TAU Parallel Performance System

(ACTS Workshop LBL)

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Tuning and Analysis Utilities

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Outline

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

TAU Performance System Framework

Tuning and Analysis Utilities

- Tuning and Analysis Utilities
- 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, configurable performance profiling/tracing facility
  - Open software approach
- University of Oregon, LANL, FZJ Germany
- http://www.cs.uoregon.edu/research/paracomp/tau

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

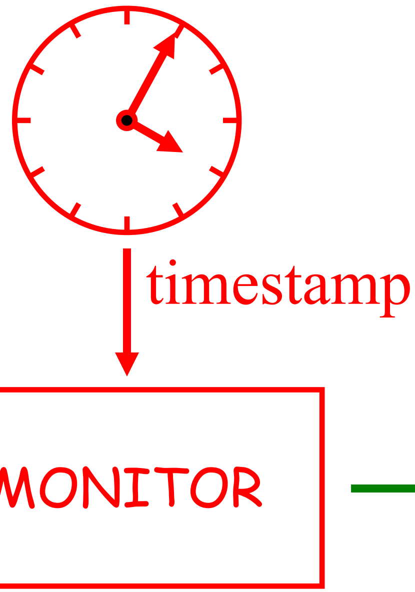
Event Tracing: Instrumentation, Monitor, Trace

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

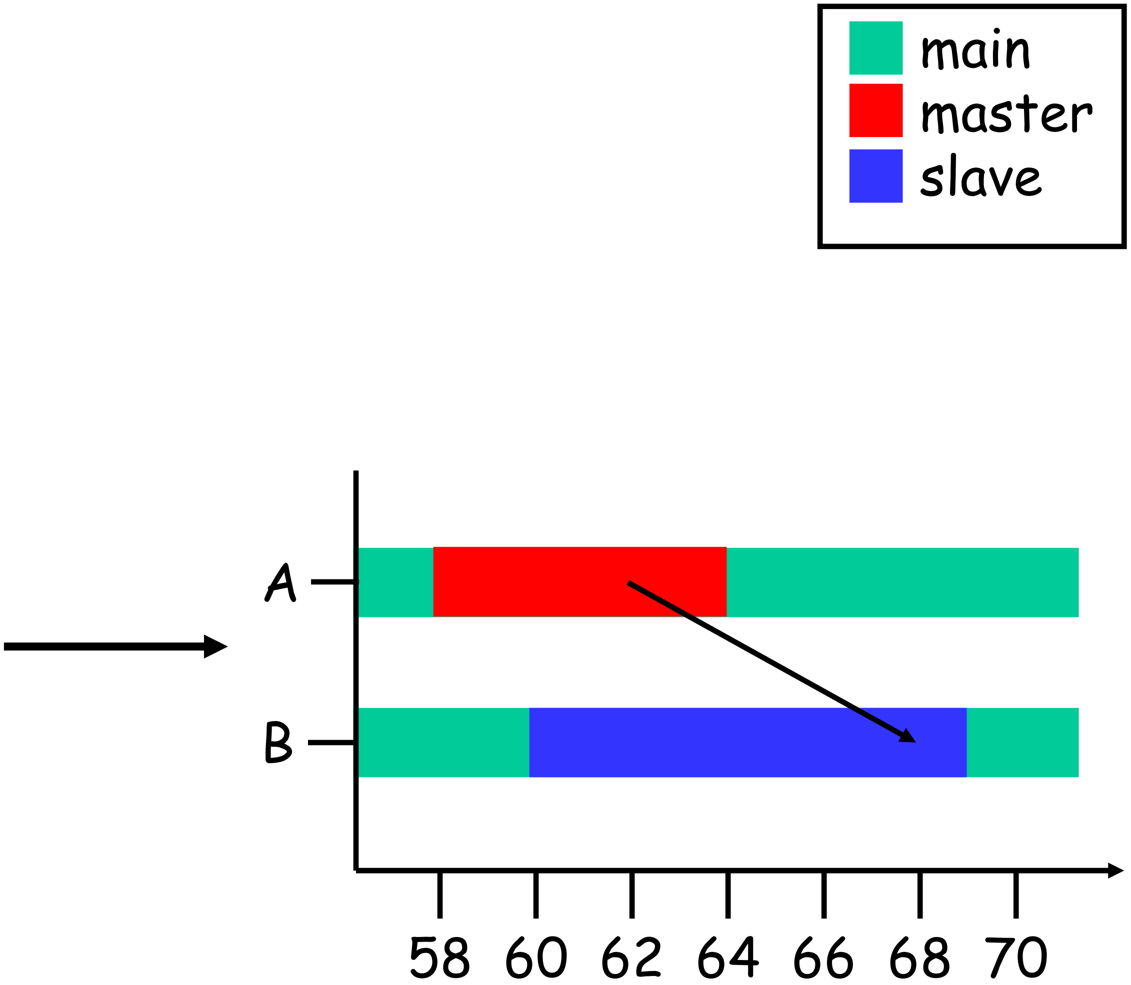
1	master
2	slave
3	...

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

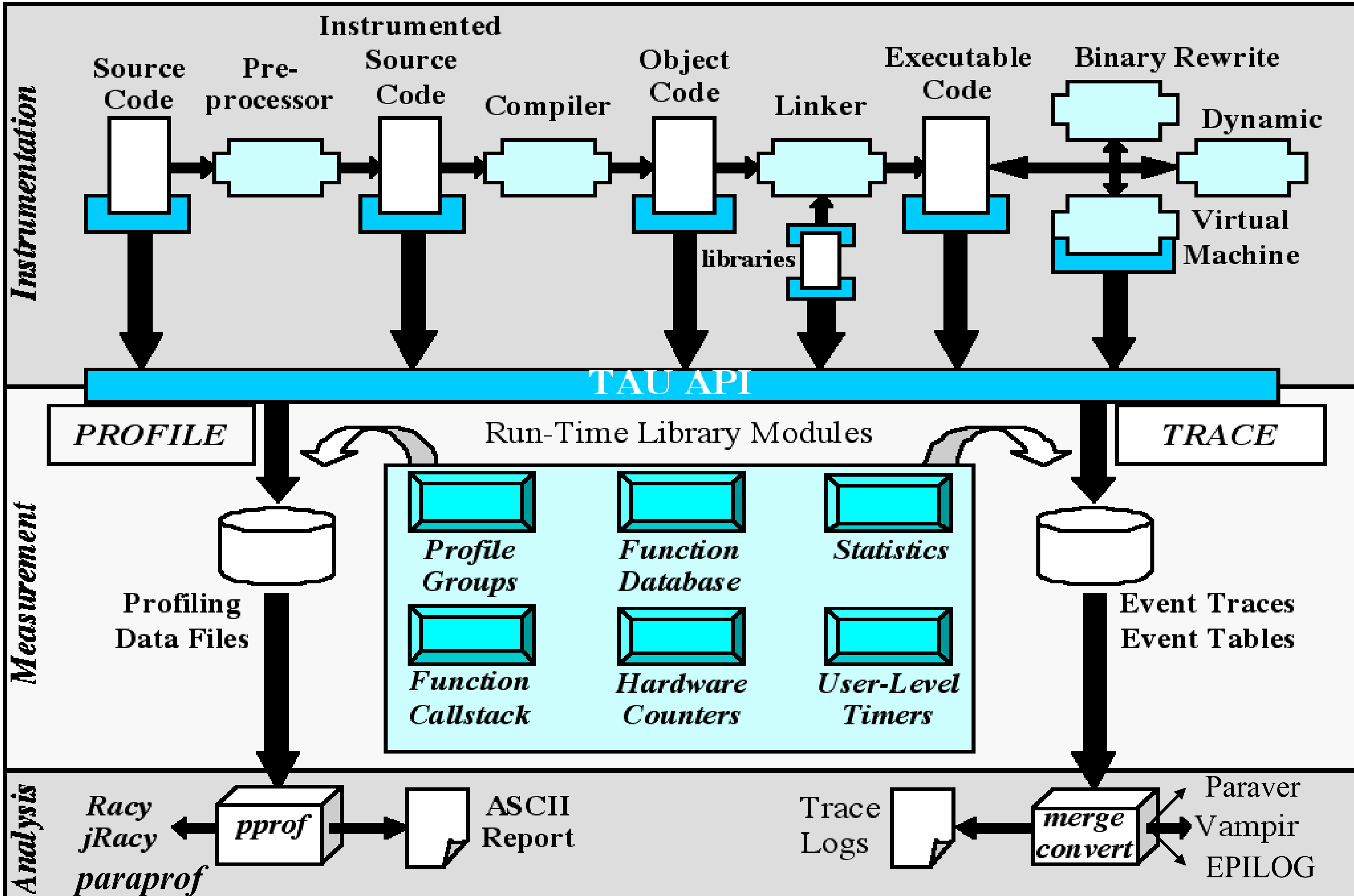
Event Tracing: "Timeline" Visualization

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
...			



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 options 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 (eliminate instrumentation in lightweight routines)

TAU Instrumentation

- Flexible instrumentation mechanisms at multiple levels
  - Source code
    - manual (TAU API, TAU Component API)
    - 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*)
  - Proxy Components

Using TAU – A tutorial

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

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
  - -vtf=<dir> — Specify location of VTF3 trace package

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

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 [UTK, FZJ], an automated bottleneck detection tool. Part of KOJAK (CUBE, EPILOG, Opari).
- Opari – Tool that instruments OpenMP programs
- Vampir – Commercial trace visualization tool [Intel]
- Paraver – Trace visualization tool [CEPBA]

PAPI Overview

- **P**erformance **A**pplication **P**rogramming **I**nterface
  - The purpose of the PAPI project is to design, standardize and implement a portable and efficient API to access the hardware performance monitor counters found on most modern microprocessors.
- Parallel Tools Consortium project
- University of Tennessee, Knoxville
- http://icl.cs.utk.edu/papi

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
  - name of merged trace file, retain intermediate trace files, etc.
- Execute application

  % mpirun –np <procs> a.out;
- Analyze performance data
  - paraprof, vampir, pprof, paraver …

Using TAU – A tutorial

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  - OpenMP – Directive rewriting
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    - Java – Runtime instrumentation
    - Python – Runtime instrumentation
- Measurement
- Performance Analysis

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 – 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
  - TAU_COMPILER — Instrument using tau_compiler.sh script

Note: Not including TAU_DEFS in CFLAGS disables instrumentation in C/C++ programs (TAU_DISABLE for f90).

Including TAU Makefile - F90 Example

```
include /usr/common/acts/TAU/tau-2.13.7/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 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++=xlC_r
  -cc=xlc_r -pdt=/usr/common/acts/TAU/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

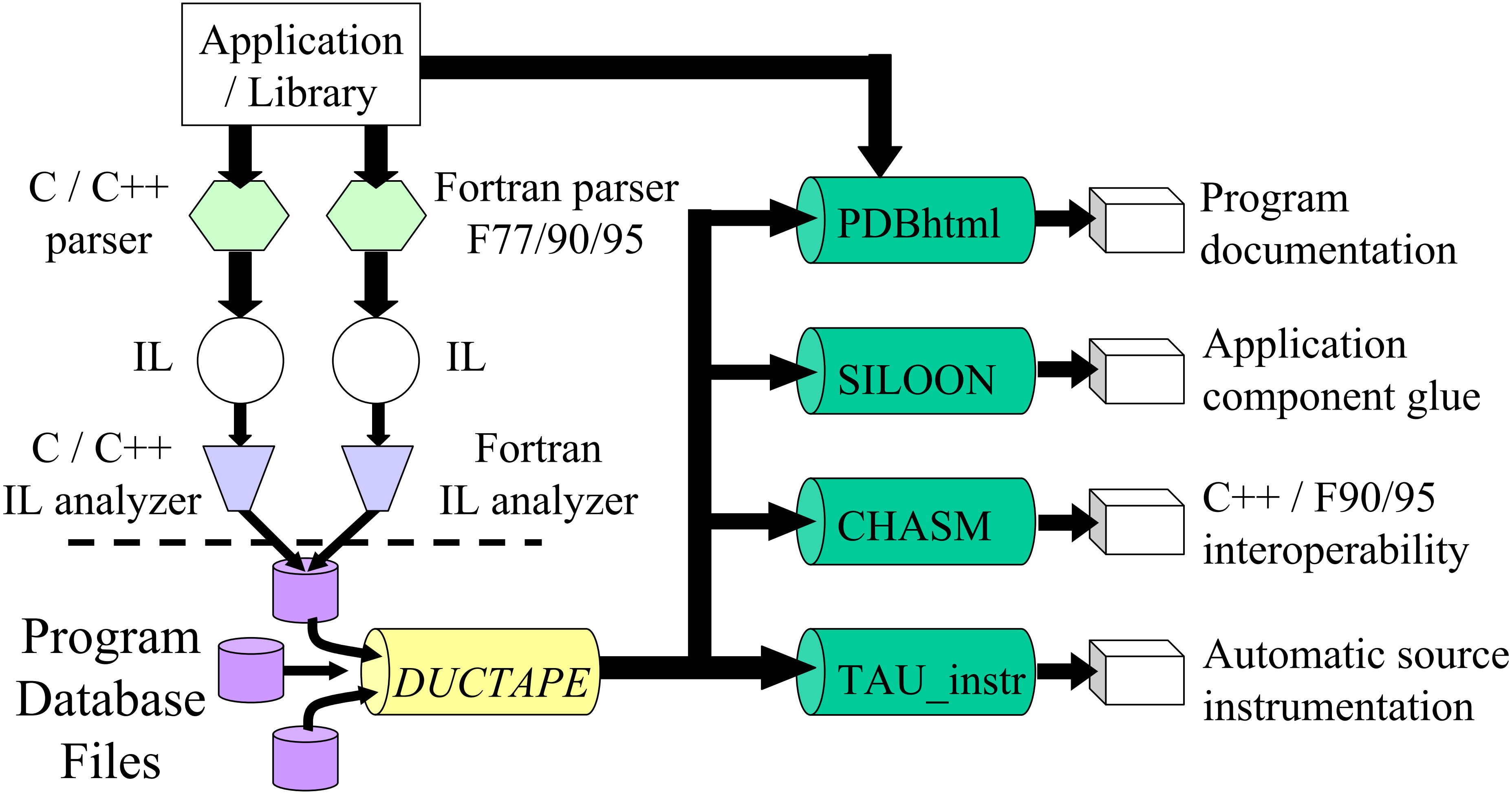
Including TAU's stub Makefile

```
include /usr/common/acts/TAU/tau-2.13.7/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 $@
```

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

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 $@;
```

Taming Growing Complexity of Rules

```
ifdef ESMF_TAU
include /home/users/sameer/TAU/tau-2.13.6/ibm64/lib/Makefile.tau-callpath-mpi-compensate-pdt
endif

...
.c.o:
ifdef PDTDIR
        -echo "Using TAU/PDT to instrument $<: Building .c.o"
        -$(PDTCPARSE) $< ${CFLAGS} ${CPPFLAGS} ${TAU_ESMC_INCLUDE} ${TAU_MPI_INCLUDE}
        -if [ -f $*.pdb ] ; then $(TAUINSTR) $*.pdb $< -o $*.inst.c -f ${TAU_SELECT_FILE}  ; fi;
        -${CC} -c ${COPTFLAGS} ${CFLAGS} ${CCPPFLAGS} ${ESMC_INCLUDE} $(TAU_DEFS) $(TAU_INCLUDE) $(TAU_MPI_INCLUDE) $*.inst.c
        if [ ! -f $*.o ] ; then ${CC} -c ${COPTFLAGS} ${CFLAGS} ${CCPPFLAGS} ${ESMC_INCLUDE} $< ; fi ;
else
        ${CC} -c ${COPTFLAGS} ${CFLAGS} ${CCPPFLAGS} ${ESMC_INCLUDE} $<
endif
```

AutoInstrumentation using TAU_COMPILER

- $(TAU_COMPILER) stub Makefile variable (v2.13.7+)
- Invokes PDT parser, TAU instrumentor, compiler through `tau_compiler.sh` shell script
- Requires minimal changes to application Makefile
  - Compilation rules are not changed
  - User adds $(TAU_COMPILER) before compiler name
    - F90=mpxlf90
      Changes to
      F90= $(TAU_COMPILER) mpxlf90
- Passes options from TAU stub Makefile to the four compilation stages
- Uses original compilation command if an error occurs

TAU_COMPILER Commandline Options

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

```
% mpxlf90 -c foo.f90
```

  Changes to

```
% f95parse foo.f90 $(OPT1)
% tau_instrumentor foo.pdb foo.f90
                  -o foo.inst.f90 $(OPT2)
% mpxlf90 -c foo.f90 $(OPT3)
```

- Linking:

```
% mpxlf90 foo.o bar.o -o app
```

  Changes to

```
% mpxlf90 foo.o bar.o -o app $(OPT4)
```

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

```
F90 = $(TAU_COMPILER) $(MYOPTIONS) mpxlf90
```

Using TAU_COMPILER

```
include /usr/common/acts/TAU/tau-2.13.7/rs6000/lib/
Makefile.tau-mpi-pdt


F90 = $(TAU_COMPILER) mpxlf90
OBJS = f1.o f2.o f3.o …
LIBS = -Lappdir -lapplib

app: $(OBJS)
    $(F90) $(OBJS) -o app $(LIBS)

.f90.o:
    $(F90) -c $<
```

Overriding Default Options:TAU_COMPILER

```
include /usr/common/acts/TAU/tau-2.13.7/rs6000/lib/
                                  Makefile.tau-mpi-pdt-trace

MYOPTIONS= -optVerbose -optKeepFiles

F90 = $(TAU_COMPILER) $(MYOPTIONS) mpxlf90
OBJS = f1.o f2.o f3.o …
LIBS = -Lappdir -lapplib1 -lapplib2 …

app: $(OBJS)
    $(F90) $(OBJS) -o app $(LIBS)

.f90.o:
    $(F90) -c $<
```

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
```

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

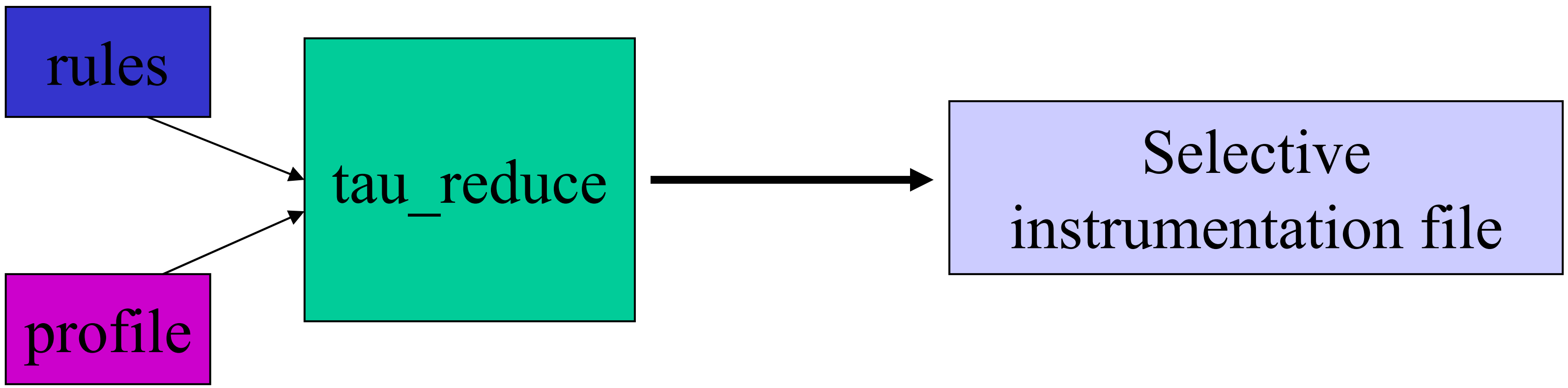
  - *GroupName* indicates rule applies to events in group
  - *Field* is a event metric attribute (from profile statistics)
    - numcalls, numsubs, percent, usec, cumusec, count [PAPI], totalcount, stdev, usecs/call, counts/call
  - *Operator* is one of >, <, or =
  - *Number* is any number
  - Compound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

Example 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**

TAU_REDUCE

- Reads profile files and rules
- Creates selective instrumentation file
  - Specifies which routines should be excluded from instrumentation



Using TAU – A tutorial

- Configuration
- Instrumentation
  - Manual
  - MPI – Wrapper interposition library
  - PDT- Source rewriting for C,C++, F77/90/95
  - OpenMP – Directive rewriting
  - Component based instrumentation – Proxy components
  - Binary Instrumentation
    - DyninstAPI – Runtime Instrumentation/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: 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 $(TAU_LIBS)

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

CCA Performance Observation Component

- Common Component Architecture for Scientific Components [www.cca-forum.org]
- Design measurement port and measurement interfaces
  - Timer
    - start/stop
    - set name/type/group
  - Control
    - enable/disable groups
  - Query
    - get timer names
    - metrics, counters, dump to disk
  - Event
    - user-defined events

CCA C++ (CCAFFEINE) Performance Interface

```
namespace performance {
 namespace ccaports {
  class Measurement: public virtual classic::gov::cca::Port {
   public:
    virtual ~ Measurement (){}

    /* Create a Timer interface */
    virtual performance::Timer* createTimer(void) = 0;
    virtual performance::Timer* createTimer(string name) = 0;
    virtual performance::Timer* createTimer(string name, string type) = 0;
    virtual performance::Timer* createTimer(string name, string type,
         string group) = 0;

    /* Create a Query interface */
    virtual performance::Query* createQuery(void) = 0;

    /* Create a user-defined Event interface */
    virtual performance::Event* createEvent(void) = 0;
    virtual performance::Event* createEvent(string name) = 0;

    /* Create a Control interface for selectively enabling and disabling
     * the instrumentation based on groups */
    virtual performance::Control* createControl(void) = 0;
  };
 }
}
```

Measurement port

Measurement interfaces

CCA Timer Interface Declaration

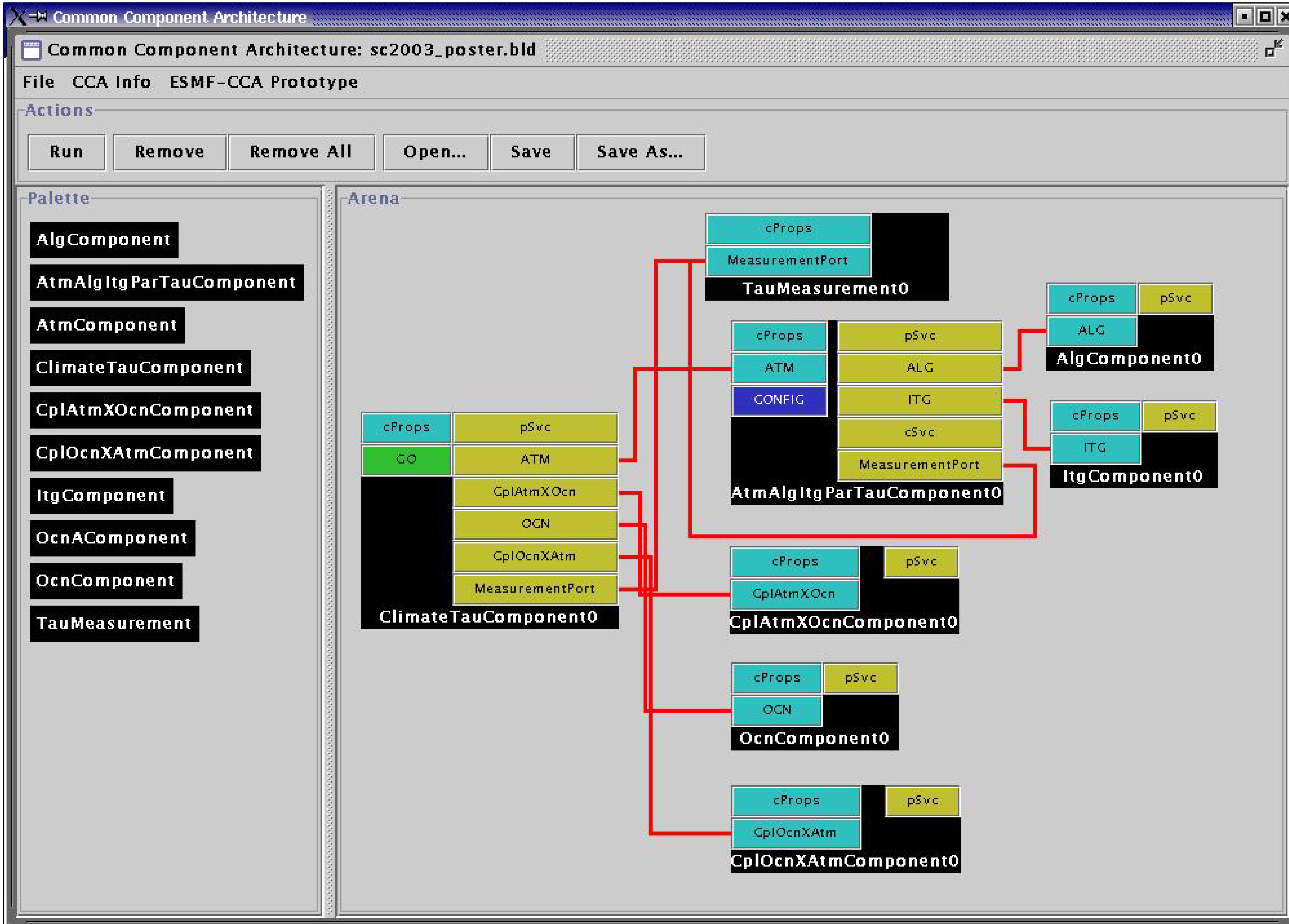
```
namespace performance {
 class Timer {
  public:
   virtual ~Timer() {}

   /* Implement methods in a derived class to provide functionality */

   /* Start and stop the Timer */
   virtual void start(void) = 0;
   virtual void stop(void) = 0;

   /* Set name and type for Timer */
   virtual void setName(string name) = 0;
   virtual string getName(void) = 0;
   virtual void setType(string name) = 0;
   virtual string getType(void) = 0;

   /* Set the group name and group type associated with the Timer */
   virtual void setGroupName(string name) = 0;
   virtual string getGroupName(void) = 0;
   virtual void setGroupId(unsigned long group ) = 0;
   virtual unsigned long getGroupId(void) = 0;
 };
}
```

Timer interface methods

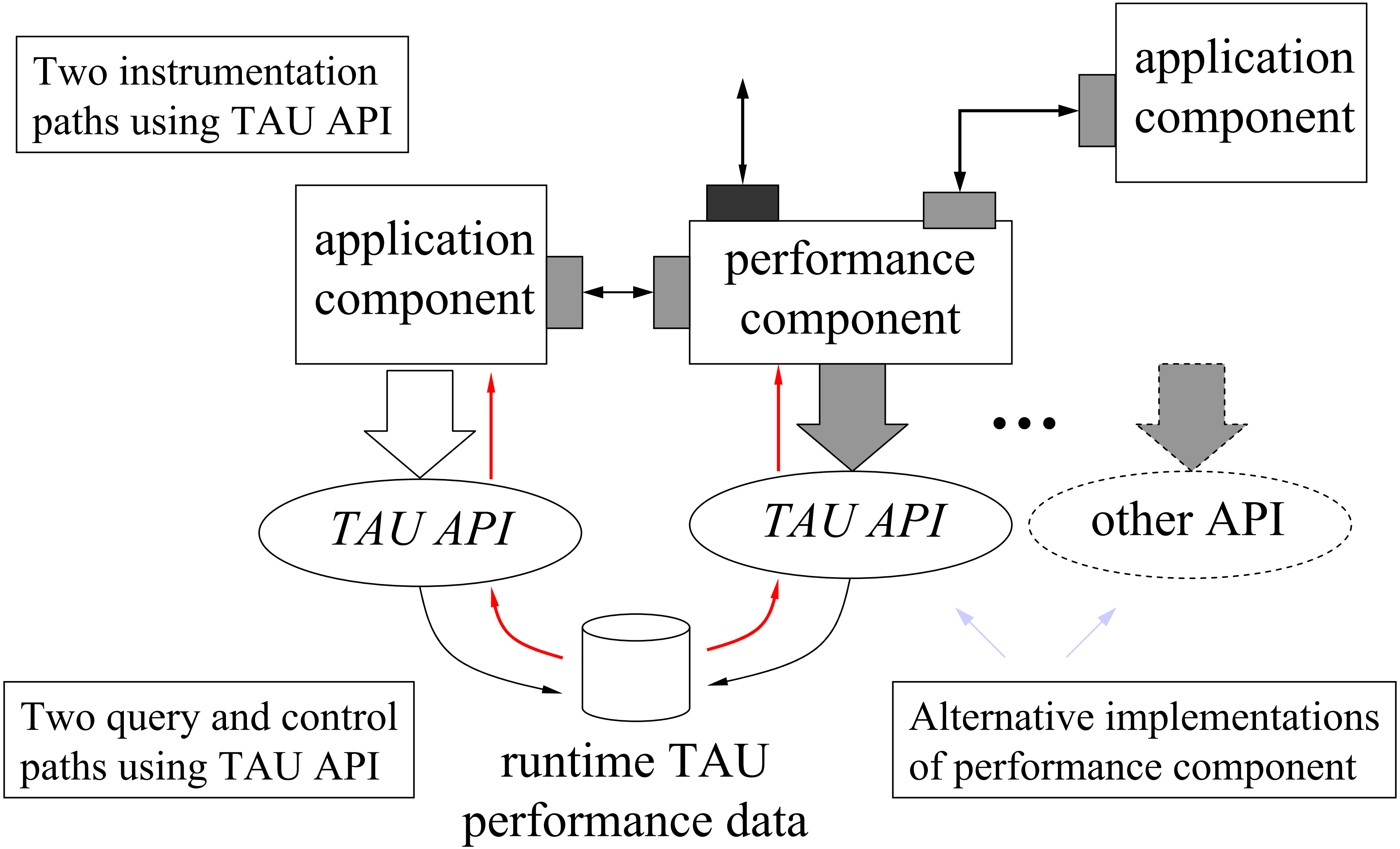
Use of Observation Component in CCA Example

```
#include "ports/Measurement_CCA.h"
...
double MonteCarloIntegrator::integrate(double lowBound, double upBound,
                                       int count) {
  classic::gov::cca::Port * port;
  double sum = 0.0;
  // Get Measurement port
  port = frameworkServices->getPort ("MeasurementPort");
  if (port)
    measurement_m = dynamic_cast < performance::ccaports::Measurement * >(port);
  if (measurement_m == 0){
    cerr << "Connected to something other than a Measurement port";
    return -1;
  }
  static performance::Timer* t = measurement_m->createTimer(
                                           string("IntegrateTimer"));
  t->start();
  for (int i = 0; i < count; i++) {
     double x = random_m->getRandomNumber ();
     sum = sum + function_m->evaluate (x);
  }
  t->stop();
}
```

Using TAU Component in ESMF/CCA [S. Zhou]

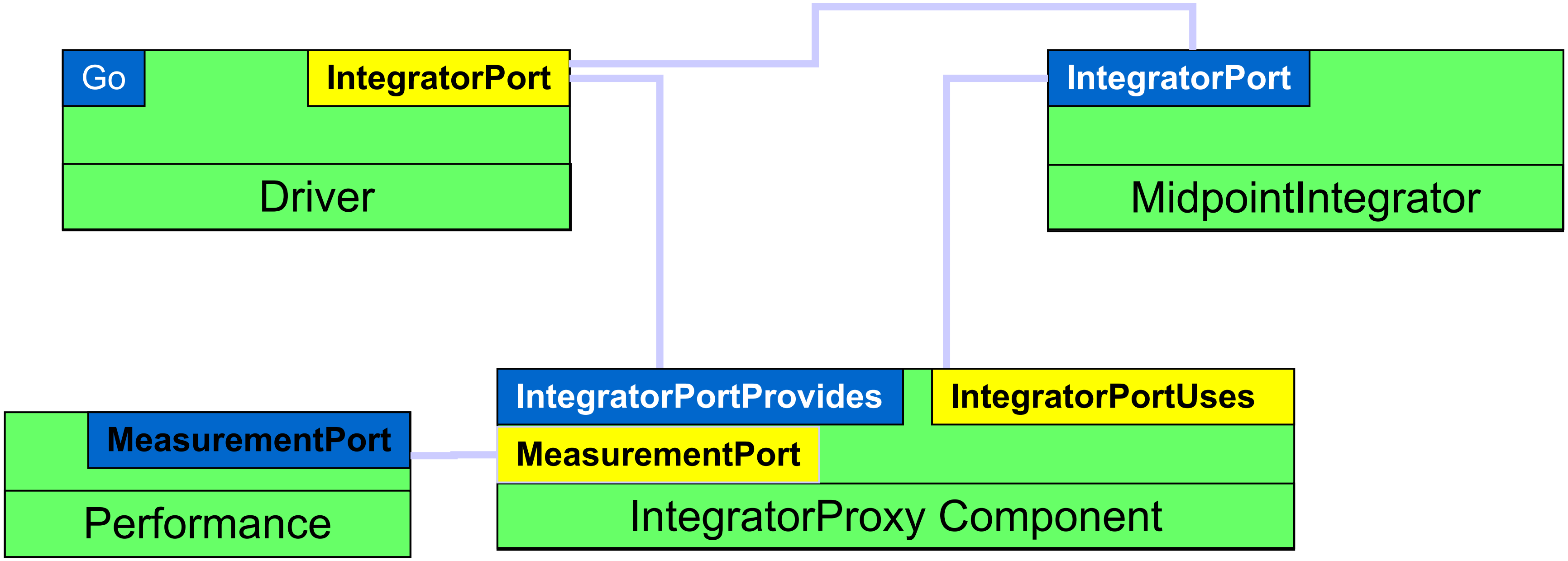


What's Going On Here?



Proxy Component

- Interpose a proxy component for each port
- Inside the proxy, track caller/callee invocations, timings
- Automate the process of proxy component creation
  - Using PDT for static analysis of components



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)

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):

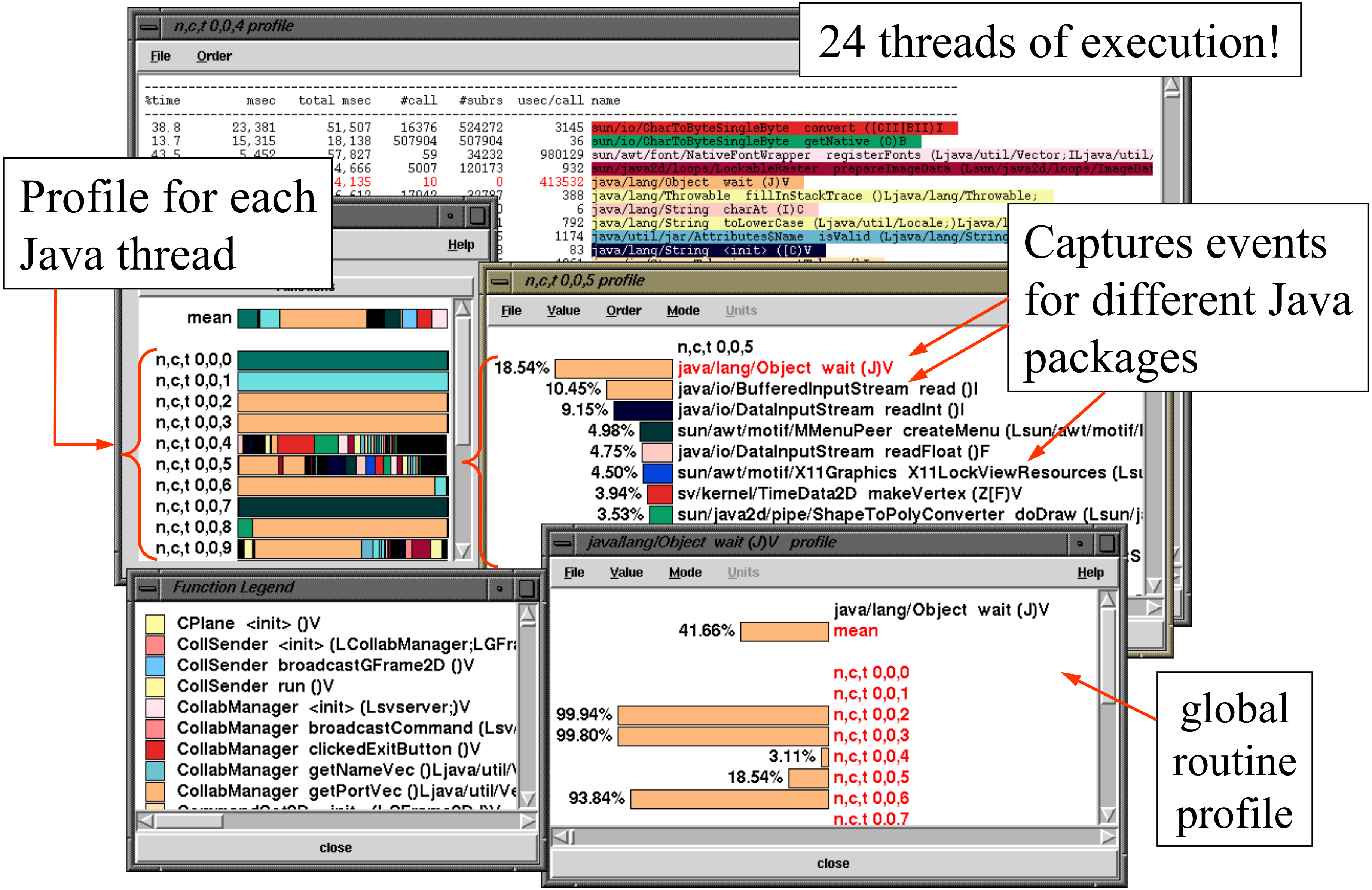
```
% java application
```

With instrumentation:

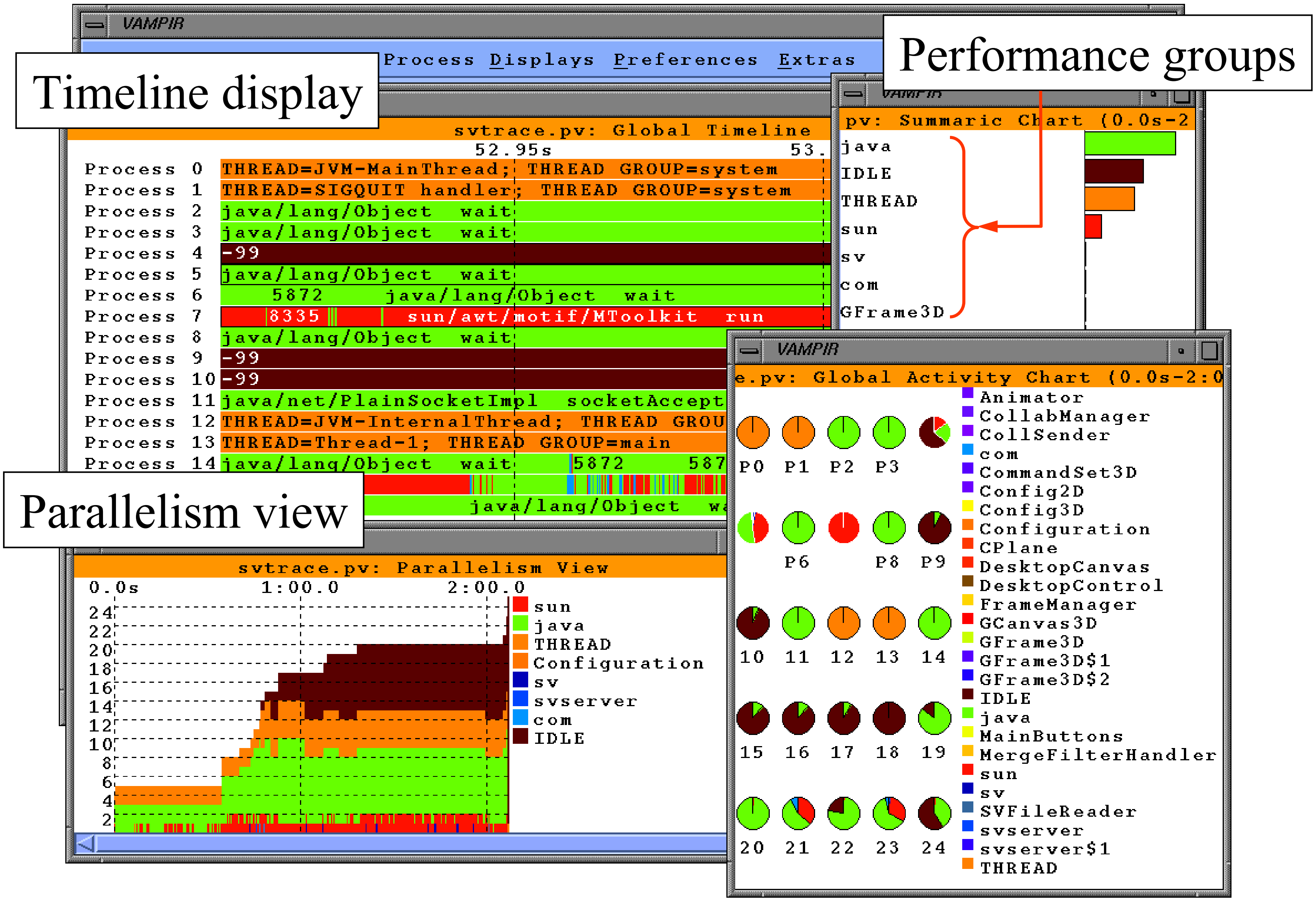
```
% java -XrunTAU application
% java -XrunTAU:exclude=sun/io,java application
```

Excludes sun/io/* and java/* classes

TAU Profiling of Java Application (SciVis)



TAU Tracing of Java Application (SciVis)



Vampir Dynamic Call Tree View (SciVis)

Per thread call tree

Expanded call tree

Annotated performance

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…
```

TAU Performance Measurement

- TAU supports profiling and tracing measurement
- TAU supports tracking application memory utilization
- 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

Memory Profiling in TAU

- Configuration option –PROFILEMEMORY
  - Records global heap memory utilization for each function
  - Takes one sample at beginning of each function and associates the sample with function name
  - Independent of instrumentation/measurement options selected
  - No need to insert macros/calls in the source code
  - User defined atomic events appear in profiles/traces
  - For Traces, see Vampir's Global Displays->CounterTimeline to view memory samples

Memory Profiling in TAU

- Instrumentation based observation of global heap memory (not per function)
  - call TAU_TRACK_MEMORY()
    - Triggers one sample every 10 secs
  - call TAU_TRACK_MEMORY_HERE()
    - Triggers sample at a specific location in source code
  - call TAU_SET_INTERRUPT_INTERVAL(seconds)
    - To set inter-interrupt interval for sampling
  - call TAU_DISABLE_TRACKING_MEMORY()
    - To turn off recording memory utilization
  - call TAU_ENABLE_TRACKING_MEMORY()
    - To re-enable tracking memory utilization

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

```
include /usr/common/acts/TAU/tau-2.13.7/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 for C/C++

```
#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>

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

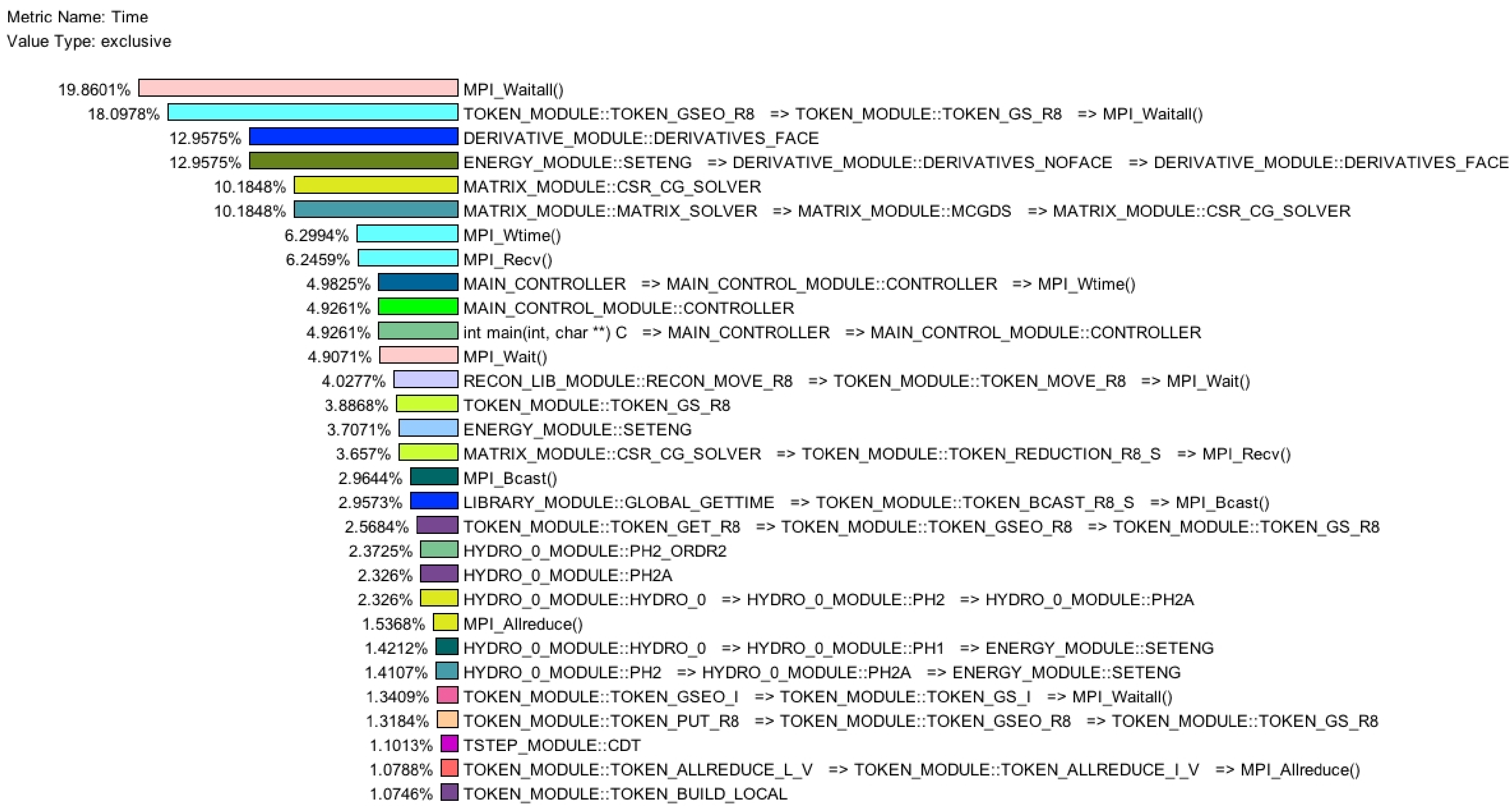
Performance Mapping in Callpath Profiling

- 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
- Callpath profiling when callgraph is unknown
  - Must determine callgraph dynamically at runtime
  - Map performance measurement to dynamic call path state
- Callpath levels
  - 1-level: current callgraph node/flat profile
  - 2-level: immediate parent (descendant)
  - *k*-level: *k*th nodes in the calling path

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

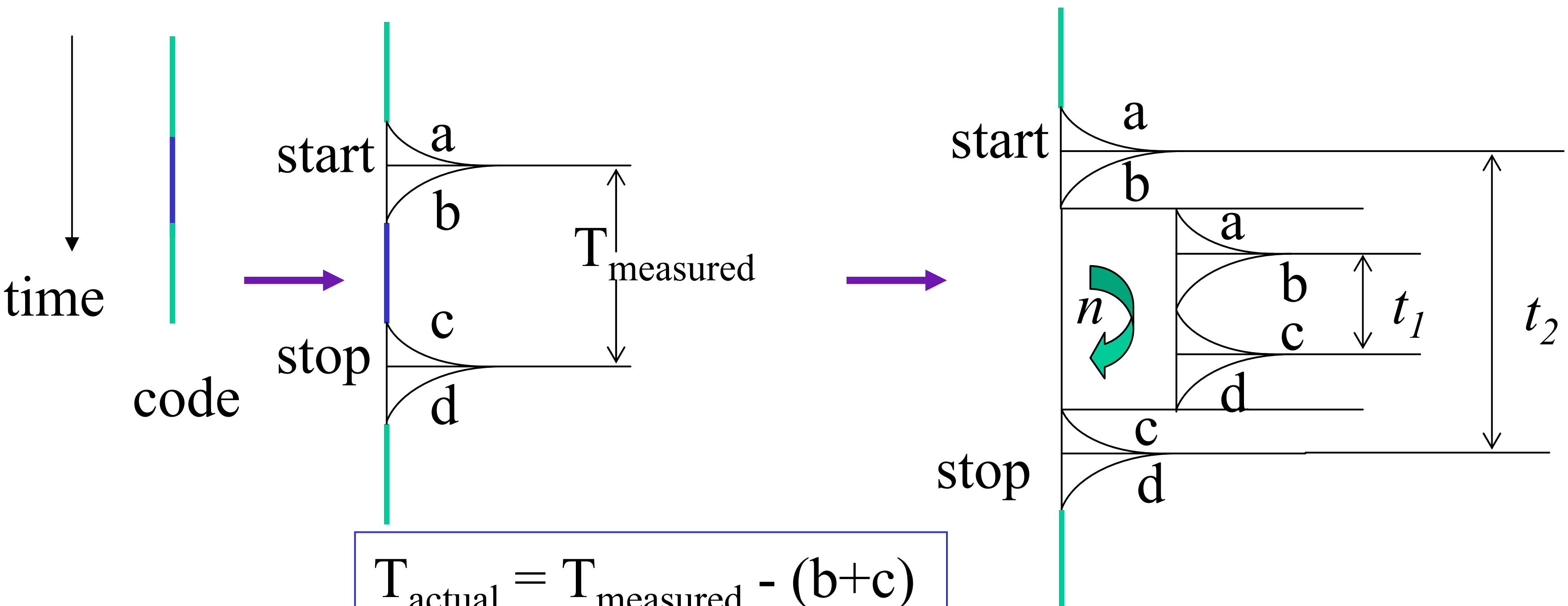
```
Metric Name: Time
Sorted By: exclusive
Units: seconds

    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)



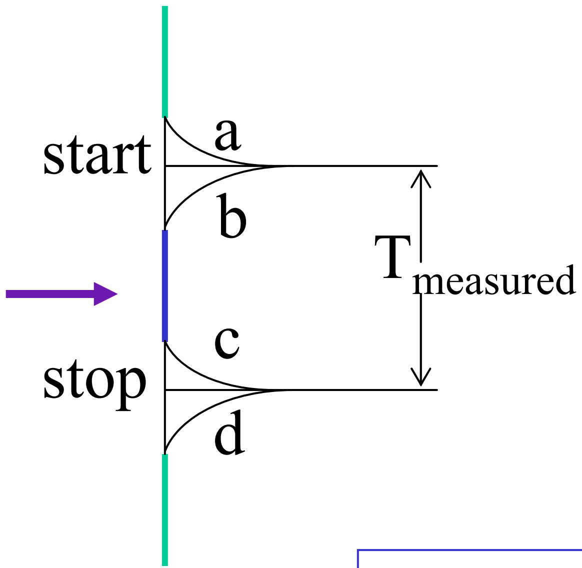
$$T_{actual} = T_{measured} - (b+c)$$

$$t_1 = n * (b+c)$$
$$t_2 = b+n*(a+b+c+d)+c$$

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

Recalculating Inclusive Time

- Number of children/grandchildren… nodes
- Traverse callstack



main
=>
f1
=> f2
…
f3
=> f4

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

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()

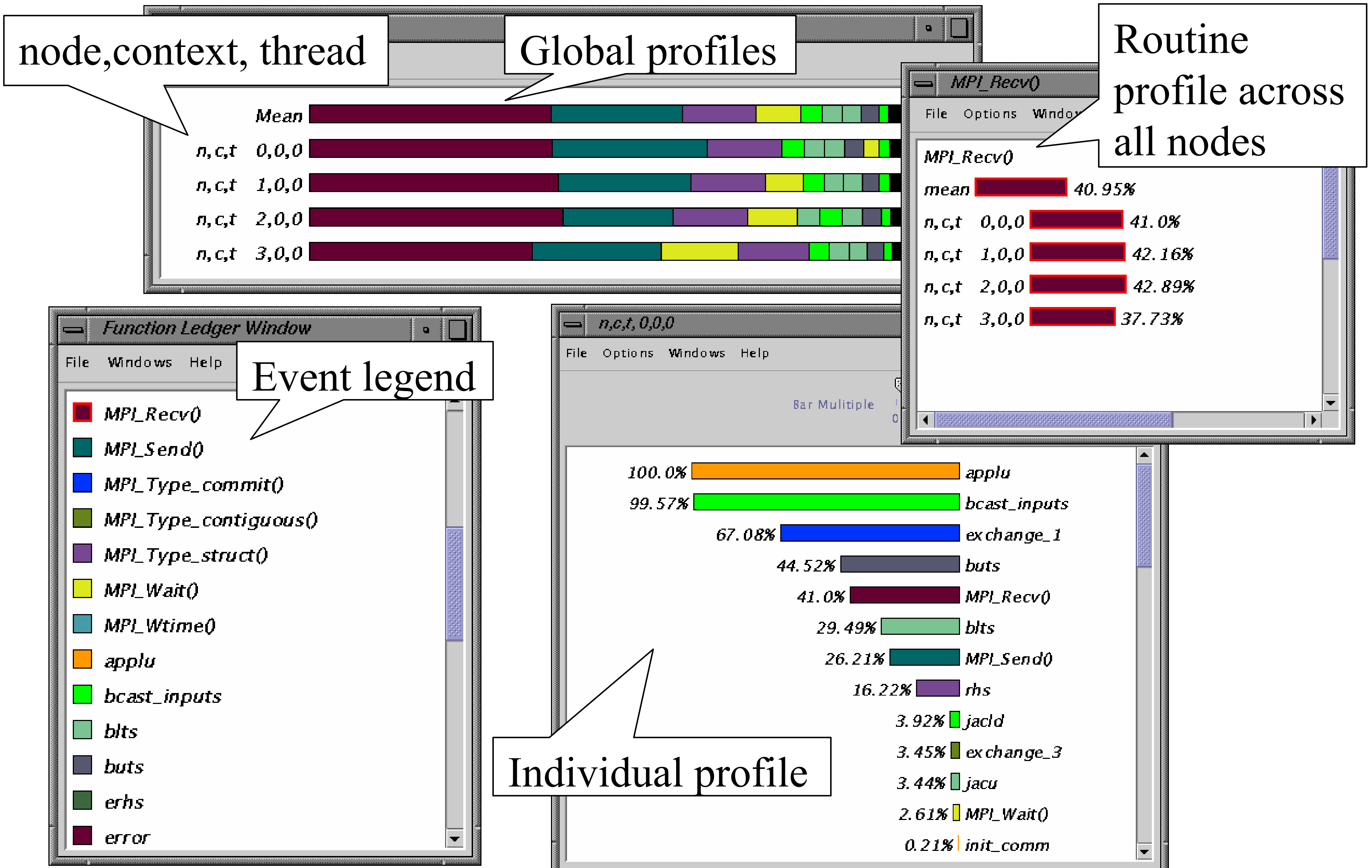
--:-- NPB_LU.out (Fundamental)--L8--Top--

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

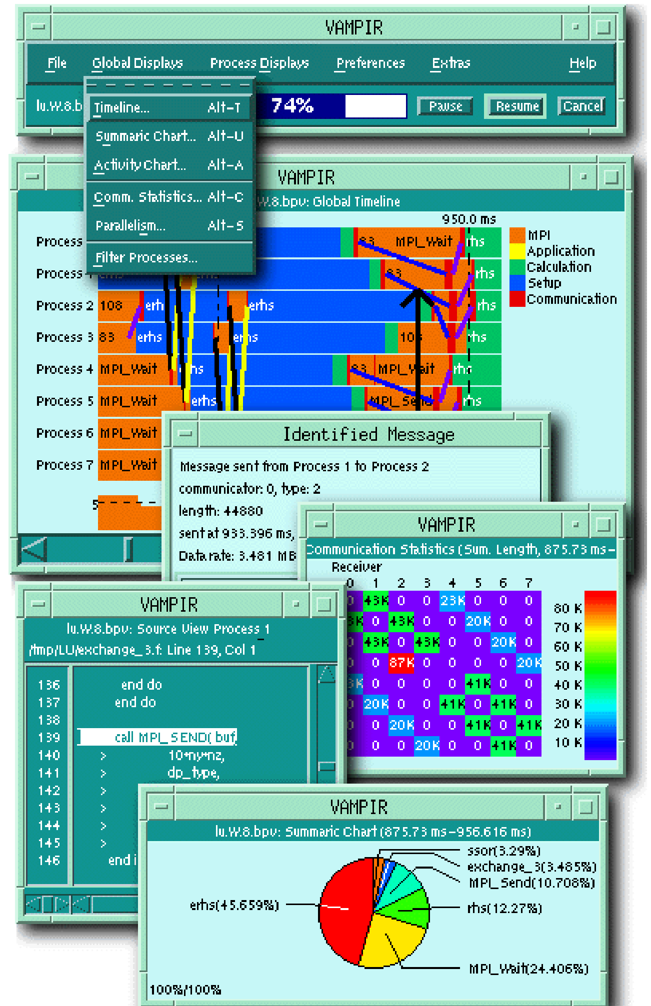
```
int main( )
{ /* takes 100 secs */

  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)

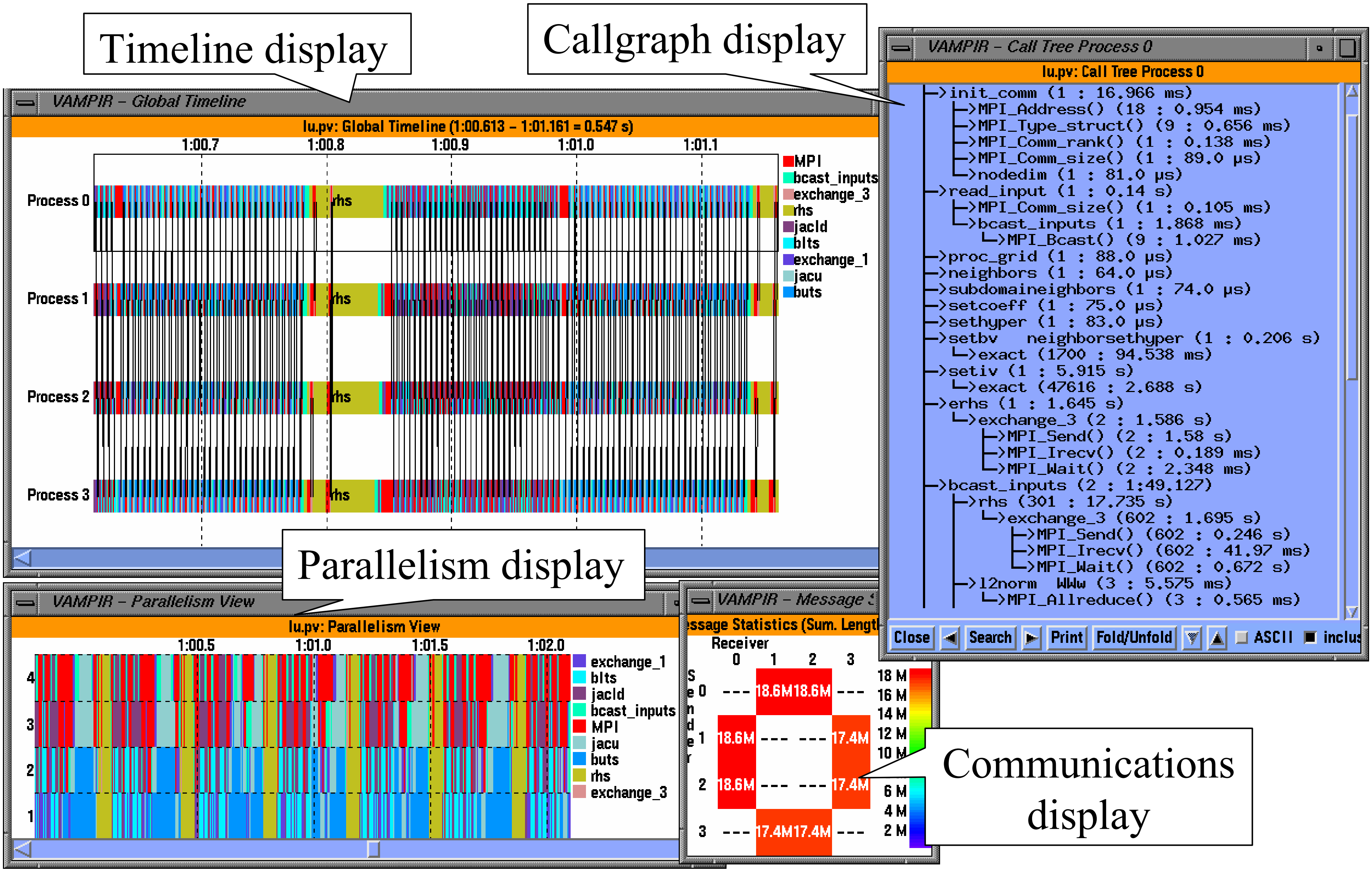


Intel Trace Analyzer/Vampir Trace Visualizer

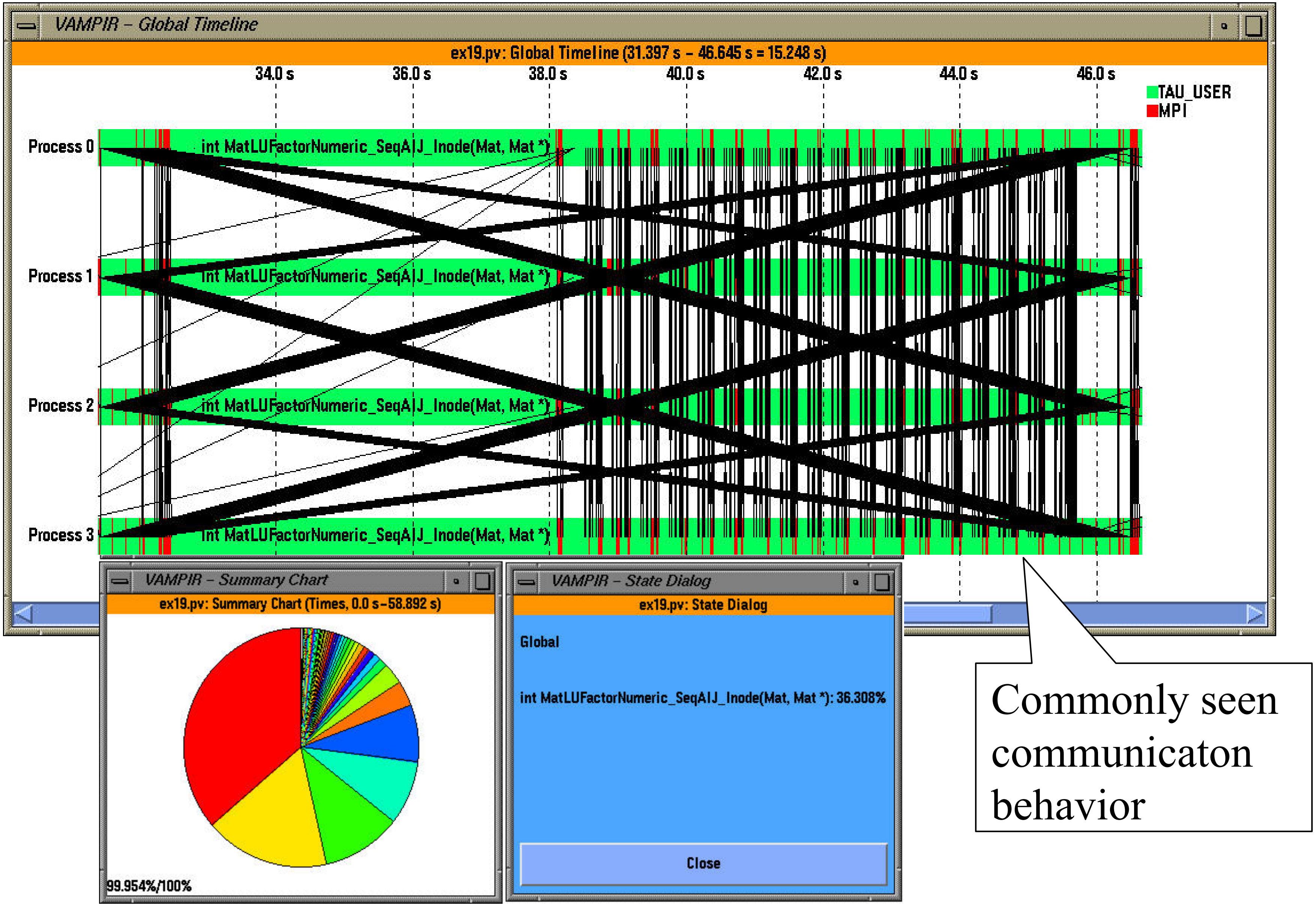
- Visualization and Analysis of MPI Programs
- Originally developed by Forschungszentrum Jülich
- Current development by Technical University Dresden, Germany
- Distributed by Intel
- **`http://www.pallas.de/pages/vampir.htm`**



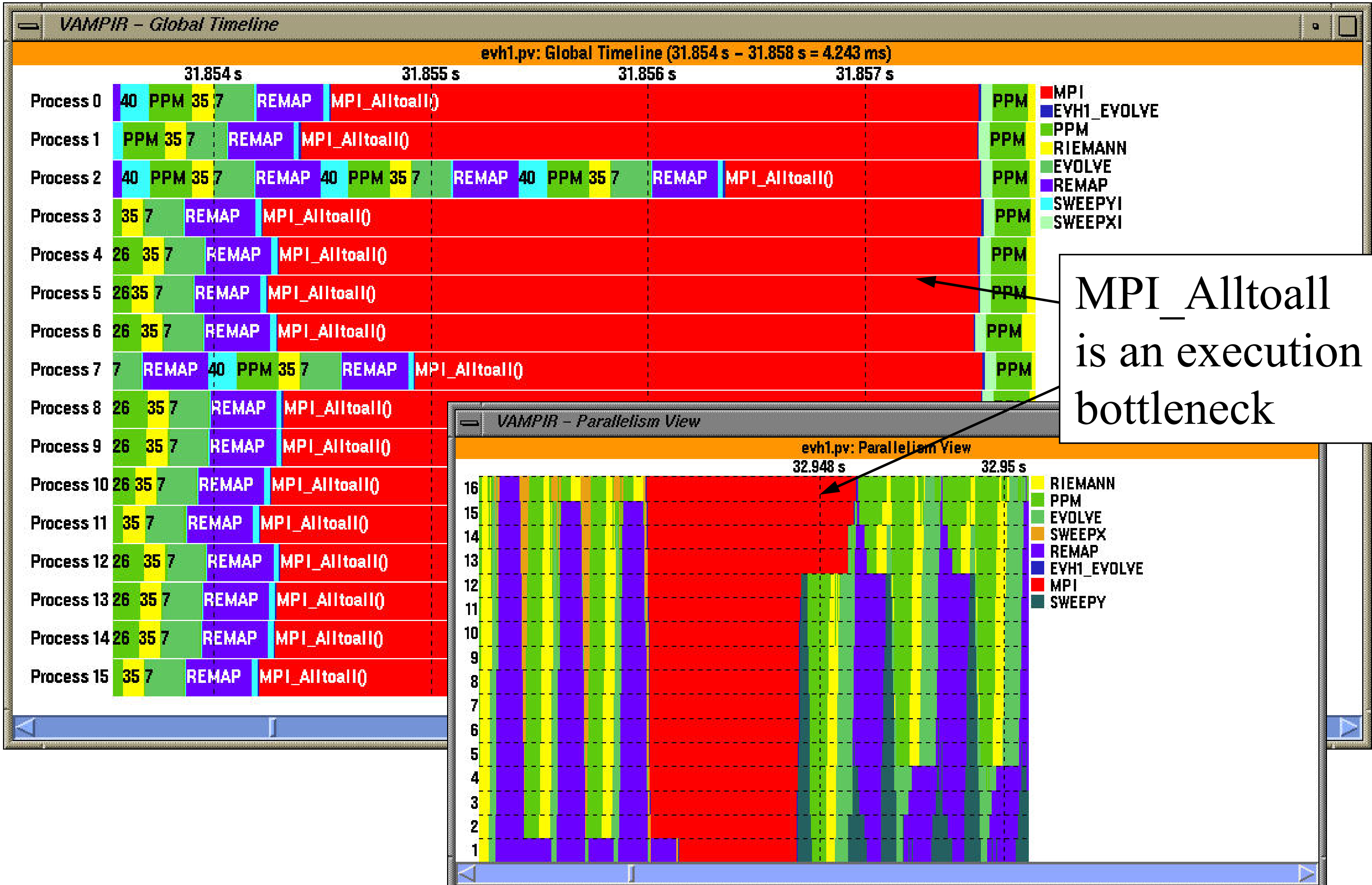
TAU + Vampir (NAS Parallel Benchmark – LU)



PETSc ex19 (Tracing)



TAU's EVH1 Execution Trace in Vampir



Using TAU with Vampir

- Configure TAU with -TRACE –vtf=dir option

```
% configure -TRACE -vtf=<dir>
  -MULTIPLECOUNTERS -papi=<dir> -mpi
  -pdt=dir …
```

- Set environment variables

```
% setenv TAU_TRACEFILE foo.vpt.gz
% setenv COUNTER1 GET_TIME_OF_DAY (reqd)
% setenv COUNTER2 PAPI_FP_INS…
```

- Execute application (automatic merge/convert)

```
% poe a.out -procs 4
% vampir foo.vpt.gz
```

Using TAU with Vampir

```
include /usr/common/acts/TAU/tau-
2.13.7/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

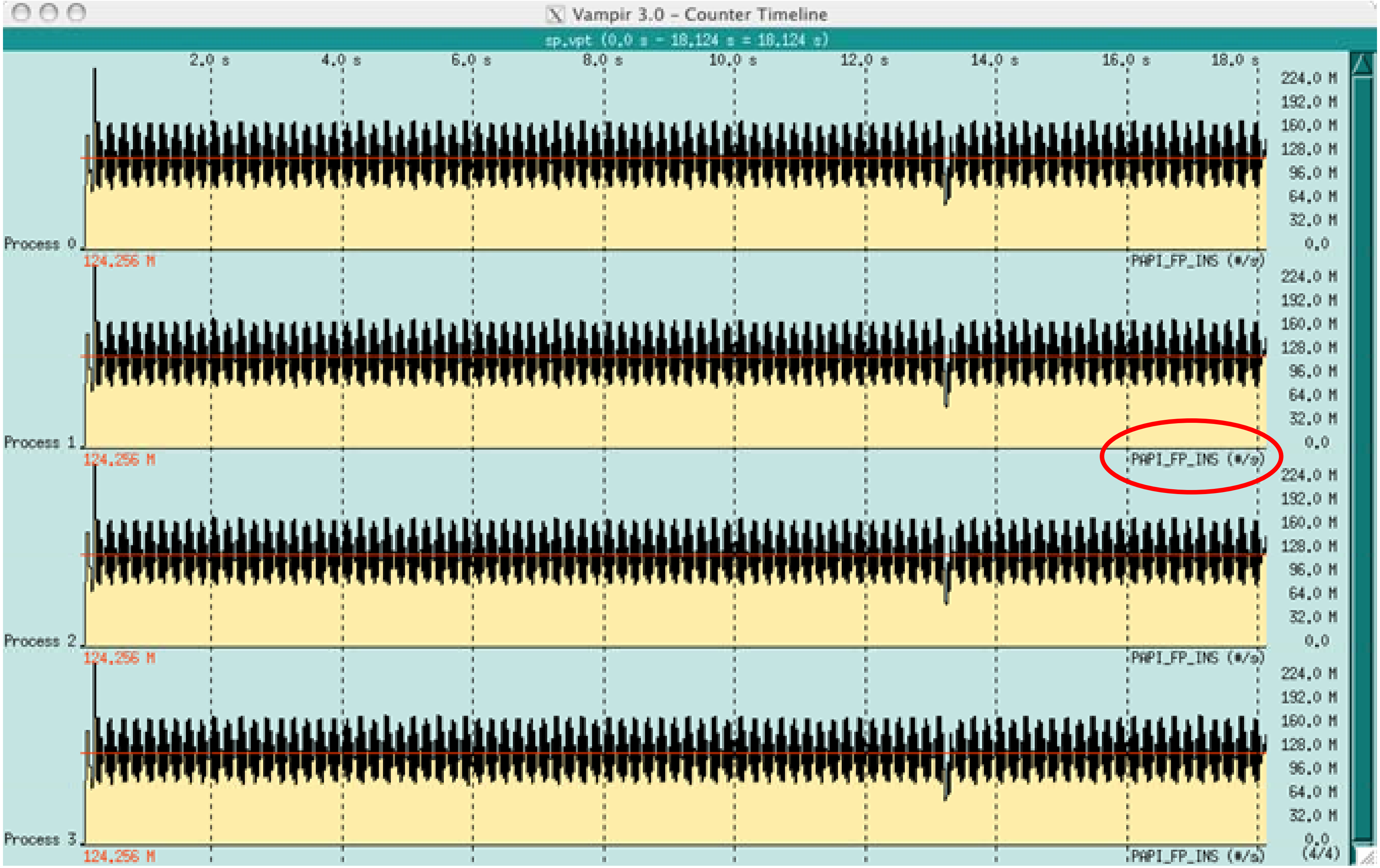
```
% tau_convert -pv app.trc tau.edf app.pv
  (use -vampir if application is multi-threaded)
% vampir app.pv
% tau_convert -paraver app.trc tau.edf app.par
  (use -paraver -t if application is multi-threaded)
% paraver app.par
```

Converting TAU Trace Files using tau2vtf to generate binary VTF3 traces with Hardware performance counter/samples data

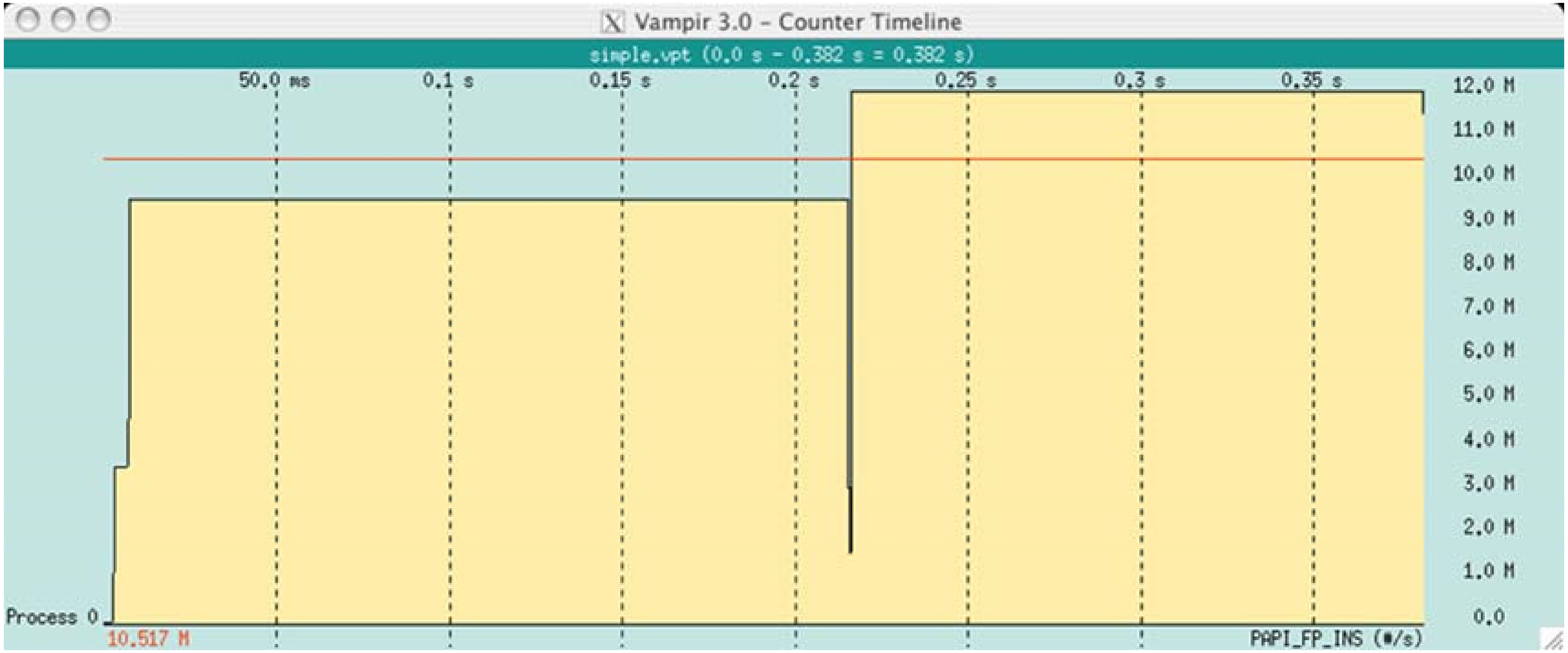
NOTE: must configure TAU with –vtf=dir option in TAU v2.13.7+

```
% tau2vtf app.trc tau.edf app.vpt.gz
% vampir app.vpt.gz
```

Visualizing TAU Traces with Counters/Samples



Visualizing TAU Traces with Counters/Samples



Environment Variables for Generating Traces

- With tau2vtf, TAU can automatically merge/convert traces environment variables:
  - TAU_TRACEFILE (name of the final VTF3 tracefile)
    - Default: not set.

```
% setenv TAU_TRACEFILE app.vpt.gz
```

  - TRACEDIR (directory where traces are stored)
    - Default: ./ or current working directory

```
% setenv TRACEDIR $SCRATCH/data/exp1
```

  - TAU_KEEP_TRACEFILES
    - Default:not set. TAU deletes intermediate trace files

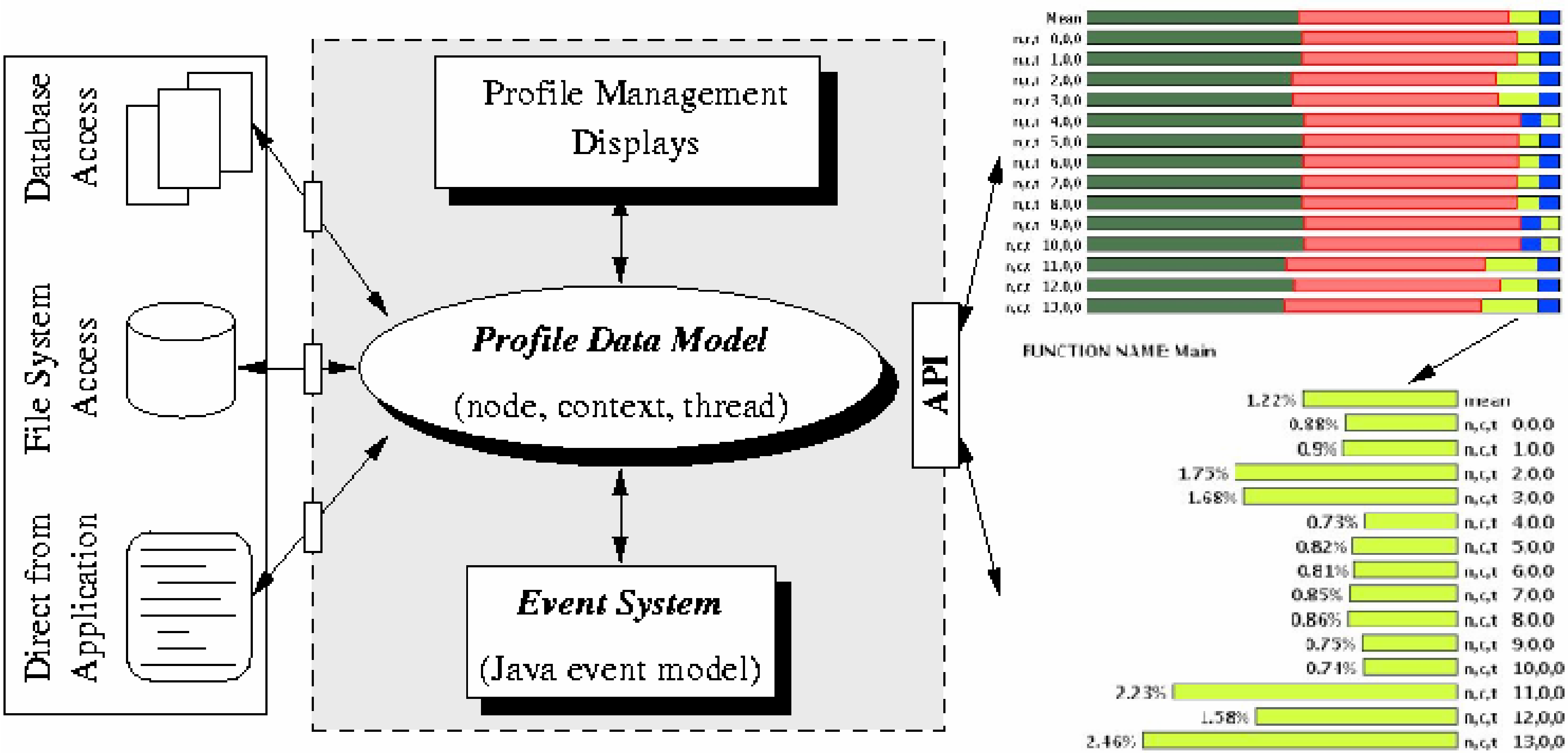
```
% setenv TAU_KEEP_TRACEFILES 1
```

Using TAU's Environment Variables

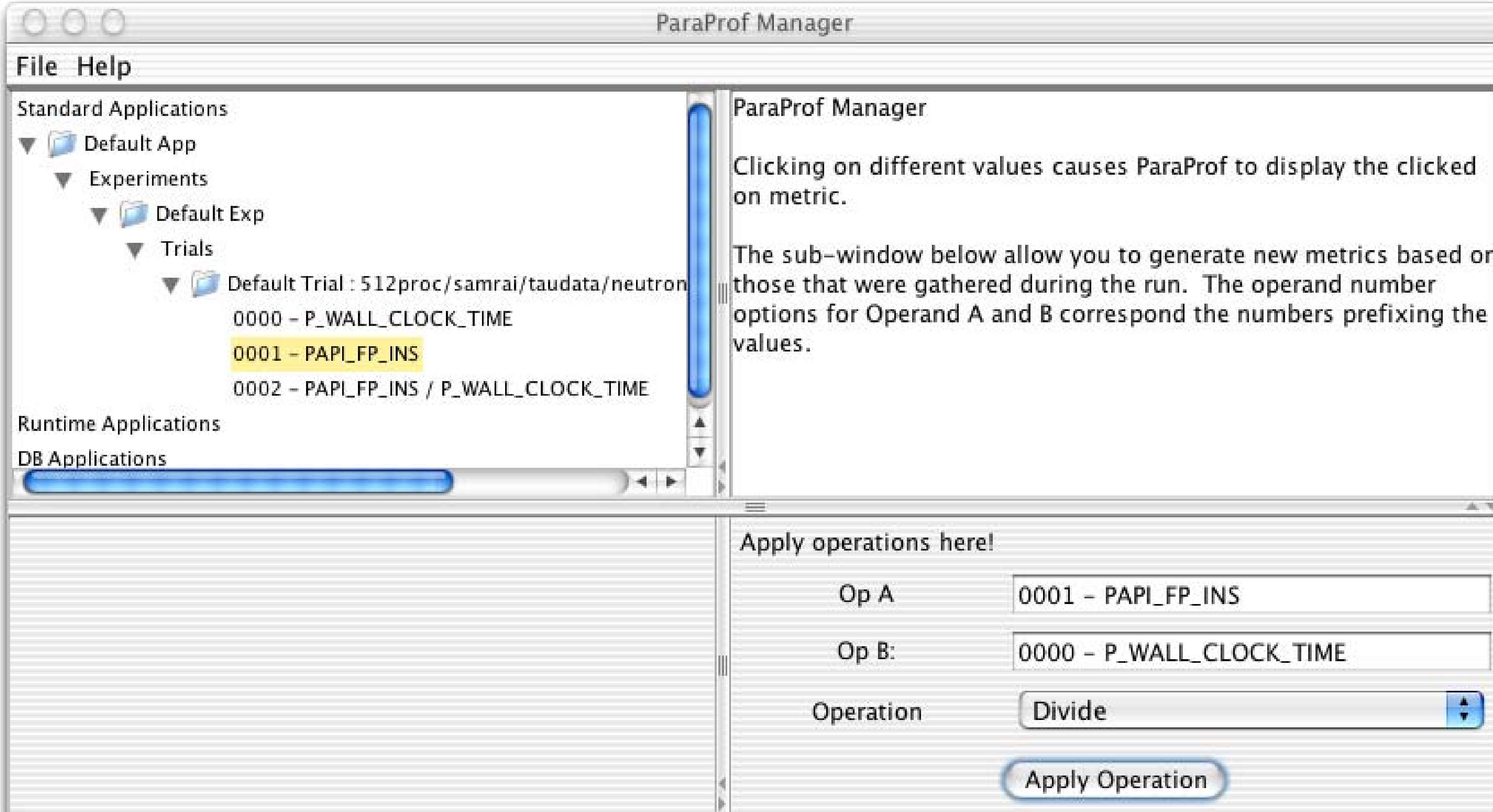
```
% llsubmit job.sh
LoadLeveler script
/usr/bin/csh
#
#...

setenv TAU_TRACEFILE    app.vpt.gz
setenv TRACEDIR         $SCRATCH/data
setenv COUNTER1         GET_TIME_OF_DAY
setenv COUNTER2         PAPI_FP_INS
setenv COUNTER3         PAPI_TOT_CYC
…
./sp.W.4
```

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

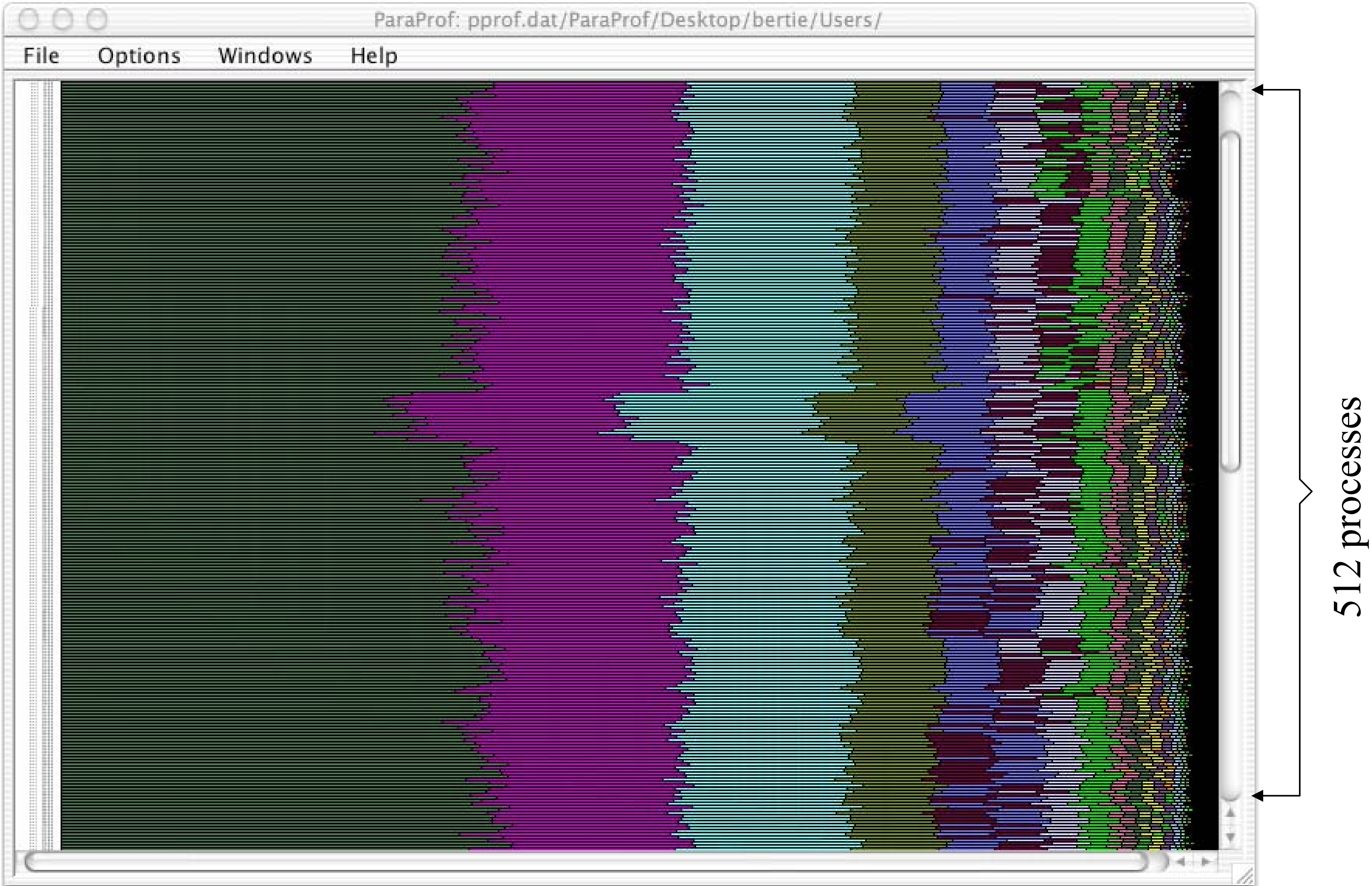


Profile Manager Window

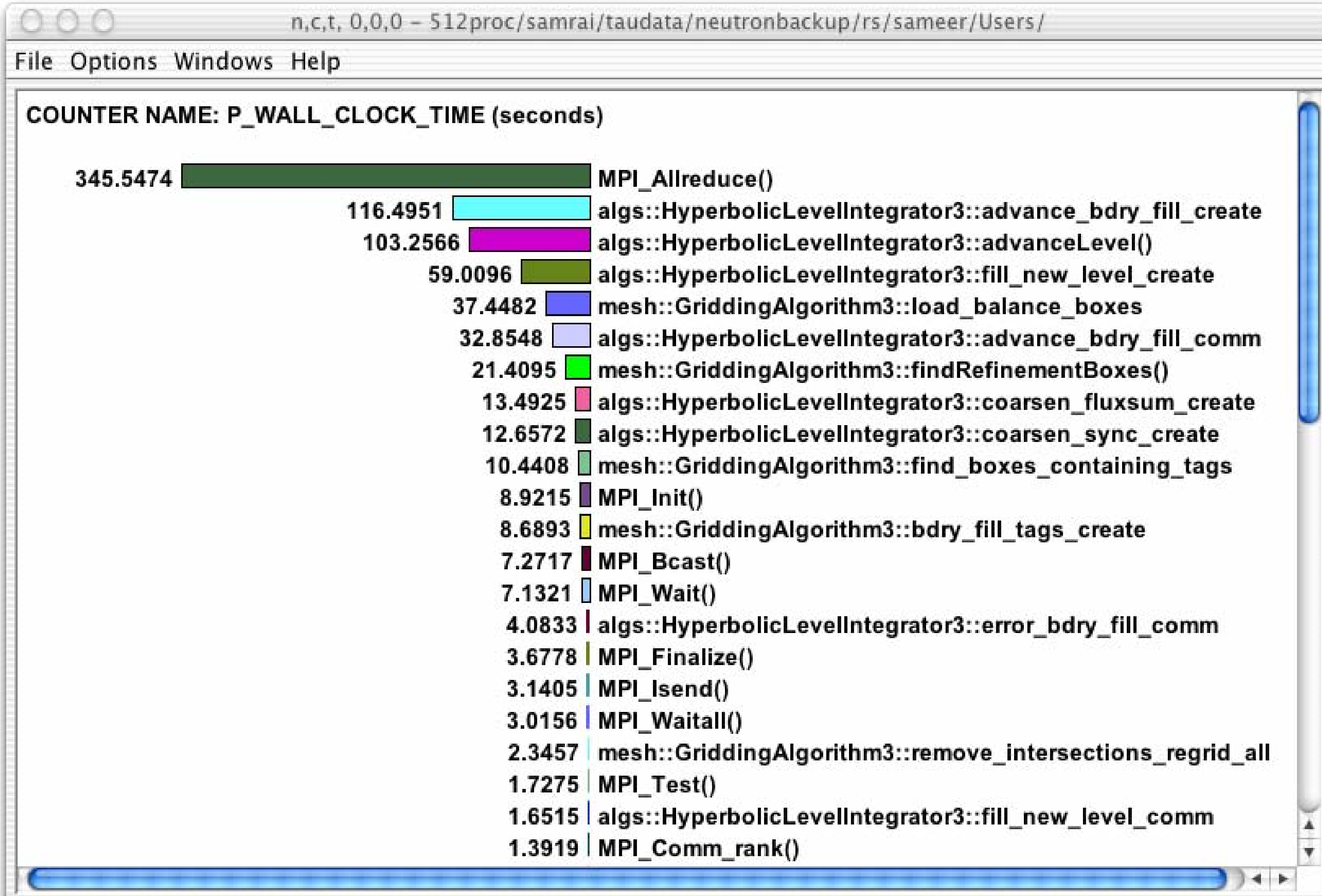


- Structured AMR toolkit (SAMRAI++), LLNL

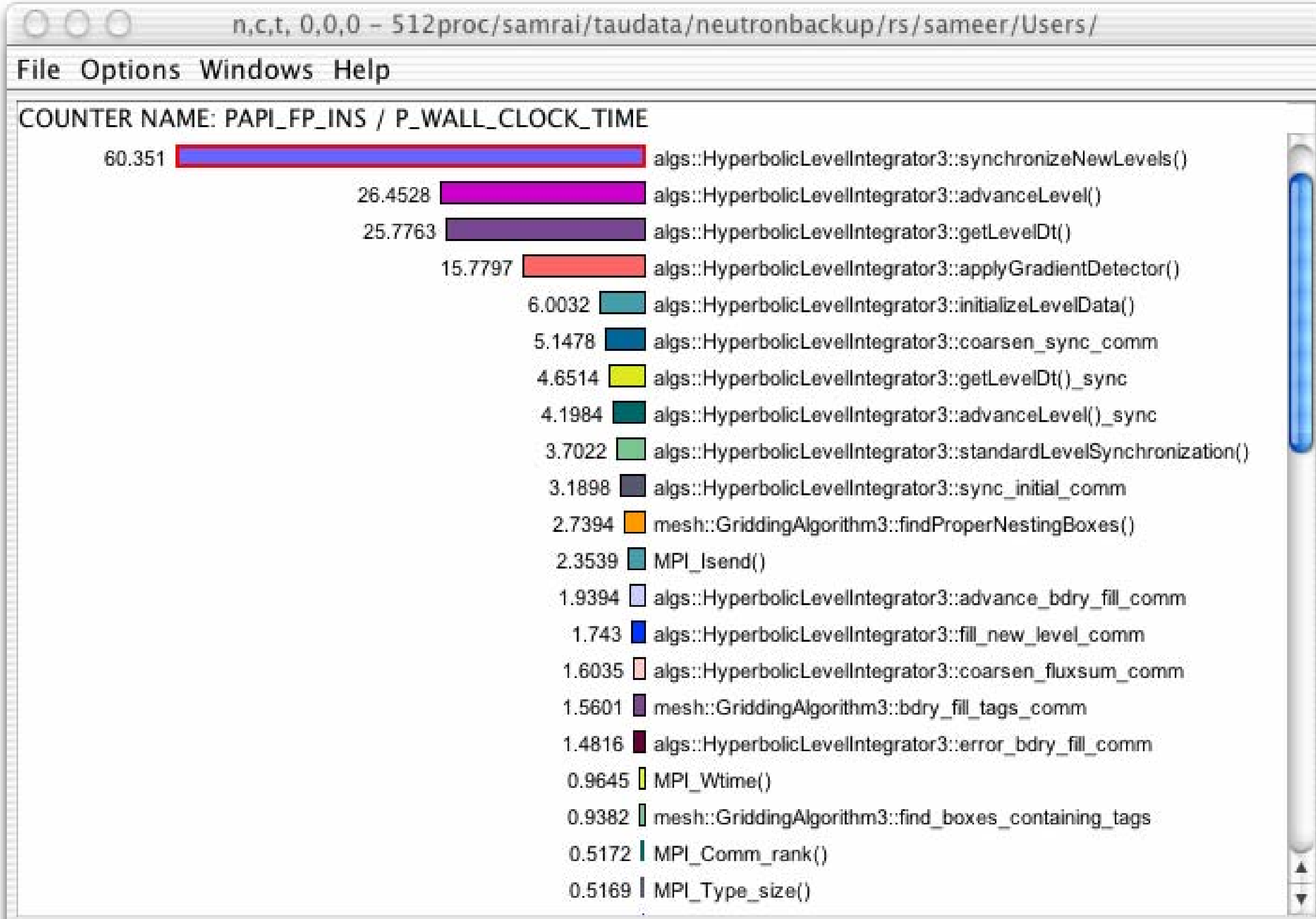
Full Profile Window (Exclusive Time)



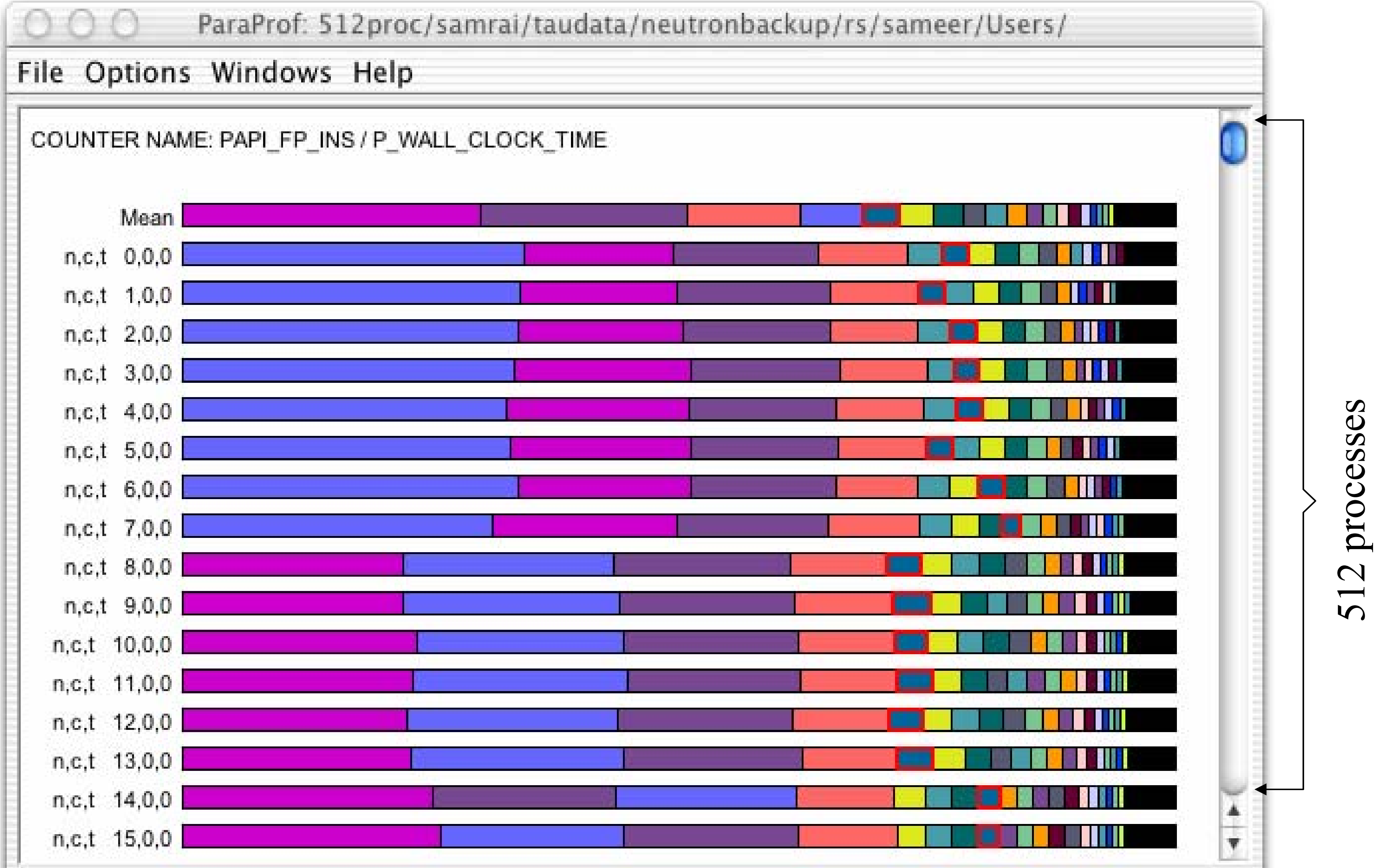
Node / Context / Thread Profile Window



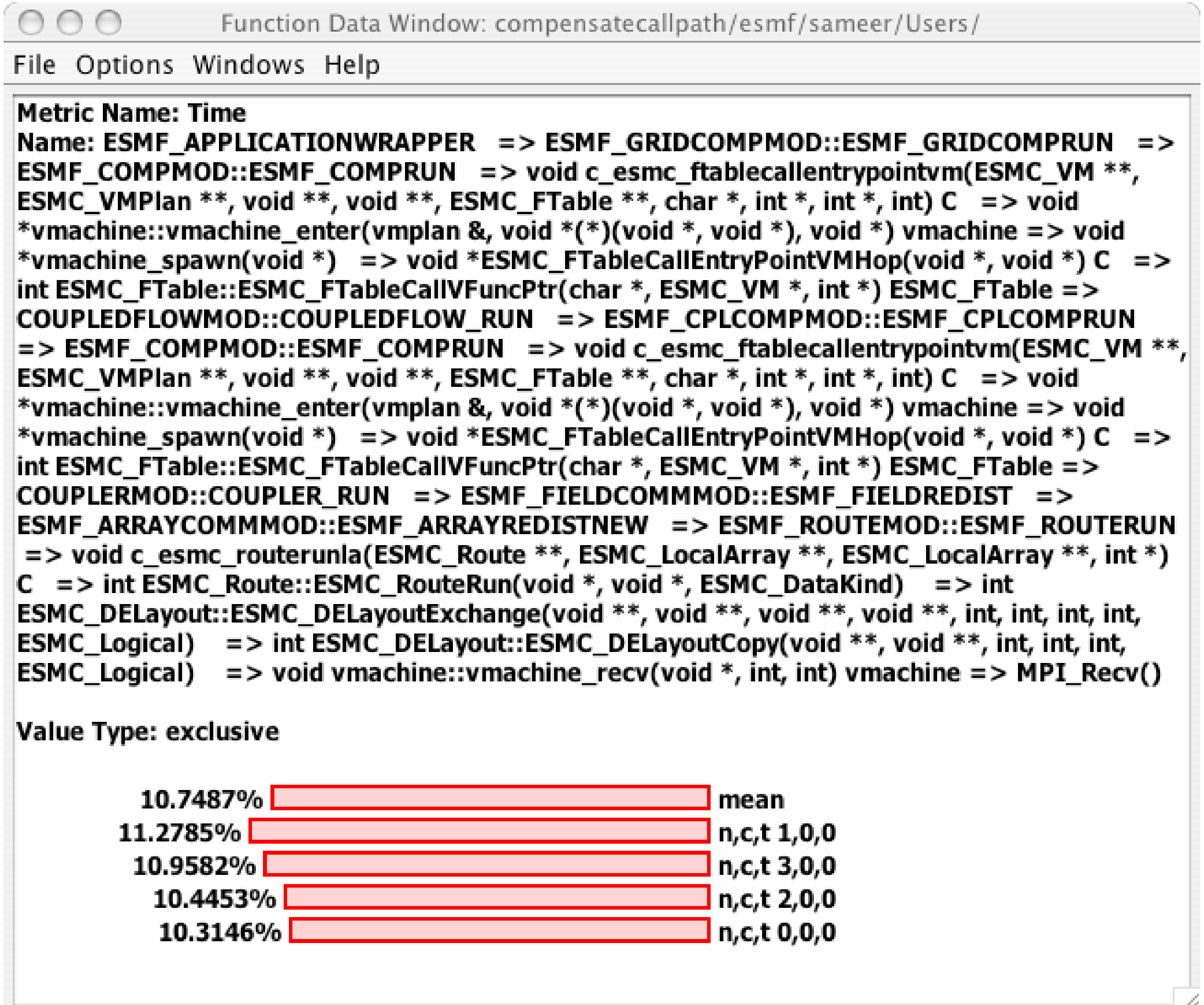
Derived Metrics



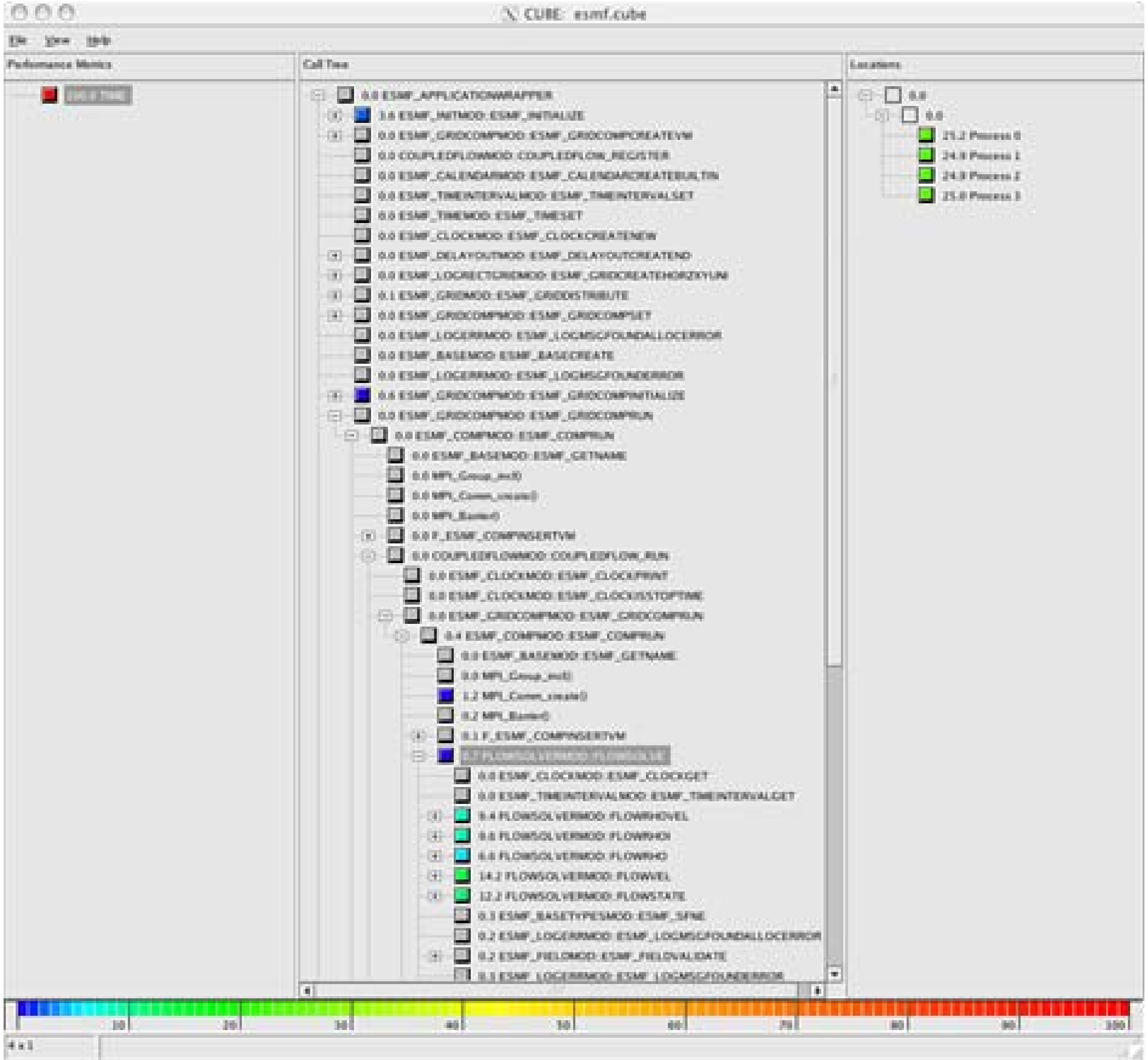
Full Profile Window (Metric-specific)



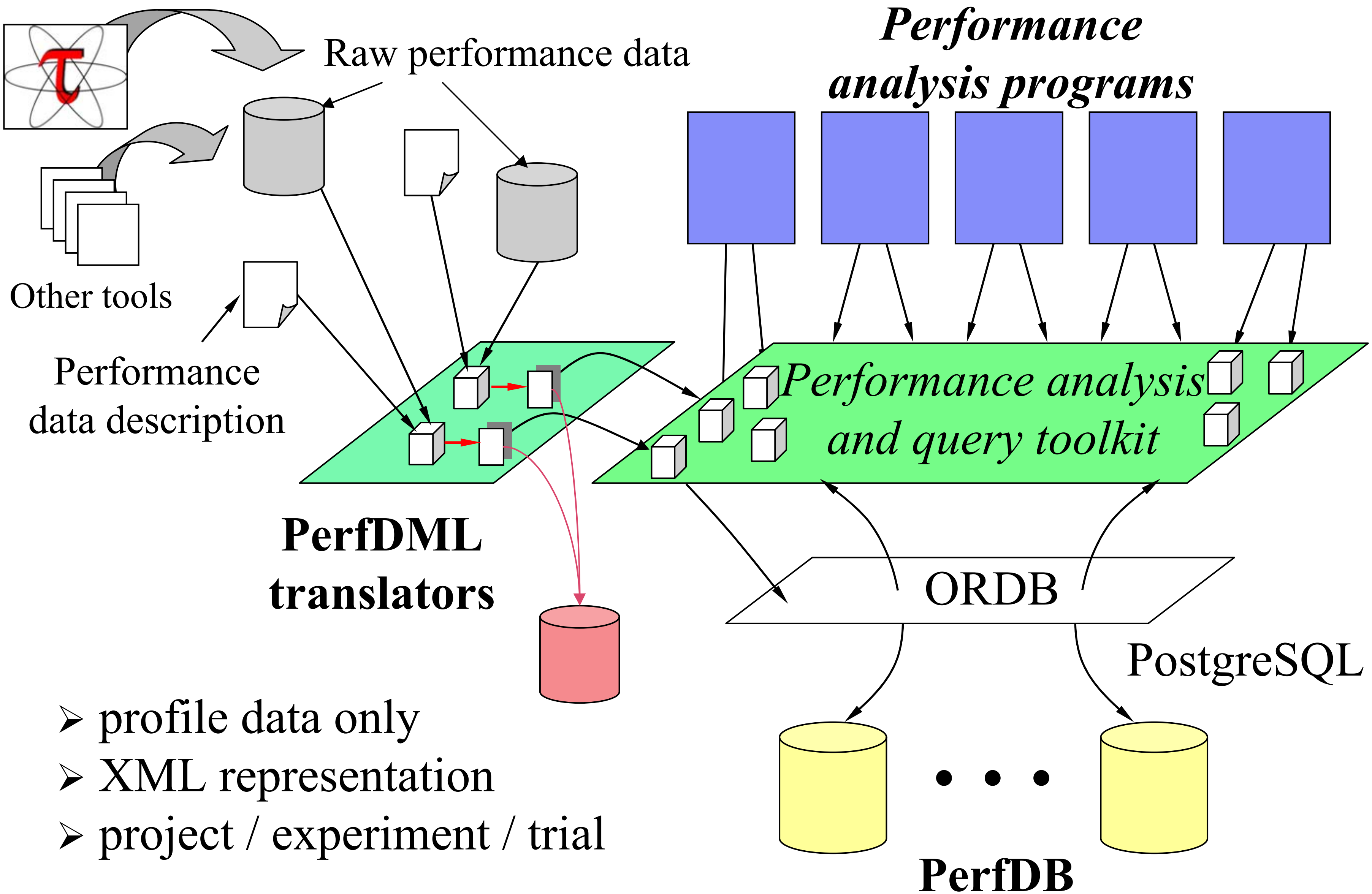
Browsing Individual Callpaths in Paraprof



CUBE (UTK, FZJ) Browser [Sept. 2004]



TAU Performance Database Framework



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

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

Hands-On Session

```
On Seaborg
% module load GNU tau java vampir
% cp -r /scratch/scratchdirs/sameer/tau ~/
% cd ~/tau
% tar zxf training.tar.gz
% cd training; make
See README, documentation and examples
```

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