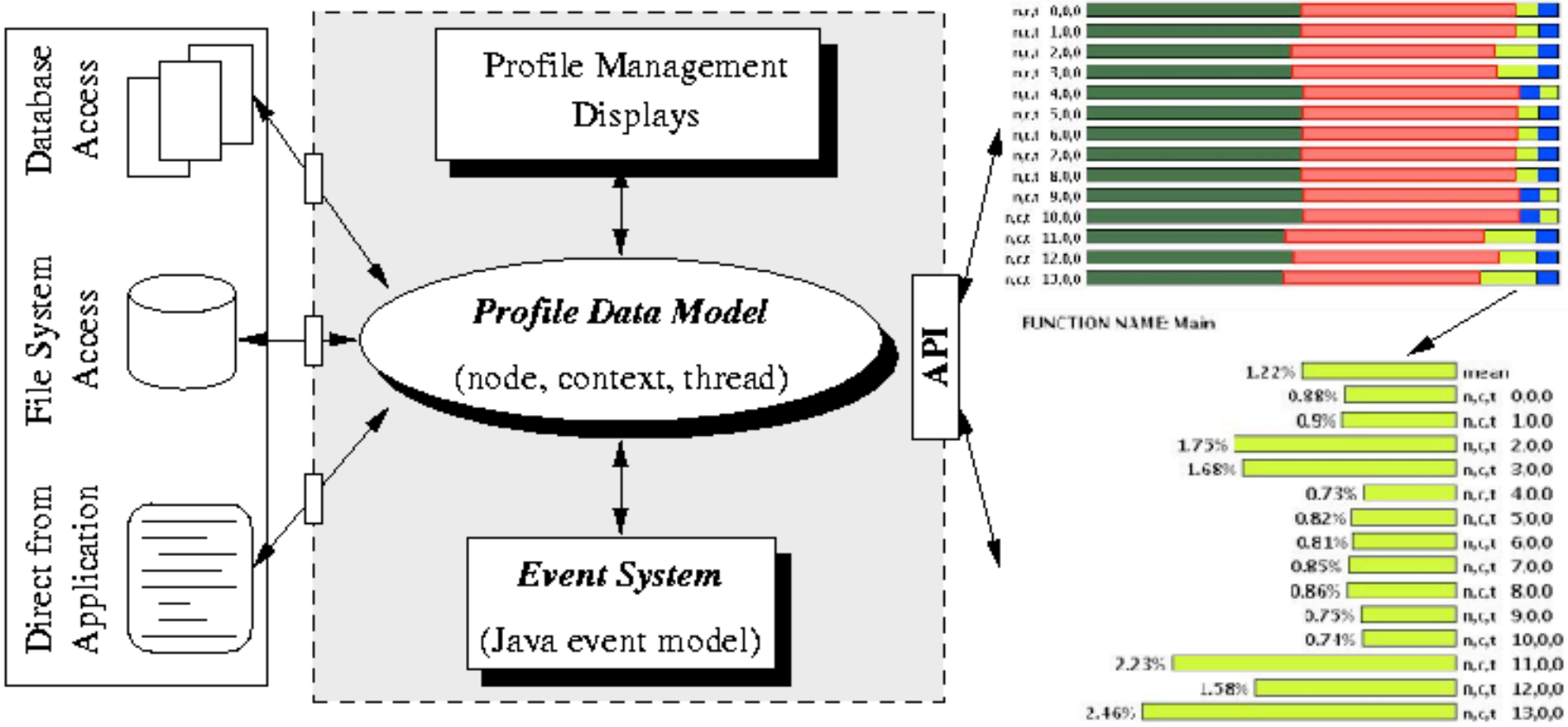
```
% set path=($path <taudir>/<arch>/bin)
% set path=($path $PET_HOME/PTOOLS/tau-2.13.5/src/rs6000/bin)
% setenv LD_LIBRARY_PATH $LD_LIBRARY_PATH\:<taudir>/<arch>/lib

For PAPI (1 counter, if multiplecounters is not used):
% setenv PAPI_EVENT PAPI_L1_DCM (Level 1 Data cache misses)
For PAPI (multiplecounters):
% setenv COUNTER1 PAPI_FP_INS    (Floating point instructions)
% setenv COUNTER2 PAPI_TOT_CYC   (Total cycles)
% setenv COUNTER3 P_VIRTUAL_TIME (Virtual time)
% setenv COUNTER4 LINUX_TIMERS   (Wallclock time)
(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)
```

TAU Performance Analysis

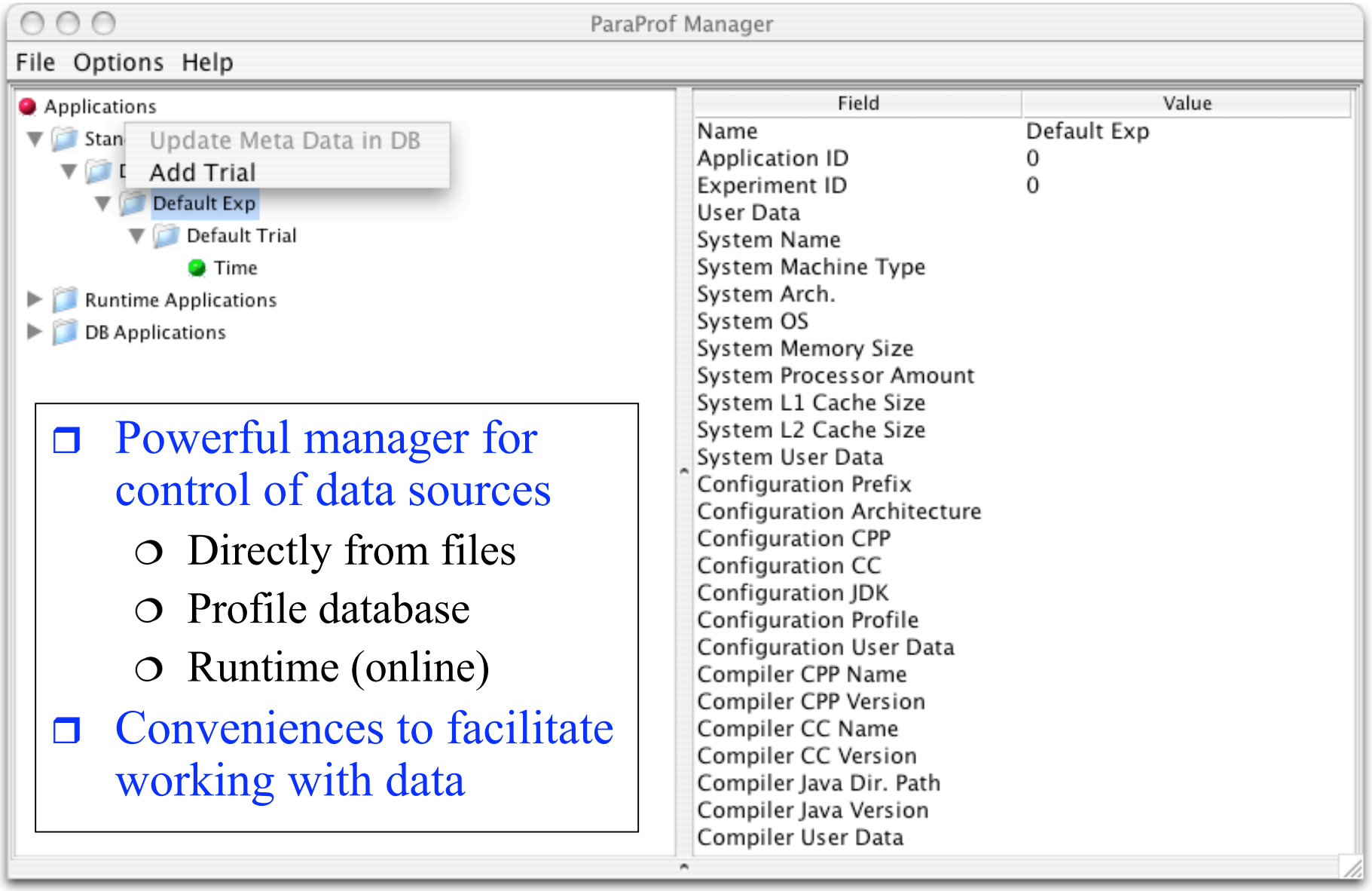
- Analysis of parallel profile and trace measurement
- Parallel profile analysis
  - *Pprof* : parallel profiler with text-based display
  - *ParaProf* : graphical, scalable parallel profile analysis
- Parallel trace analysis
  - Format conversion (ALOG, VTF 3.0, Paraver, EPILOG)
  - Trace visualization using *Vampir* (Pallas/Intel)
  - Parallel profile generation from trace data

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



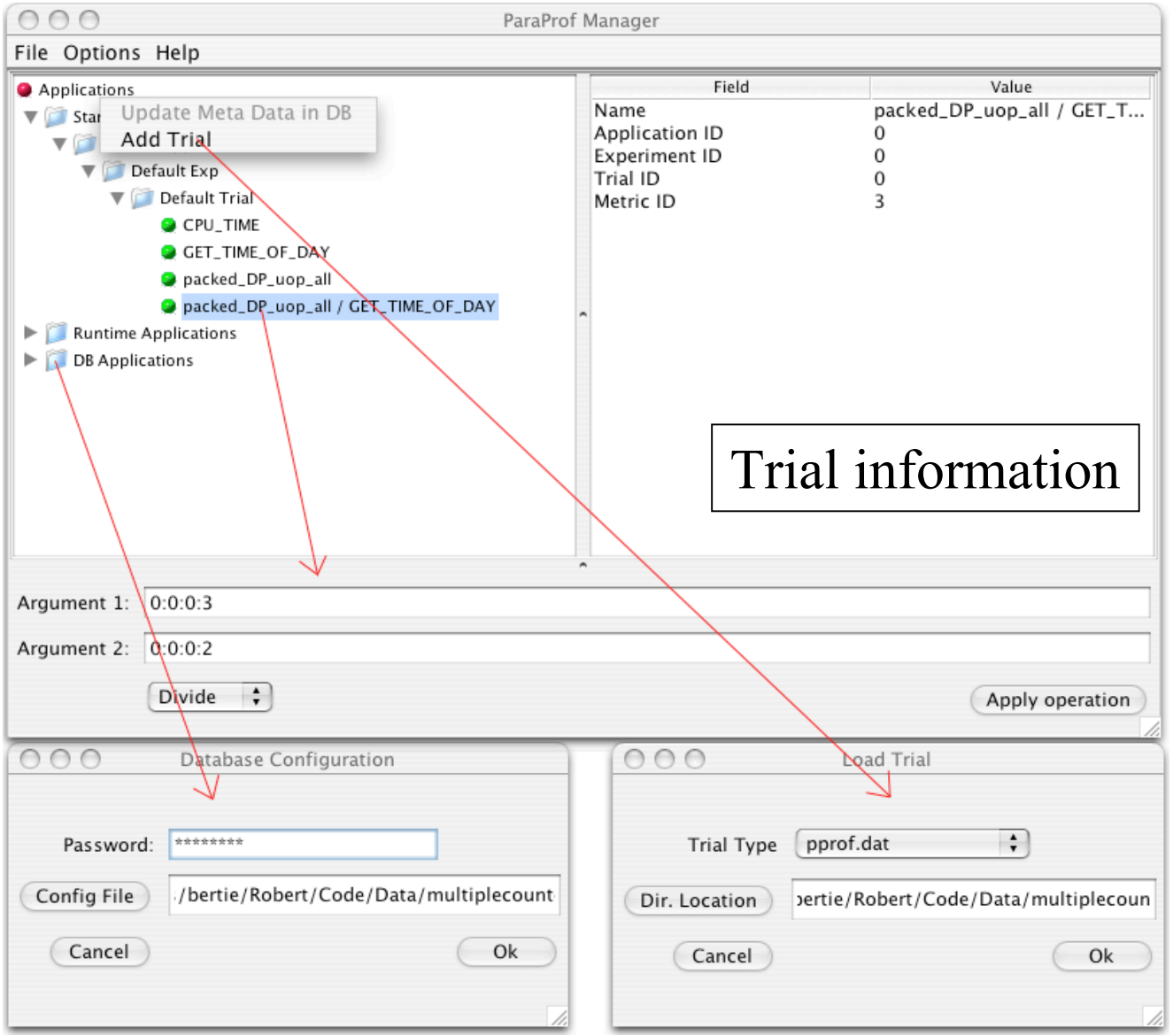
ParaProf Manager



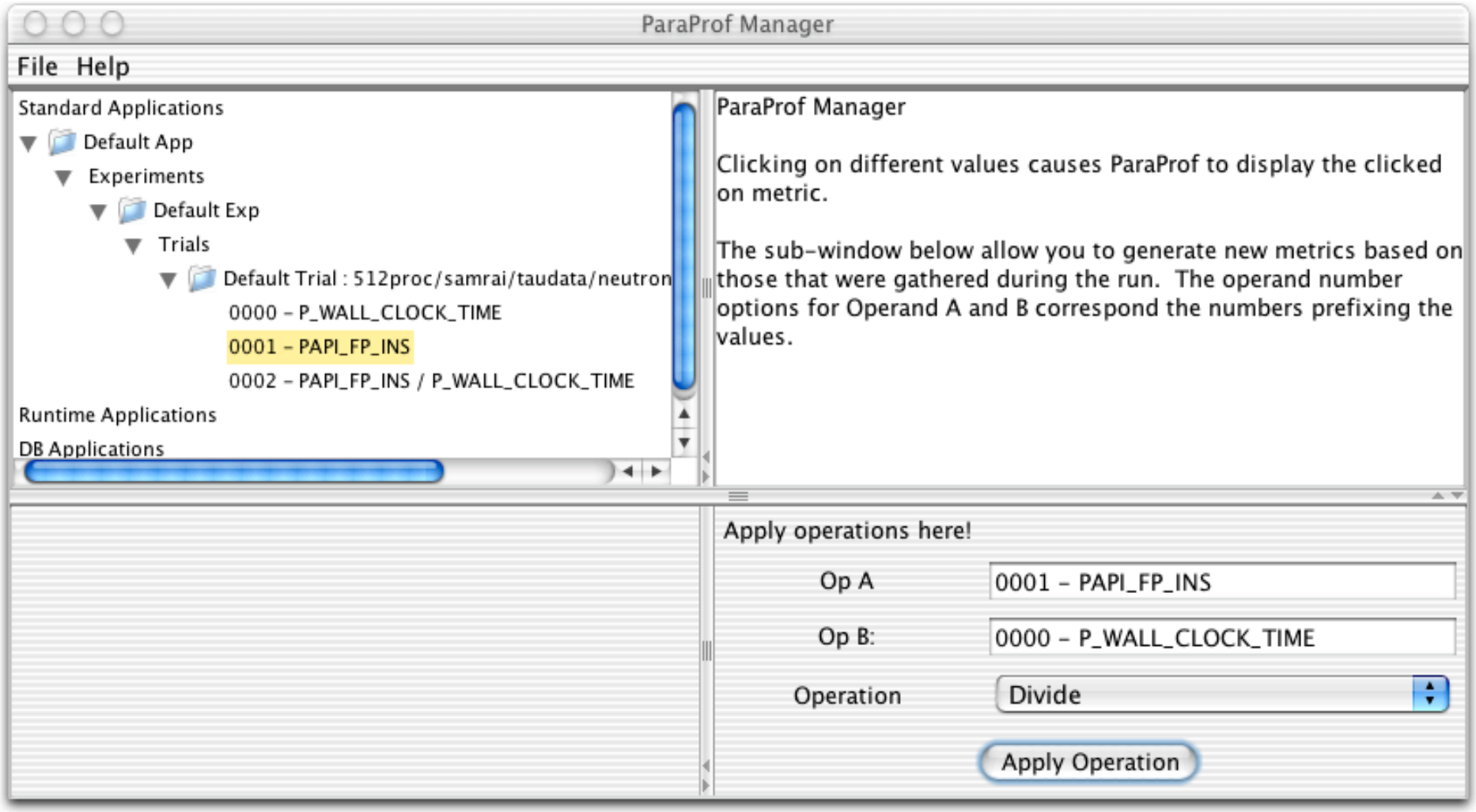
- Powerful manager for control of data sources
  - Directly from files
  - Profile database
  - Runtime (online)
- Conveniences to facilitate working with data

ParaProf Manager (continued)

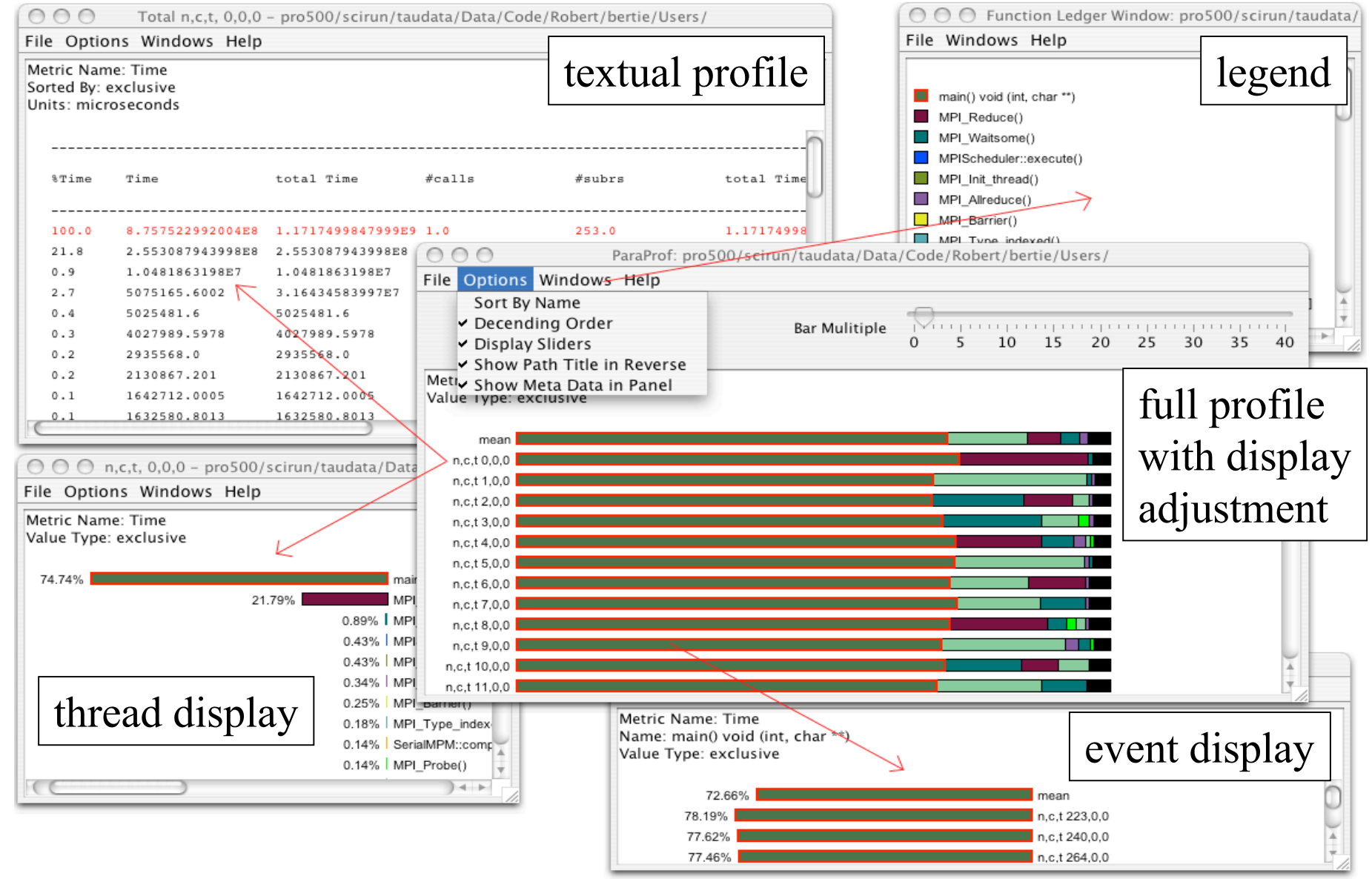
- Data management windows
  - Loading flat files from disk
  - Generating new derived metrics
  - Database interface



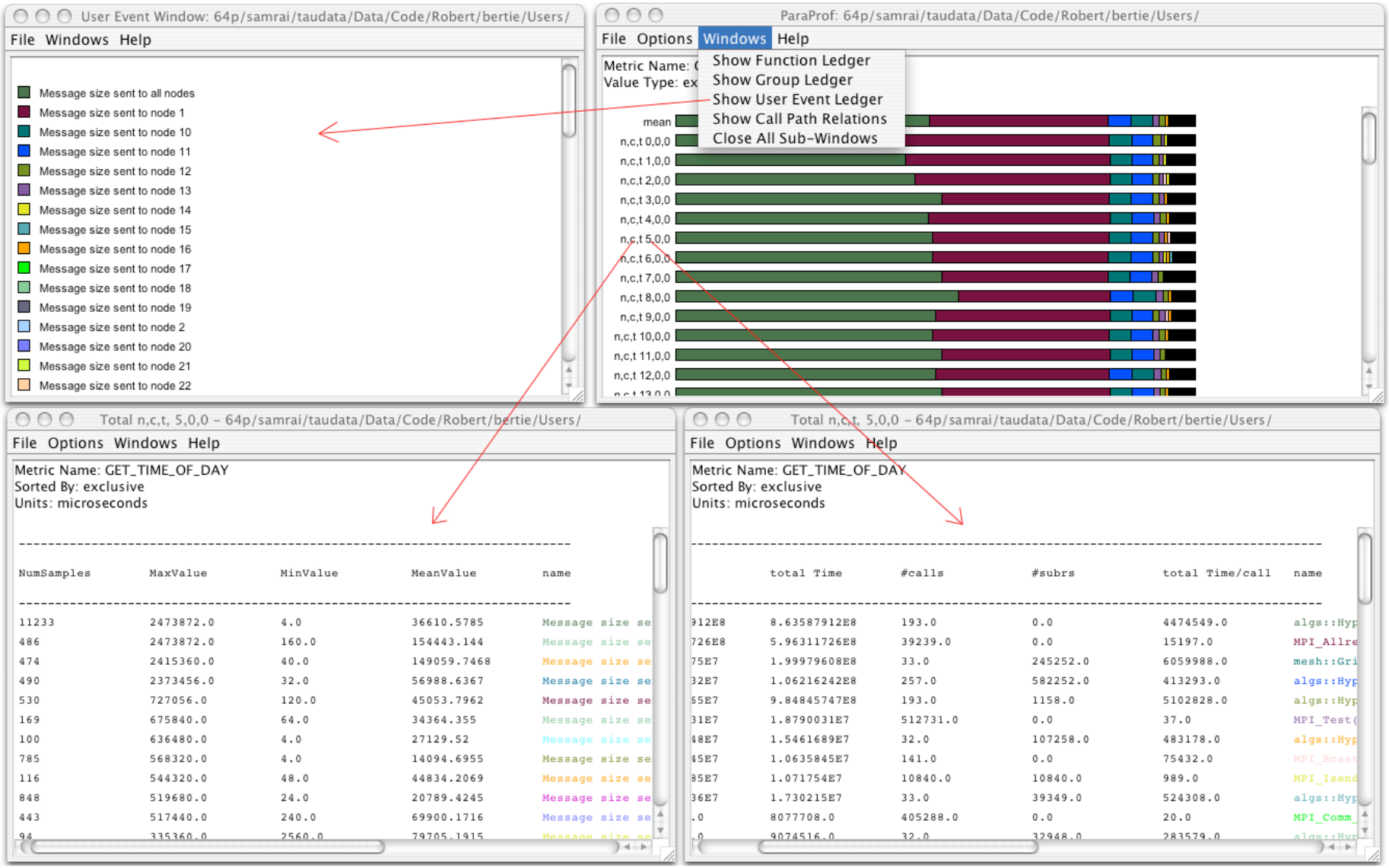
ParaProf Derived Metrics



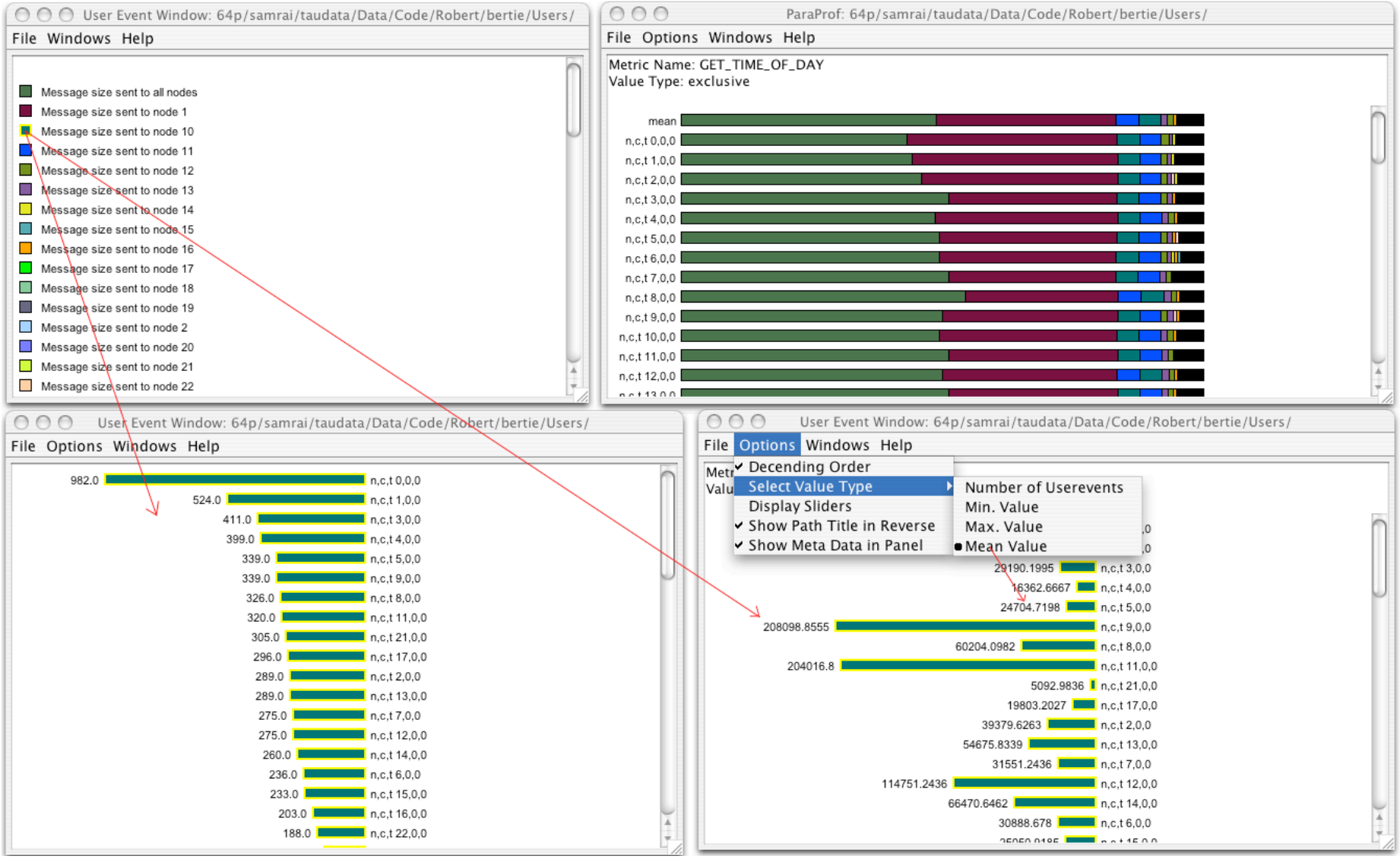
ParaProf Profile Analysis Displays



ParaProf User Event Display (MPI message size)



ParaProf User Event Details (MPI message size)



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>

ParaProf Profile Analysis Features

- Inter-window event management
  - Full event propagation
  - Hyperlinked displays
- Window configuration and help management
  - Popup menus
  - Full preference control
  - Data view control
- Maturation of profile performance data views
- Java-based implementation
  - Extensible
- Performance database connectivity

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

Callpath Profiling Example (NAS LU v2.3)

```
% configure -PROFILECALLPATH -SGITIMERS -arch=sgi64
   -mpiinc=/usr/include -mpilib=/usr/lib64 -useropt=-O2
```

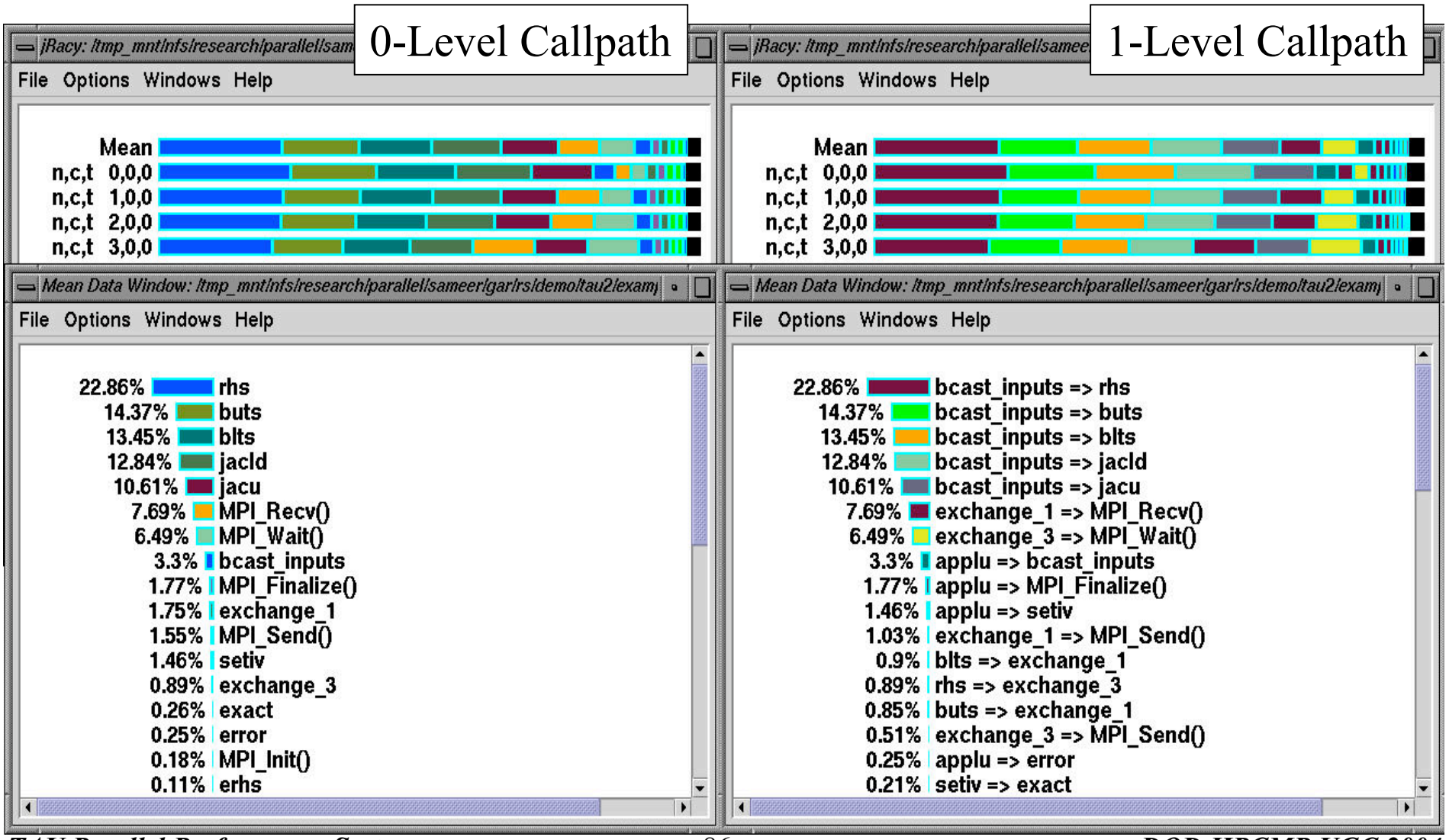
Mean Total Stat Window: /tmp_mnt/nfs/research/parallel/sameer/gar/rs/demo/tau2/examples/NPB2.3/bin/pprof.dat

File Options Windows Help

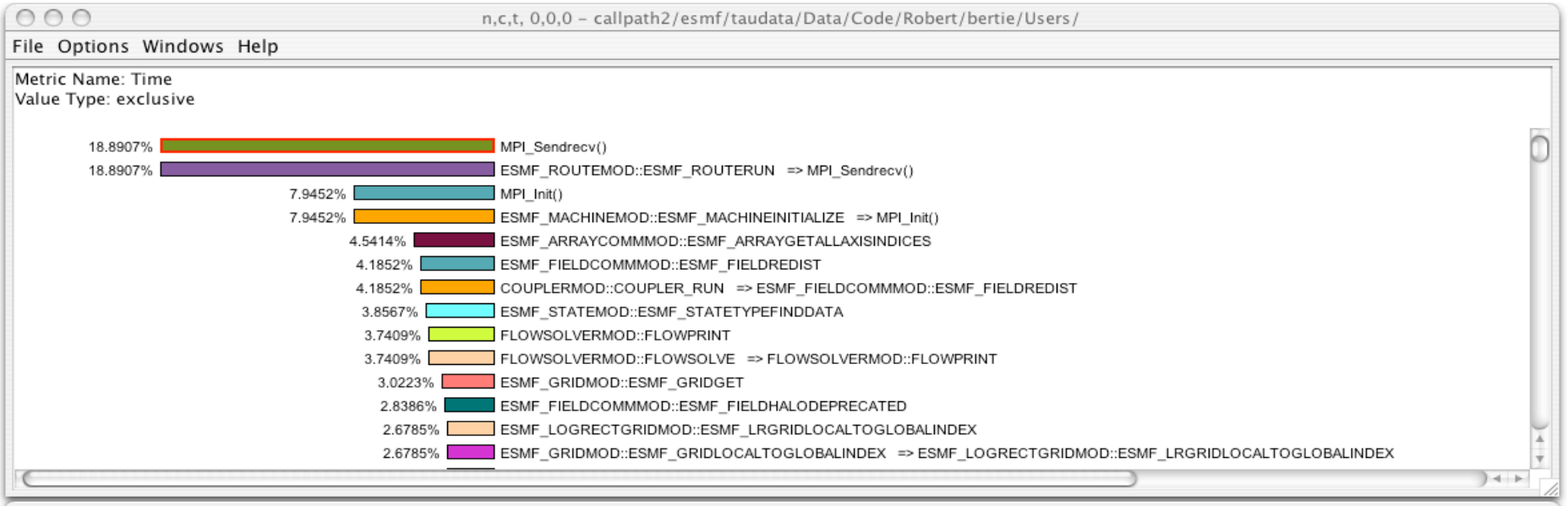
%time	msec	total msec	#call	#subrs	usec/call	name
30.7	13,037	17,495	301	602	58126	bcast_inputs => rhs
30.7	13,037	17,495	301	602	58126	rhs
17.3	8,195	9,838	9300	18600	1058	bcast_inputs => buts
17.3	8,195	9,838	9300	18600	1058	buts
21.0	7,669	11,998	9300	18600	1290	bcast_inputs => blts
21.0	7,669	11,998	9300	18600	1290	blts
12.8	7,320	7,320	9300	0	787	bcast_inputs => jacld
12.8	7,320	7,320	9300	0	787	jacld
10.6	6,049	6,049	9300	0	651	bcast_inputs => jacu
10.6	6,049	6,049	9300	0	651	jacu
7.7	4,385	4,385	18600	0	236	MPI_Recv()
7.7	4,385	4,385	18600	0	236	exchange_1 => MPI_Recv()
6.5	3,700	3,700	606	0	6106	MPI_Wait()
6.5	3,700	3,700	604	0	6126	exchange_3 => MPI_Wait()
95.8	1,882	54,609	2.25	37517	24270831	bcast_inputs
95.7	1,882	54,604	1.25	37508	43683863	applu => bcast_inputs
1.8	1,012	1,012	1	0	1012219	MPI_Finalize()
1.8	1,012	1,012	1	0	1012219	applu => MPI_Finalize()
10.5	996	5,971	37200	37200	161	exchange_1
1.5	882	882	19206	0	46	MPI_Send()
1.7	833	950	1	44686.5	950499	applu => setiv

Callpath Parallel Profile Display

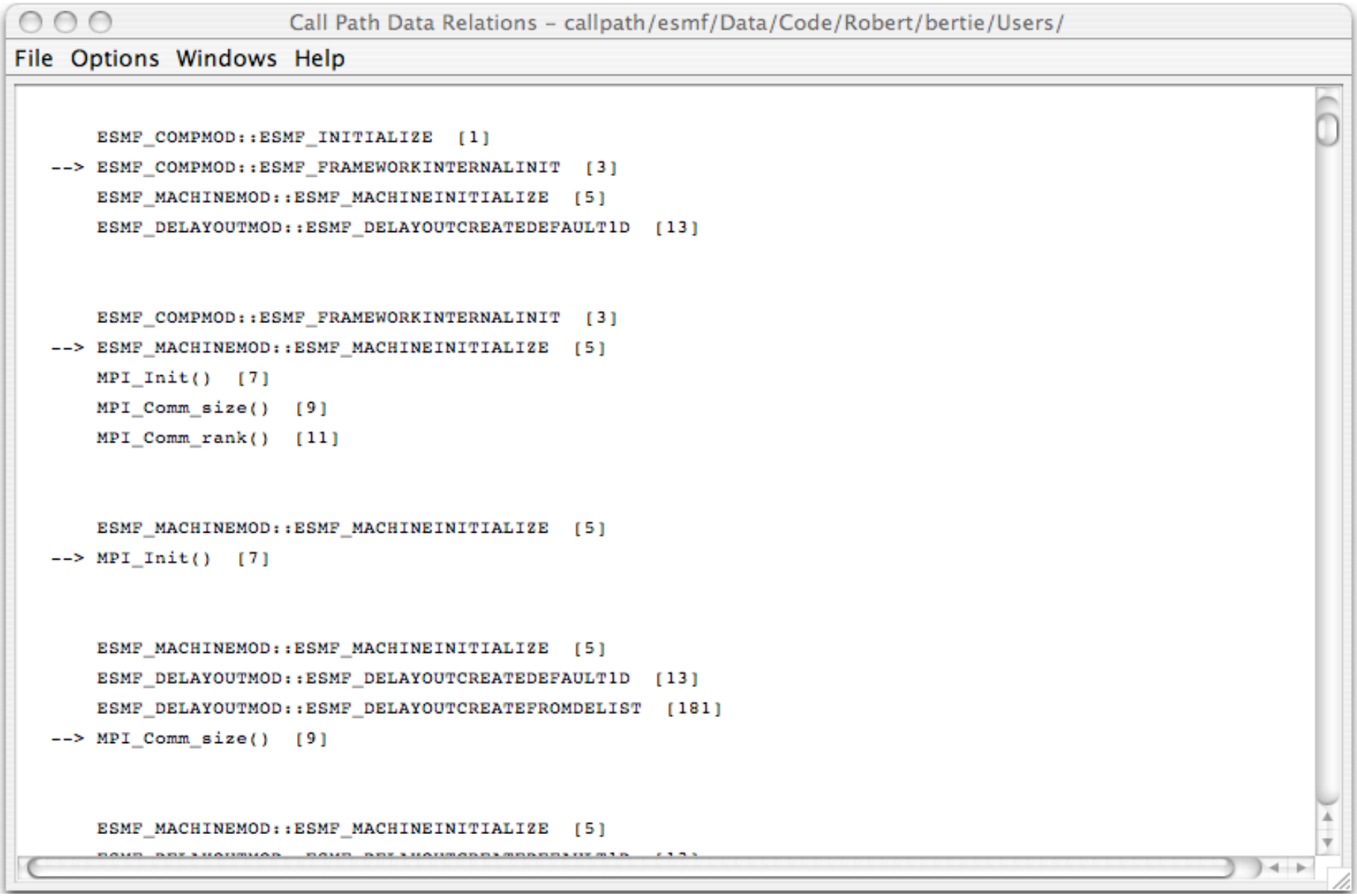
- 0-level and 1-level callpath grouping



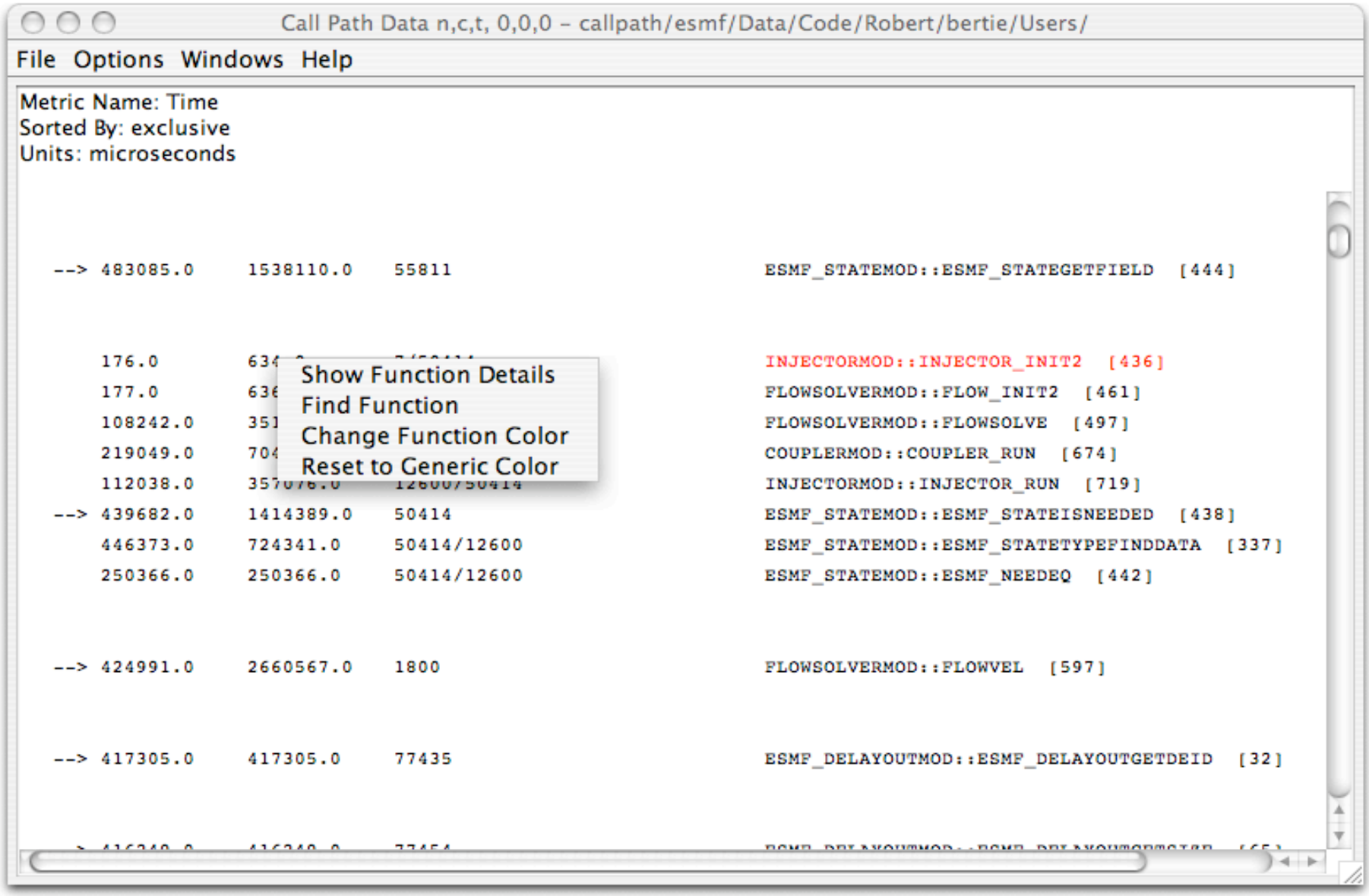
Callpath Profiling Screenshot



Callpath Profiling Parent/Child Relations



Callpath Profiling Screenshot (cont.)

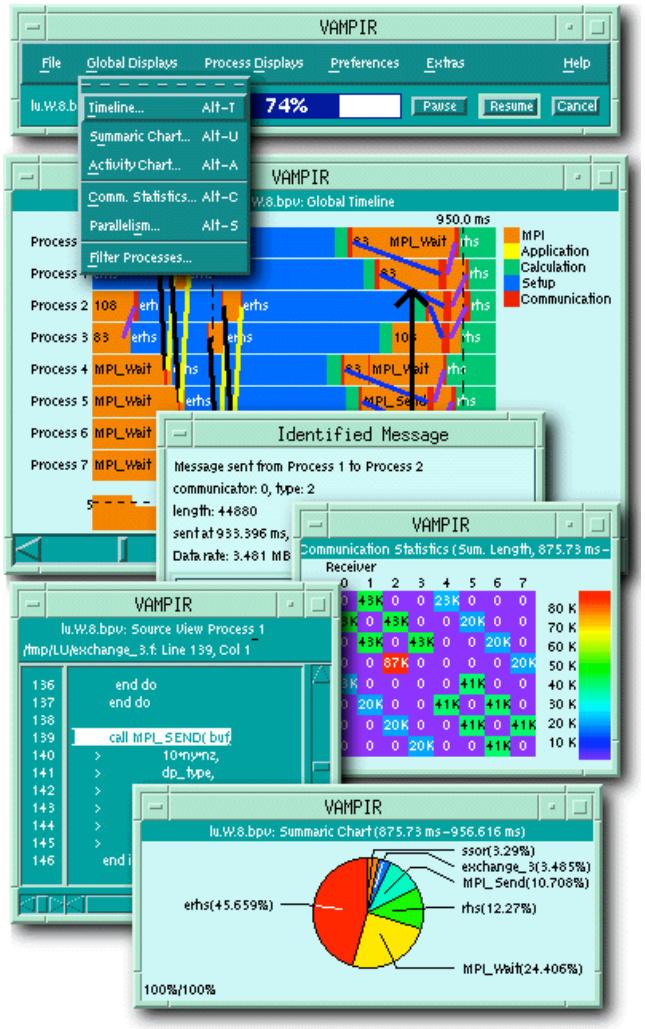


Vampir Trace Visualization

- Visualization and Analysis of **MPI** PRograms
- Originally developed by Forschungszentrum Jülich

- Current development by Technical University Dresden

- Distributed by PALLAS, Germany



- **`http://www.pallas.de/pages/vampir.htm`**

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

- 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
```

- Load generated trace file in Vampir

```
% vampir app.pv
```

Case Study: SIMPLE Performance Analysis

- SIMPLE hydrodynamics benchmark
  - C code with MPI message communication
  - Multiple instrumentation methods
    - source-to-source translation (PDT)
    - MPI wrapper library level instrumentation (PMPI)
    - pre-execution binary instrumentation (DyninstAPI)
  - Alternative measurement strategies
    - statistical profiles of software actions
    - statistical profiles of hardware actions (PCL, PAPI)
    - program event tracing
    - choice of time source
      - gettimeofday, physical clock, CPU, process virtual

SIMPLE Source Instrumentation (Preprocessed)

- PDT automatically generates instrumentation code
  - Names events with full function signatures

```
int compute_heat_conduction(
   double theta_hat[X][Y], double deltat, double new_r[X][Y],
   double new_z[X][Y], double new_alpha[X][Y],
   double new_rho[X][Y], double theta_l[X][Y],
   double Gamma_k[X][Y], double Gamma_l[X][Y])
{
   TAU_PROFILE("int compute_heat_conduction(
       double (*)[259], double, double (*)[259],
       double (*)[259], double (*)[259], double (*)[259],
   double (*)[259], double (*)[259], double (*)[259])",
       " ", TAU_USER);
   ...
}
```

- Similarly for all other routines in SIMPLE program

MPI Library Instrumentation (MPI_Send)

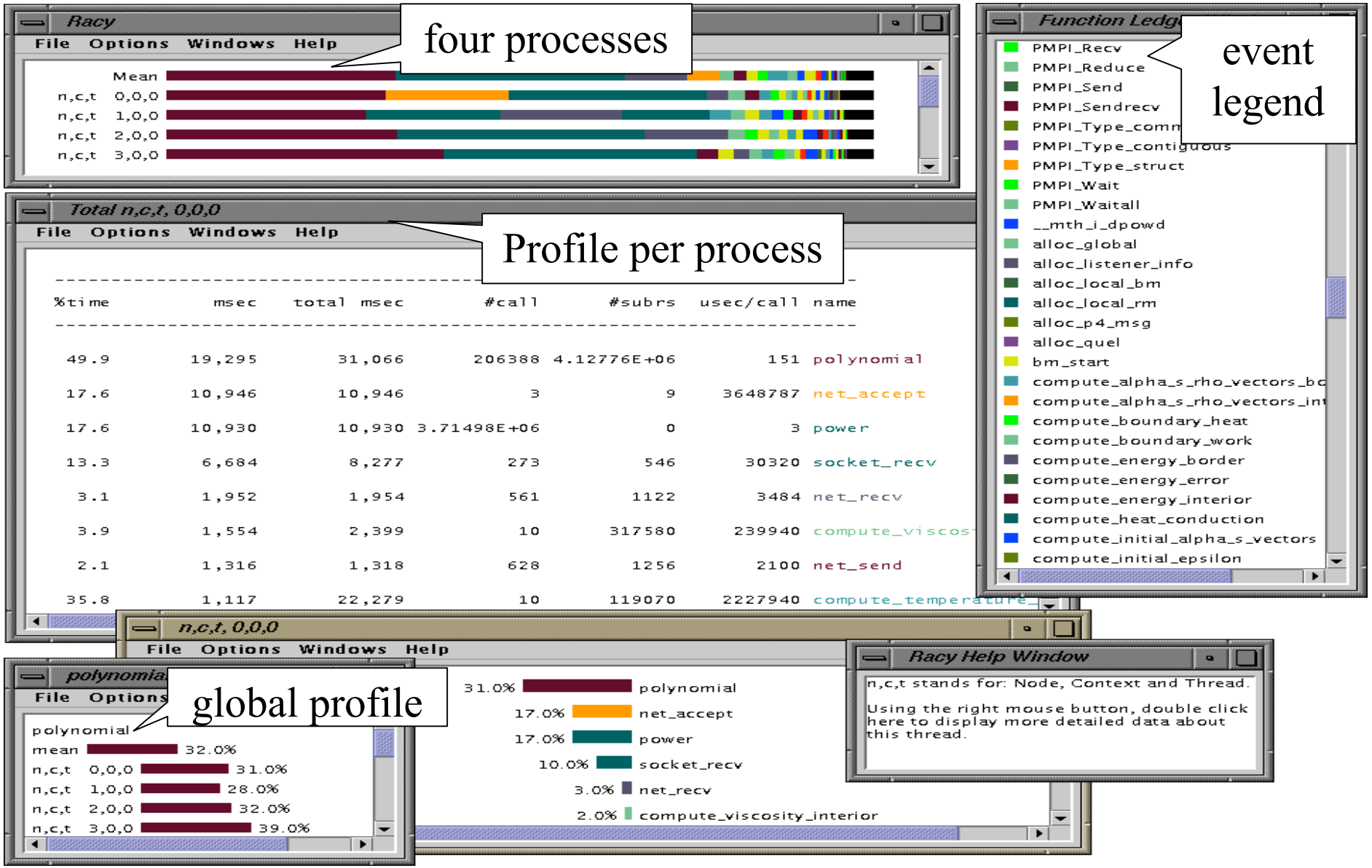
- Uses MPI profiling interposition library (PMPI)

```
int  MPI_Send(…)
...
{
  int  returnVal, typesize;
  TAU_PROFILE_TIMER(tautimer, "MPI_Send()", " ", TAU_MESSAGE);
  TAU_PROFILE_START(tautimer);
  if (dest != MPI_PROC_NULL) {
    PMPI_Type_size(datatype, &typesize);
    TAU_TRACE_SENDMSG(tag, dest, typesize*count);
  }
  returnVal = PMPI_Send(buf, count, datatype, dest, tag, comm);
  TAU_PROFILE_STOP(tautimer);
  return returnVal;
}
```

MPI Library Instrumentation (MPI_Recv)

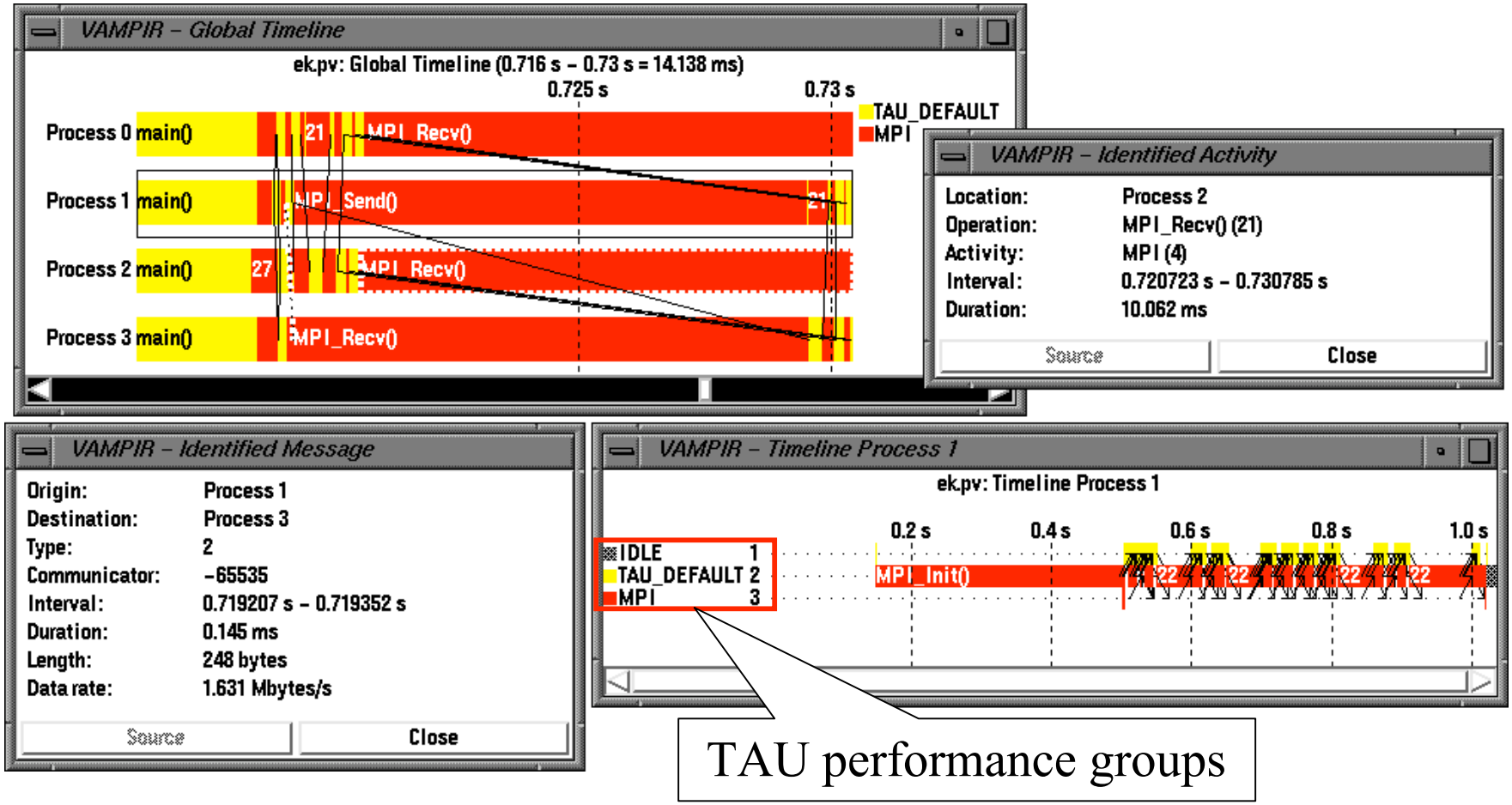
```
int  MPI_Recv(…)
...
{
   int  returnVal, size;
   TAU_PROFILE_TIMER(tautimer, "MPI_Recv()",  " ", TAU_MESSAGE);
   TAU_PROFILE_START(tautimer);
   returnVal = PMPI_Recv(buf, count, datatype, src, tag, comm,
      status);
   if (src != MPI_PROC_NULL && returnVal == MPI_SUCCESS) {
      PMPI_Get_count( status, MPI_BYTE, &size );
      TAU_TRACE_RECVMSG(status->MPI_TAG, status->MPI_SOURCE,
        size);
   }
   TAU_PROFILE_STOP(tautimer);
   return returnVal;
}
```

Multi-Level Instrumentation (Profiling)



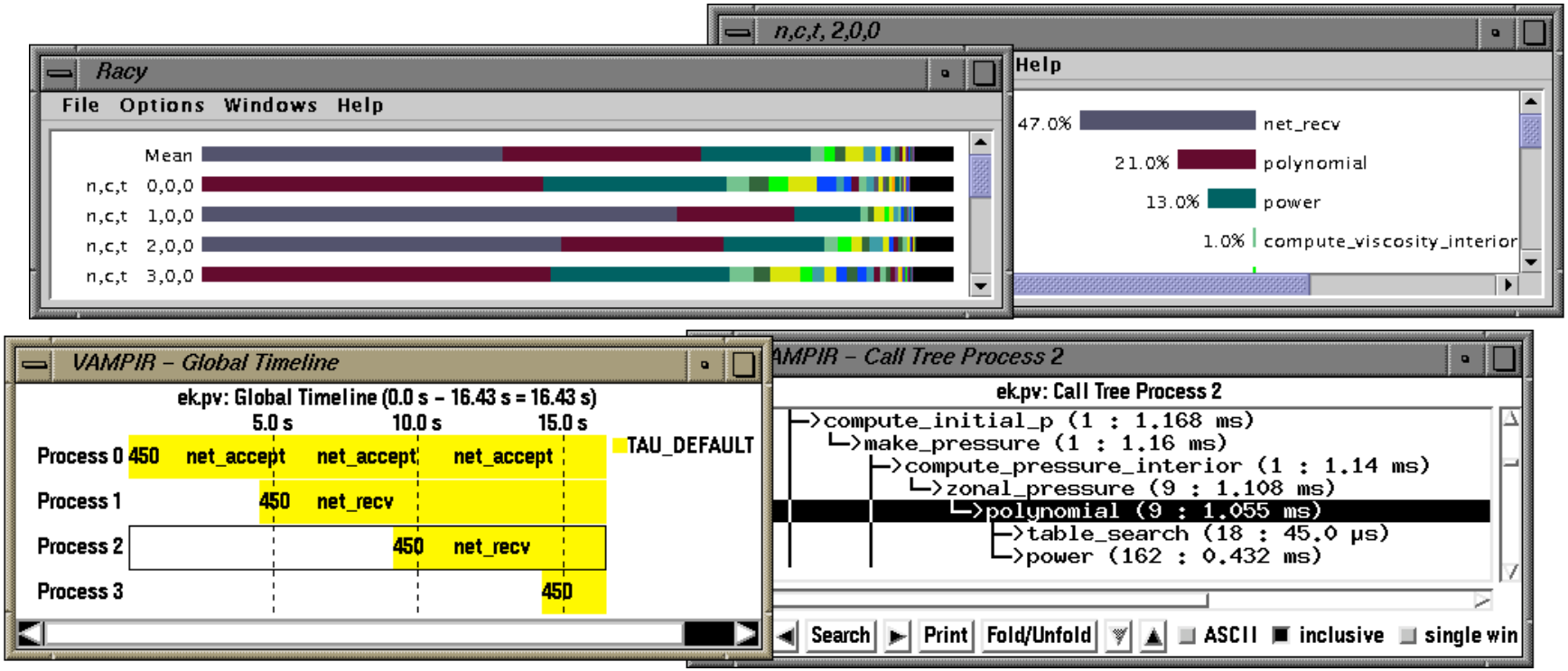
Multi-Level Instrumentation (Tracing)

- Relink with TAU library configured for tracing
  - No modification of source instrumentation required!



Dynamic Instrumentation of SIMPLE

- Uses DynInstAPI for runtime code patching
- Mutator loads measurement library, instruments mutatee
  - One mutator (*tau_run*) per executable image
  - mpirun –np <n> tau.shell



Event Tracing using DyninstAPI