Tuning and Analysis Utilities

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Tuning and Analysis Utilities

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NIC

Definitions – Profiling

- Profiling
  - Recording of summary information during execution
    - execution 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

Definitions – Instrumentation

- Instrumentation
  - Insertion of extra code (hooks) into program
  - Source instrumentation
    - Done by compiler, source-to-source translator, or manually

      \+ portable

      \+ links back to program code

      – re-compile is necessary for (change in) instrumentation

      – requires source to be available

      – hard to use in standard way for mix-language programs

      – source-to-source translators hard to develop for C++, F90
  - Object code instrumentation
    - "re-writing" the executable to insert hooks

Definitions – Instrumentation (continued)

- Dynamic code instrumentation
  - a debugger-like instrumentation approach
  - executable code instrumentation on running program
  - DynInst [U. Maryland, U. Wisc] and DPCL are examples
  - +/– switch around compared to source instrumentation
- Pre-instrumented library
  - typically used for MPI and PVM program analysis
  - supported by link-time library interposition
  - \+ easy to use since only re-linking is necessary
  - – can only record information about library entities

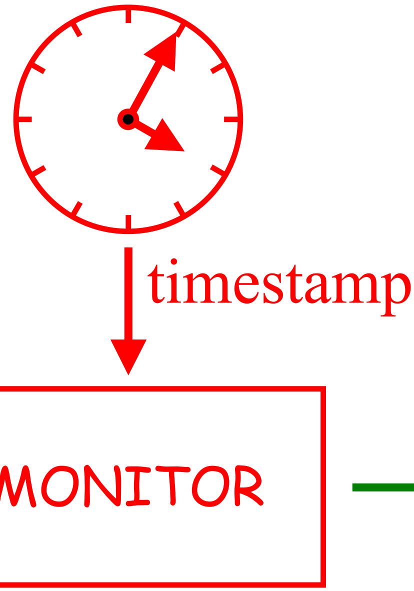
Event Tracing: *Instrumentation*, *Monitor*, *Trace*

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

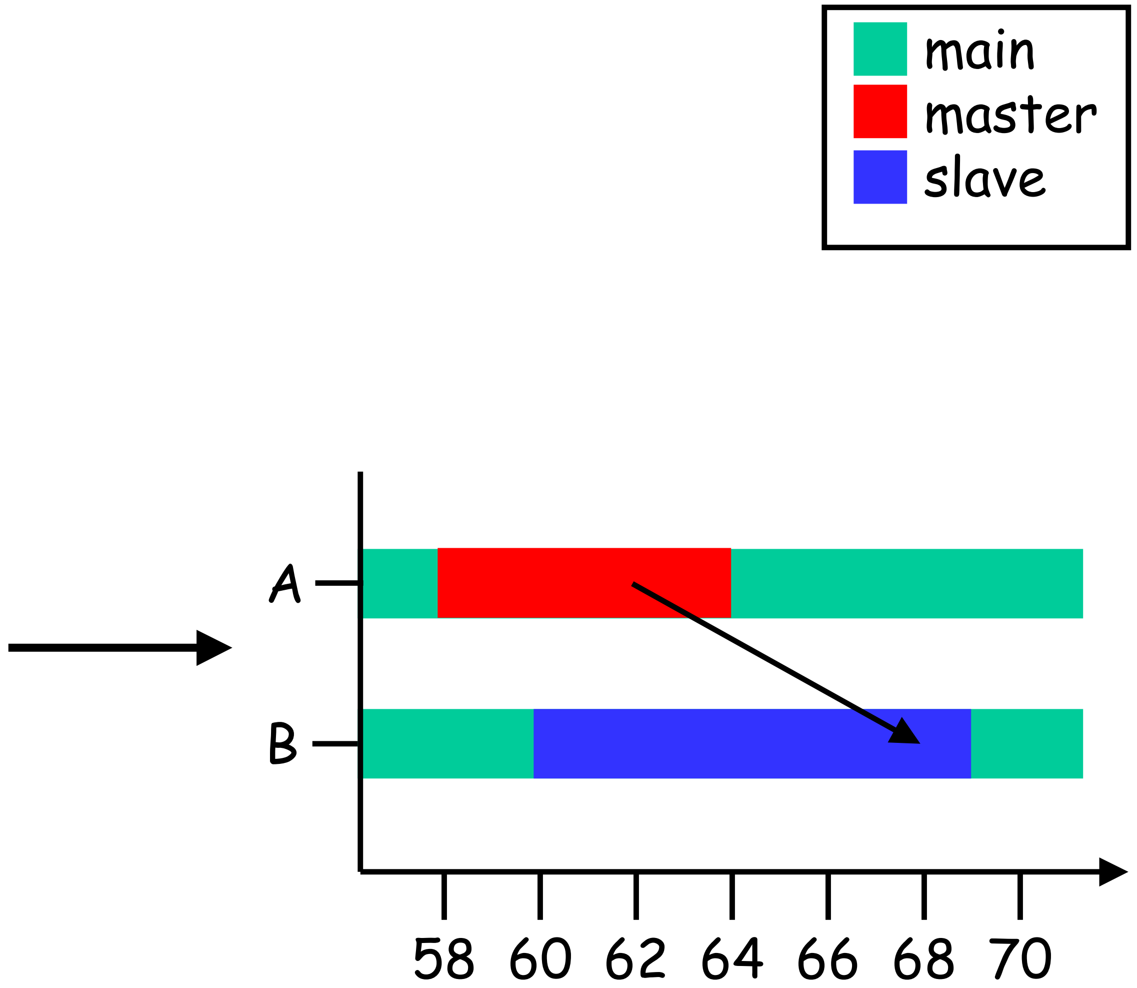
1	master
2	slave
3	...

...			
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 Framework

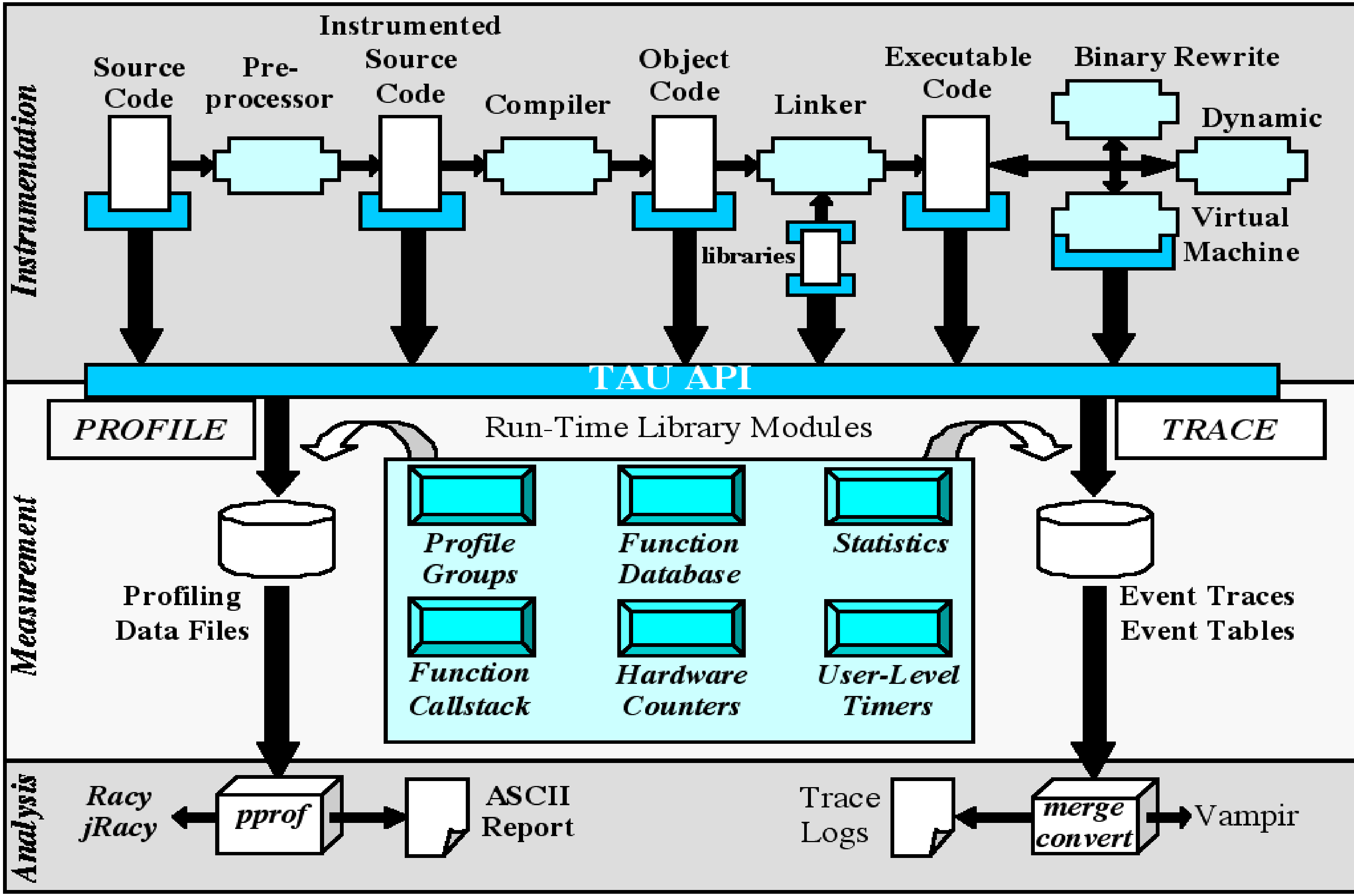
Tuning and Analysis Utilities

- 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

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
    - when is performance instrumentation done
    - how are performance measurement/instrumentation chosen
- Strategies for achieving flexibility and portability goals
  - Limited performance methods restrict evaluation scope
  - Non-portable methods force use of different techniques
  - Integration and combination of strategies

TAU Performance System Architecture



TAU Instrumentation

- Flexible instrumentation mechanisms at multiple levels
  - Source code
    - manual
    - automatic using *Program Database Toolkit (PDT), OPARI*
  - Object code
    - pre-instrumented libraries (e.g., MPI using PMPI)
    - statically linked
    - dynamically linked (e.g., Virtual machine instrumentation)
    - fast breakpoints (compiler generated)
  - Executable code
    - dynamic instrumentation (pre-execution) using *DynInstAPI*

TAU Instrumentation (continued)

- Targets common measurement interface (*TAU API*)
- Object-based design and implementation
  - Macro-based, using constructor/destructor techniques
  - Program units: function, classes, templates, blocks
  - Uniquely identify functions and templates
    - name and type signature (name registration)
    - static object creates performance entry
    - dynamic object receives static object pointer
    - runtime type identification for template instantiations
  - C and Fortran instrumentation variants
- Instrumentation and measurement optimization

Multi-Level Instrumentation

- Uses multiple instrumentation interfaces
- Shares information: cooperation between interfaces
- Taps information at multiple levels
- Provides selective instrumentation at each level
- Targets common measurement interface (*TAU API*)
- Targets a common performance model
- Presents a unified view of execution

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)
    - *PCL* (Performance Counter Library) (ZAM, Germany)
    - consistent, portable API
- Organization
  - Node, context, thread levels
  - Profile groups for collective events (runtime selective)
  - Performance data mapping between software levels

TAU Measurement (continued)

- Parallel profiling
  - Function-level, block-level, statement-level
  - Supports user-defined events
  - TAU parallel profile database
  - Call path profiles
  - Hardware counts values (in replace of time)
- Tracing
  - All profile-level events
  - Interprocess communication events
  - Timestamp synchronization
- User-configurable measurement library (user controlled)

TAU Measurement System Configuration

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

TAU Measurement System Configuration

- configure [OPTIONS]
  - -TRACE Generate binary TAU traces
  - -PROFILE (default) Generate profiles (summary)
  - -PROFILECALLPATH Generate call path profiles
  - -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

Description of Optional Packages

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

TAU Measurement 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++=guidec++ -cc=guidec
  -papi=/usr/local/packages/papi –openmp
  -mpiinc=/usr/packages/mpich/include
  -mpilib=/usr/packages/mpich/lib
  - Use OpenMP+MPI using KAI's Guide compiler suite and use PAPI for accessing hardware performance counters for measurements
- Typically configure multiple measurement libraries

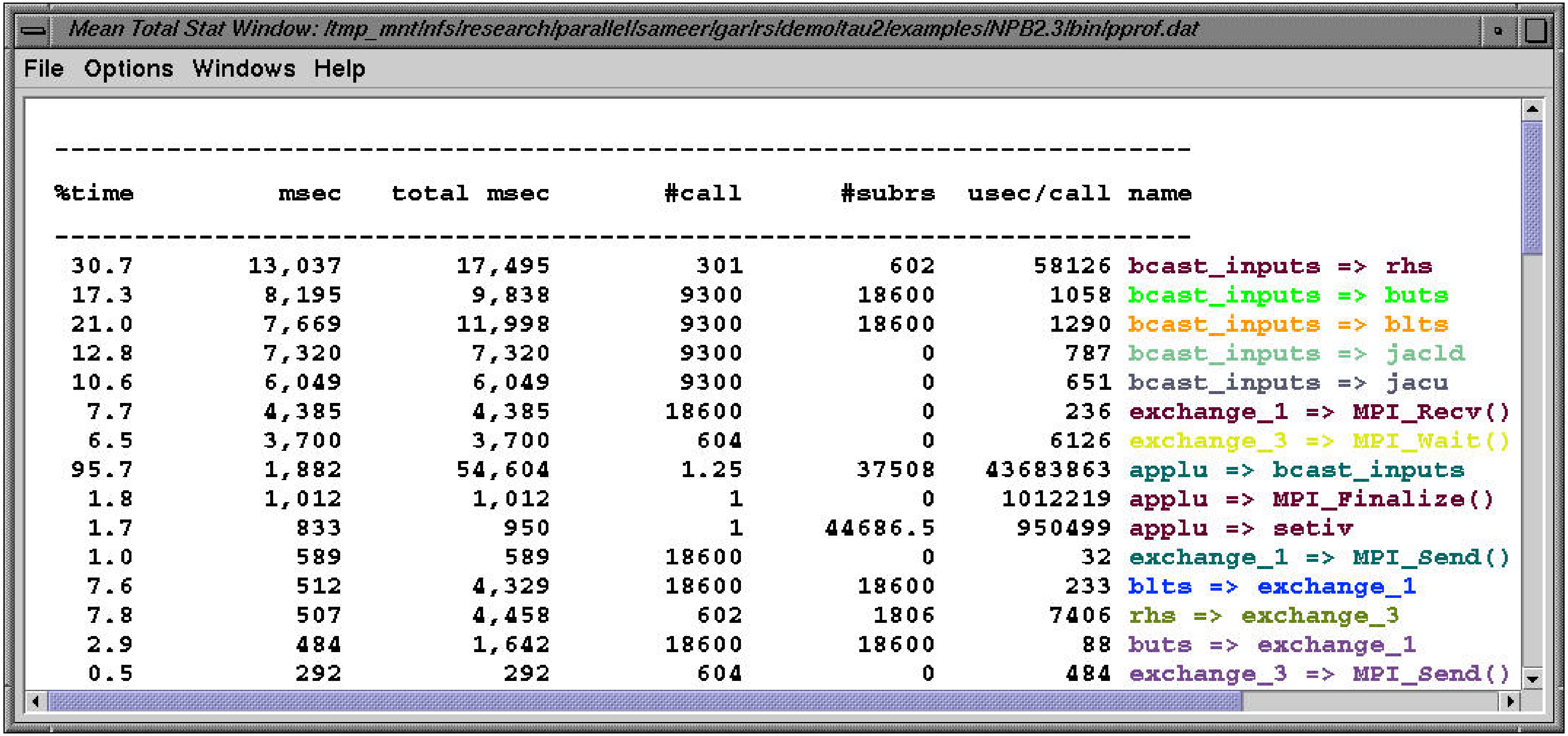
Performance Mapping

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

k-Level Callpath Implementation in TAU

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

k-Level Callpath Implementation in TAU



%time	msec	total msec	#call	#subrs	usec/call	name
30.7	13,037	17,495	301	602	58126	bcast_inputs => rhs
17.3	8,195	9,838	9300	18600	1058	bcast_inputs => buts
21.0	7,669	11,998	9300	18600	1290	bcast_inputs => blts
12.8	7,320	7,320	9300	0	787	bcast_inputs => jacld
10.6	6,049	6,049	9300	0	651	bcast_inputs => jacu
7.7	4,385	4,385	18600	0	236	exchange_1 => MPI_Recv()
6.5	3,700	3,700	604	0	6126	exchange_3 => MPI_Wait()
95.7	1,882	54,604	1.25	37508	43683863	applu => bcast_inputs
1.8	1,012	1,012	1	0	1012219	applu => MPI_Finalize()
1.7	833	950	1	44686.5	950499	applu => setiv
1.0	589	589	18600	0	32	exchange_1 => MPI_Send()
7.6	512	4,329	18600	18600	233	blts => exchange_1
7.8	507	4,458	602	1806	7406	rhs => exchange_3
2.9	484	1,642	18600	18600	88	buts => exchange_1
0.5	292	292	604	0	484	exchange_3 => MPI_Send()

TAU Instrumentation Options

- Manual instrumentation
  - TAU Profiling API
- Automatic instrumentation approaches
  - PDT – Source-to-source translation
  - MPI - Wrapper interposition library
  - Opari – OpenMP directive rewriting
  - DyninstAPI – Runtime instrumentation, rewrite binary

Manual Instrumentation – Using TAU

- Install TAU

  % configure ; make clean install

- Instrument application
  - TAU Profiling API
- 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 …

Setup: Running Applications

```
% setenv PROFILEDIR /home/data/experiments/profile/01
% setenv TRACEDIR   /home/data/experiments/trace/01(optional)
% set path=($path <taudir>/<arch>/bin)
% setenv LD_LIBRARY_PATH $LD_LIBRARY_PATH\:<taudir>/<arch>/lib

For PAPI (1 counter):
% setenv PAPI_EVENT PAPI_FP_INS
For PAPI (multiplecounters):
% setenv COUNTER1 PAPI_FP_INS     (PAPI's Floating point ins)
% setenv COUNTER2 PAPI_L1_DCM    (PAPI's L1 Data cache misses)
% setenv COUNTER3 P_VIRTUAL_TIME   (PAPI's virtual time)
% setenv COUNTER4 LINUX_TIMERS    (Wallclock time)
% mpirun -np <n> <application>
% llsubmit job.sh
For Callpath Profiling:
% setenv TAU_CALLPATH_DEPTH 10
```

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
  - 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);
- 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();

Manual Instrumentation – C++ Example

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

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

Manual Instrumentation – C Example

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

Manual Instrumentation – F90 Example

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

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;
}
```

Python Manual Instrumentation Example

```
#!/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
```

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, sleep…
```

CCA Performance Observation Component

- 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

Measurement port

```
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 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();
}
```

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_DISABLE	TAU's dummy F90 stub library

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

Including TAU Makefile - Example

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

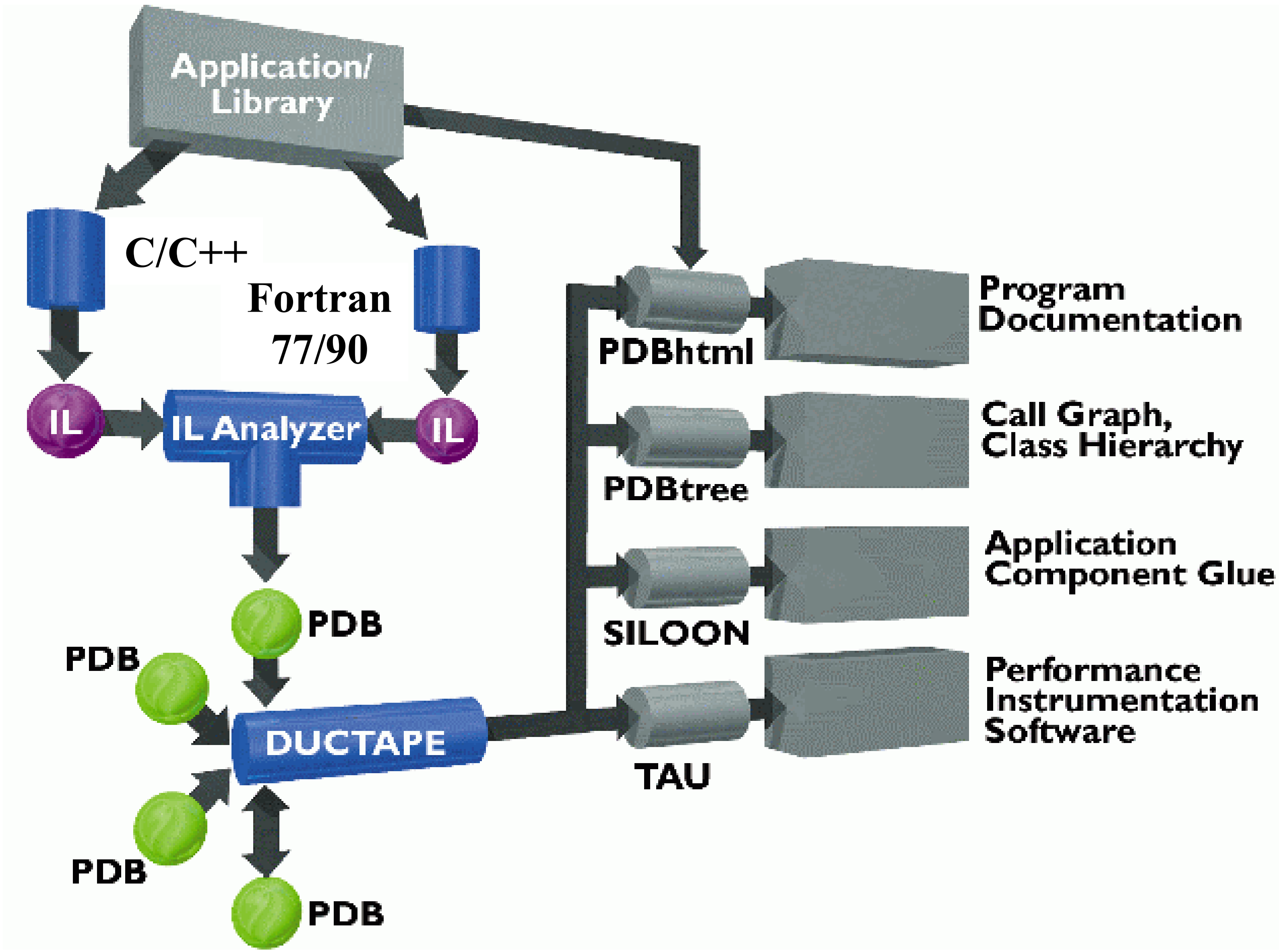
TAU Instrumentation Options

- Manual instrumentation
  - TAU Profiling API
- Automatic instrumentation approaches
  - PDT – Source-to-source translation
  - MPI - Wrapper interposition library
  - Opari – OpenMP directive rewriting
  - DyninstAPI – Runtime instrumentation, rewrite binary

Program Database Toolkit (PDT)

- Program code analysis framework for developing 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
- Target and integrate multiple source languages
- Use in TAU to build automated performance instrumentation tools

PDT Architecture and Tools



PDT Components

- Language front end
  - Edison Design Group (EDG): C, C++, Java
  - Mutek Solutions Ltd.: F77, F90
  - Cleanscape FortranLint F95 parser/analyzer (in progress)
  - 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
  - processes and merges PDB files
  - C++ library to access the PDB for PDT applications

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)
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 $@
```

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

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

% cat selective.dat
# Selective instrumentation: Specify an exclude/include list.

BEGIN_EXCLUDE_LIST
void quicksort(int *, int, int)
void sort_5elements(int *)
void interchange(int *, int *)
END_EXCLUDE_LIST

# If an include list is specified, the routines in the list will be the only
# routines that are instrumented.
# To specify an include list (a list of routines that will be instrumented)
# remove the leading # to uncomment the following lines
#BEGIN_INCLUDE_LIST
#int main(int, char **)
#int select_
#END_INCLUDE_LIST
```

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

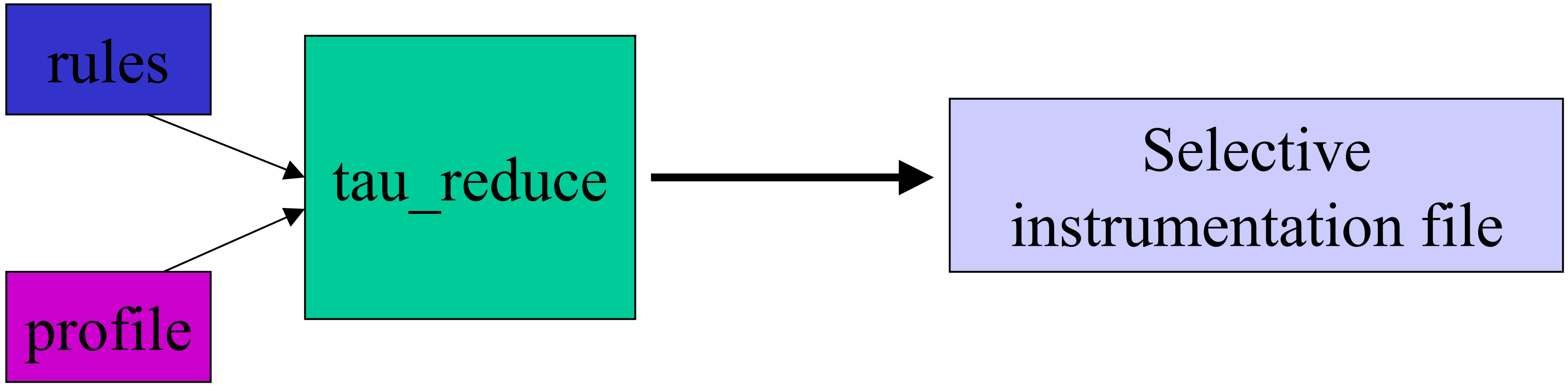
  - *GroupName* indicates rule applies to events in group
  - *Field* is a event metric attribute (from profile statistics)
    - numcalls, numsubs, percent, usec, cumusec, count [PAPI], totalcount, stdev, usecs/call, counts/call
  - *Operator* is one of >, <, or =
  - *Number* is any number
  - Compound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



TAU Instrumentation Options

- Manual instrumentation
  - TAU Profiling API
- Automatic instrumentation approaches
  - PDT – Source-to-source translation
  - MPI - Wrapper interposition library
  - Opari – OpenMP directive rewriting
  - DyninstAPI – Runtime instrumentation, rewrite binary

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

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

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

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Instrumentation of OpenMP Constructs

- **O**penMP **P**ragma **A**nd **R**egion **I**nstrumentor
- Source-to-Source translator to insert POMP calls around OpenMP constructs and API functions
- Done: Supports
  - Fortran77 and Fortran90, OpenMP 2.0
  - C and C++, OpenMP 1.0
  - POMP Extensions
  - EPILOG and TAU POMP implementations
  - Preserves source code information (`#line` *`line file`*)
- Work in Progress:
  Investigating standardization through OpenMP Forum

OpenMP API Instrumentation

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

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

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

Example: !$OMP PARALLEL DO *Instrumentation*

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

Opari Instrumentation: Example

- OpenMP directive instrumentation

```
pomp_for_enter(&omp_rd_2);
#line 252 "stommel.c"
#pragma omp for schedule(static) reduction(+: diff) private(j)
  firstprivate (a1,a2,a3,a4,a5) nowait
for( i=i1;i<=i2;i++) {
  for(j=j1;j<=j2;j++){
    new_psi[i][j]=a1*psi[i+1][j] + a2*psi[i-1][j] + a3*psi[i][j+1]
      + a4*psi[i][j-1] - a5*the_for[i][j];
    diff=diff+fabs(new_psi[i][j]-psi[i][j]);
  }
}
pomp_barrier_enter(&omp_rd_2);
#pragma omp barrier
pomp_barrier_exit(&omp_rd_2);
pomp_for_exit(&omp_rd_2);
#line 261 "stommel.c"
```

OPARI: Basic Usage (f90)

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

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Runtime Instrumentation

For Java (without instrumentation):

```
% java application
```

With instrumentation:

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

For DyninstAPI:

```
% a.out
% tau_run a.out
% tau_run -XrunTAUsh-papi a.out
% tau_run -o a.out.instr a.out
% tau_run -f select.dat a.out
```

Rewrites a.out with TAU calls (under development)

Selective instrumentation file specifies routines/files:

```
BEGIN_FILE_INCLUDE_LIST
*.f90
*.cpp
END_FILE_INCLUDE_LIST
```

TAU Analysis

- Profile analysis
  - Pprof
    - parallel profiler with text-based display
  - Paraprof
    - Redesigned version of jracy/racy (tcl/tk) browsers
    - Access to multiple experiments, derived metrics
- Trace analysis and visualization
  - Trace merging (tau_merge)
  - Trace format conversion (tau_convert)
    - Vampir, Paraver, text, ALOG, SDDF,
  - Vampir (Pallas) trace visualization

Pprof Command

- pprof [-c|-b|-m|-t|-e|-i] [-r] [-s] [-n num] [-f file] [-l] [nodes]
  - -c Sort according to number of calls
  - -b Sort according to number of subroutines called
  - -m Sort according to msecs (exclusive time total)
  - -t Sort according to total msecs (inclusive time total)
  - -e Sort according to exclusive time per call
  - -i Sort according to inclusive time per call
  - -v Sort according to standard deviation (exclusive usec)
  - -r Reverse sorting order
  - -s Print only summary profile information
  - -n num Print only first number of functions
  - -f file Specify full path and filename without node ids
  - -l List all functions and exit

Pprof Output (NAS Parallel Benchmark – LU)

- Intel Quad PIII Xeon, RedHat, PGI F90
- F90 + MPICH
- Profile for:
  - Node
  - Context
  - Thread
- Application events and MPI events

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

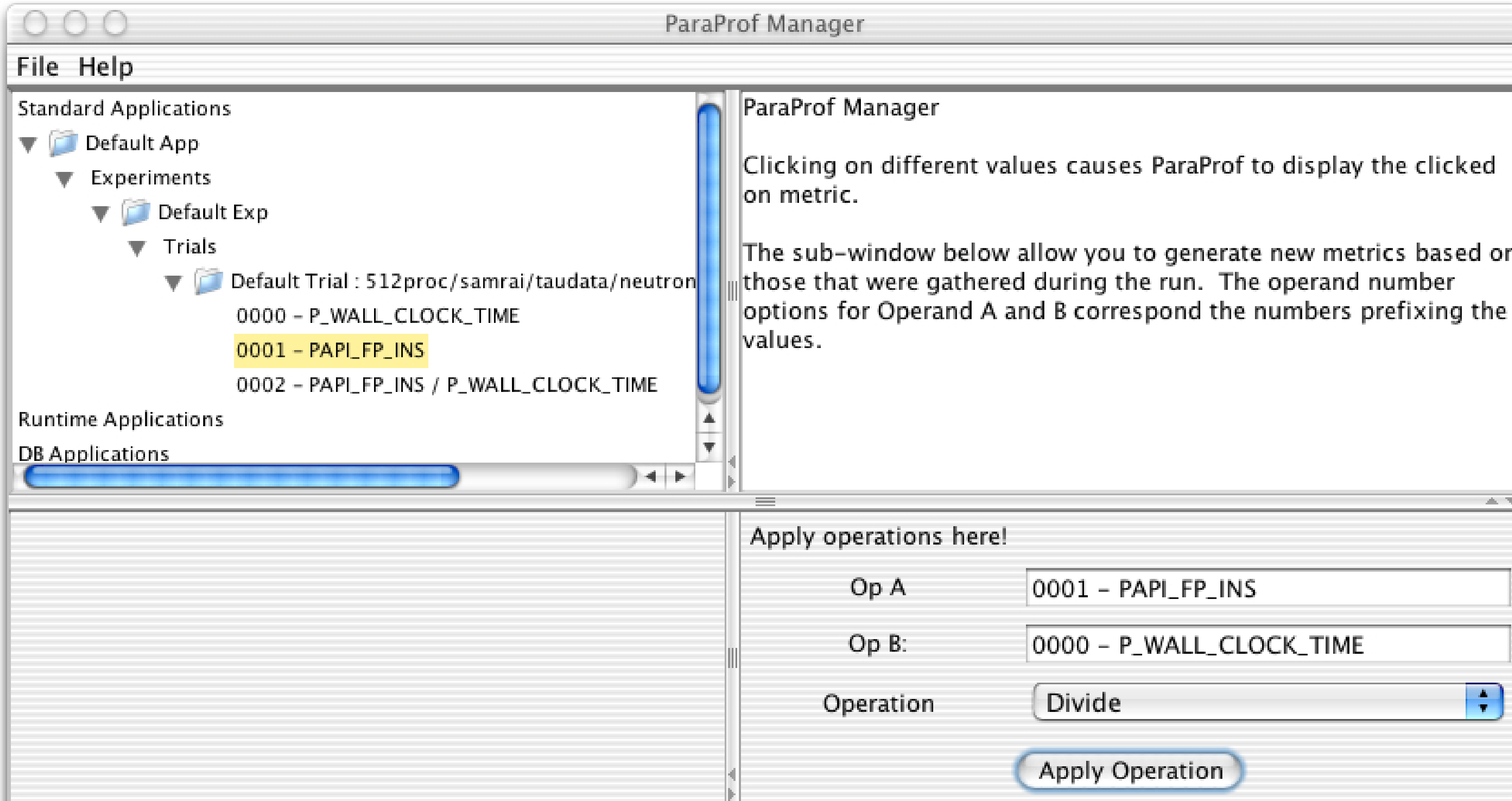
```
int main( )
{ /* takes 100 secs */

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

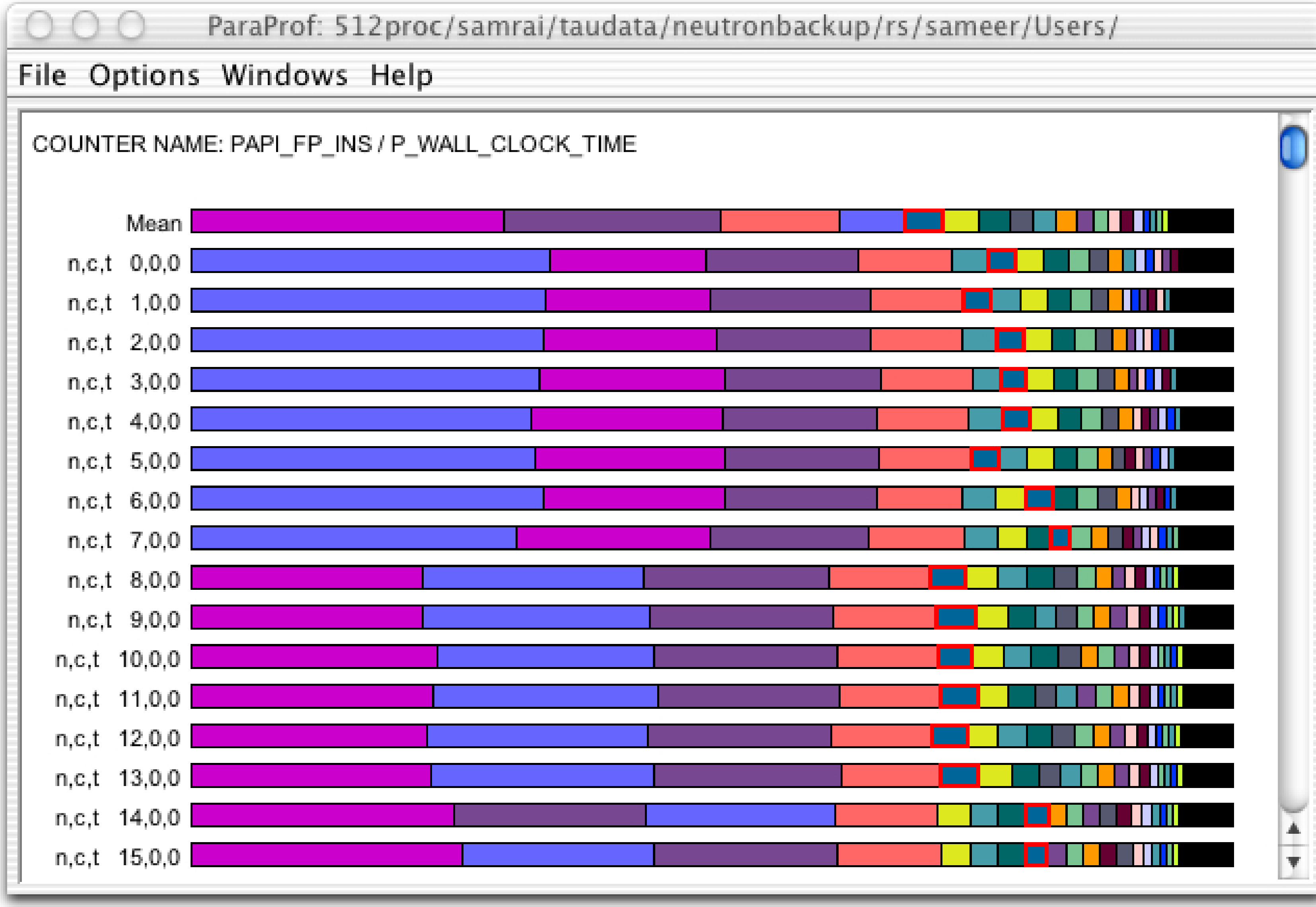
  /* other work */
}

/*
Time can be replaced by  counts
*/
```

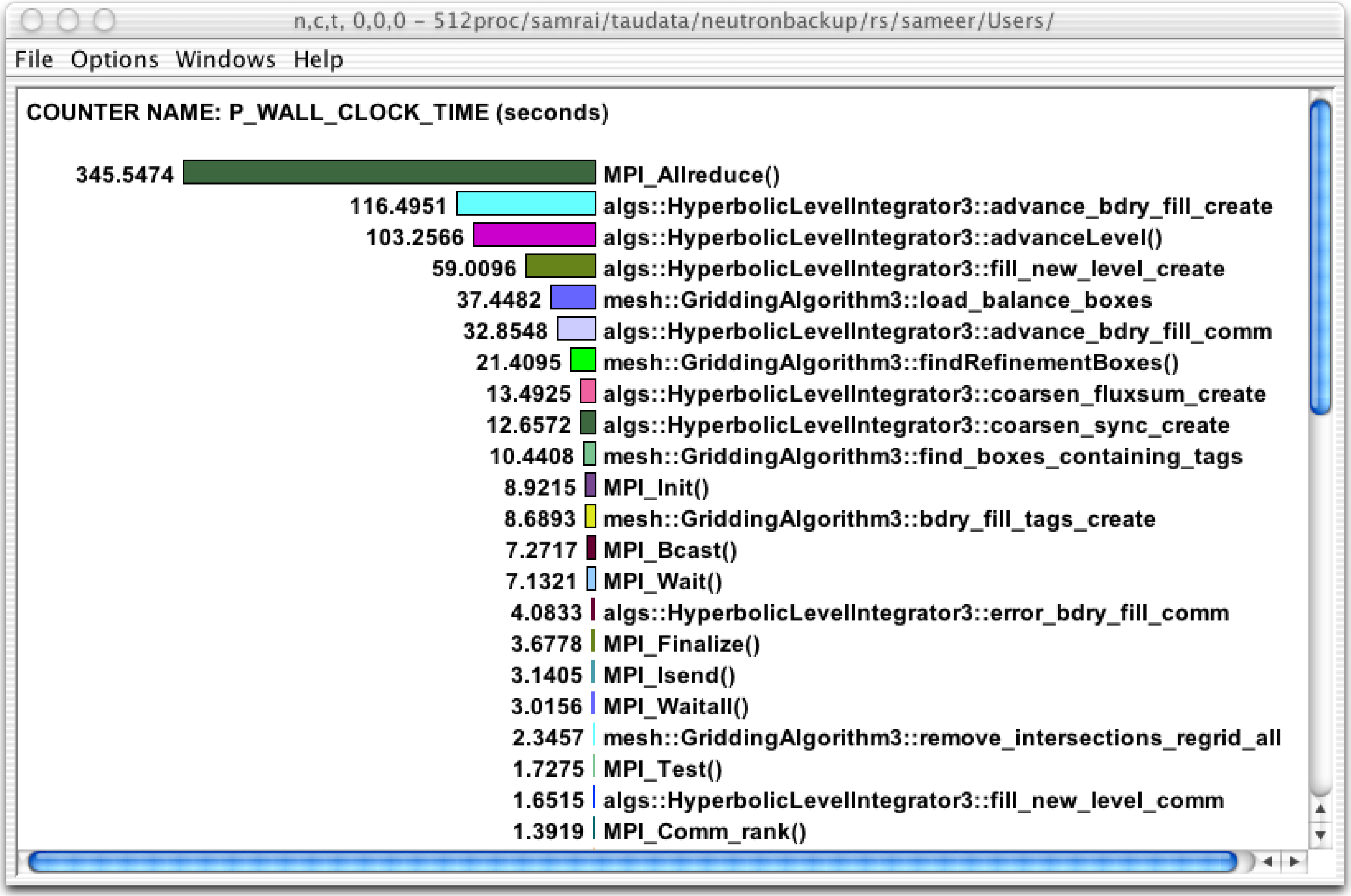
Paraprof Profile Browser



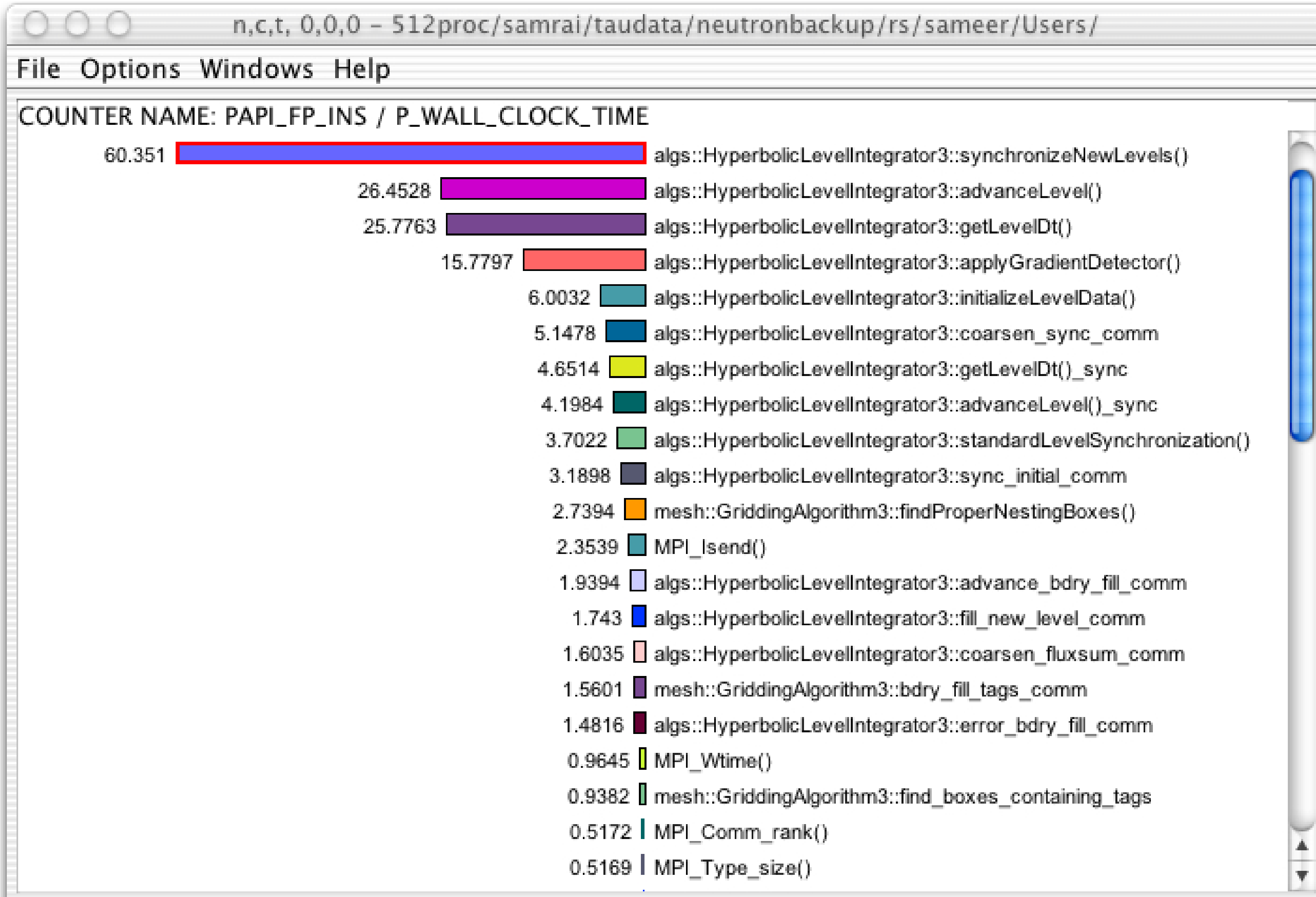
Paraprof Profile Browser Main Window



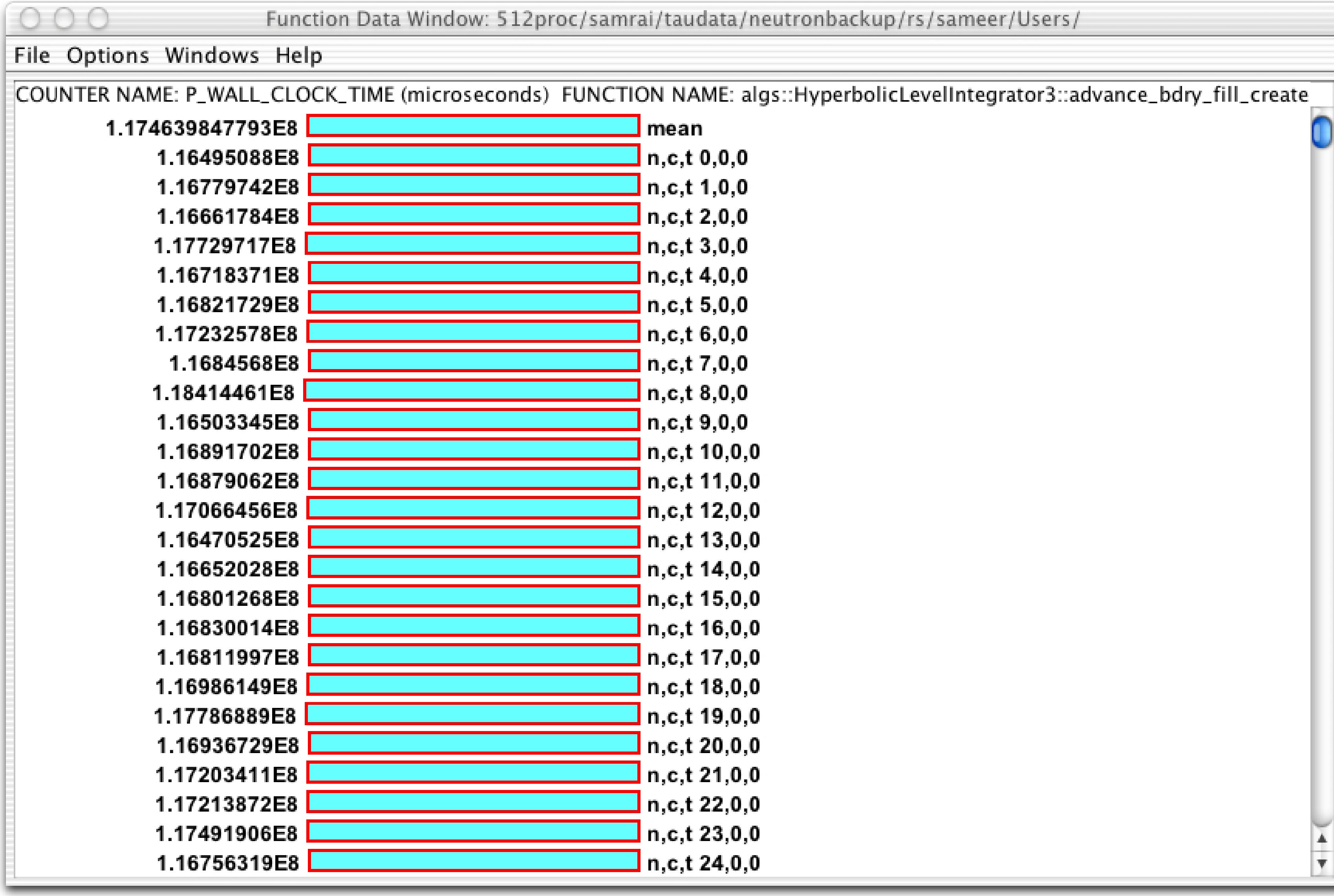
Paraprof Profile Browser Node Window



Paraprof Profile Browser (Derived Metrics)

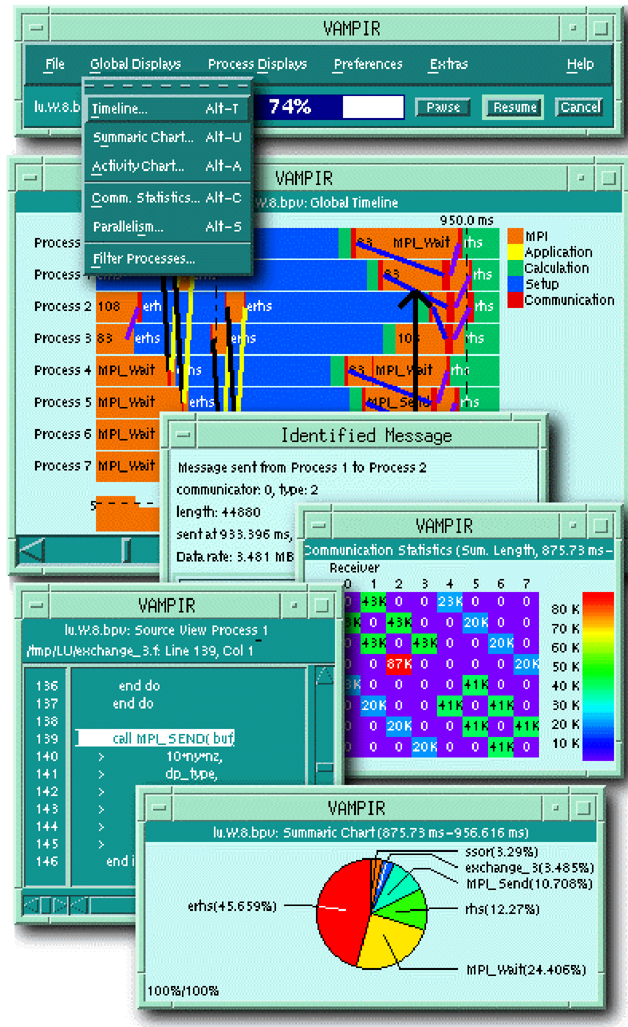


Paraprof Profile Browser Routine Window



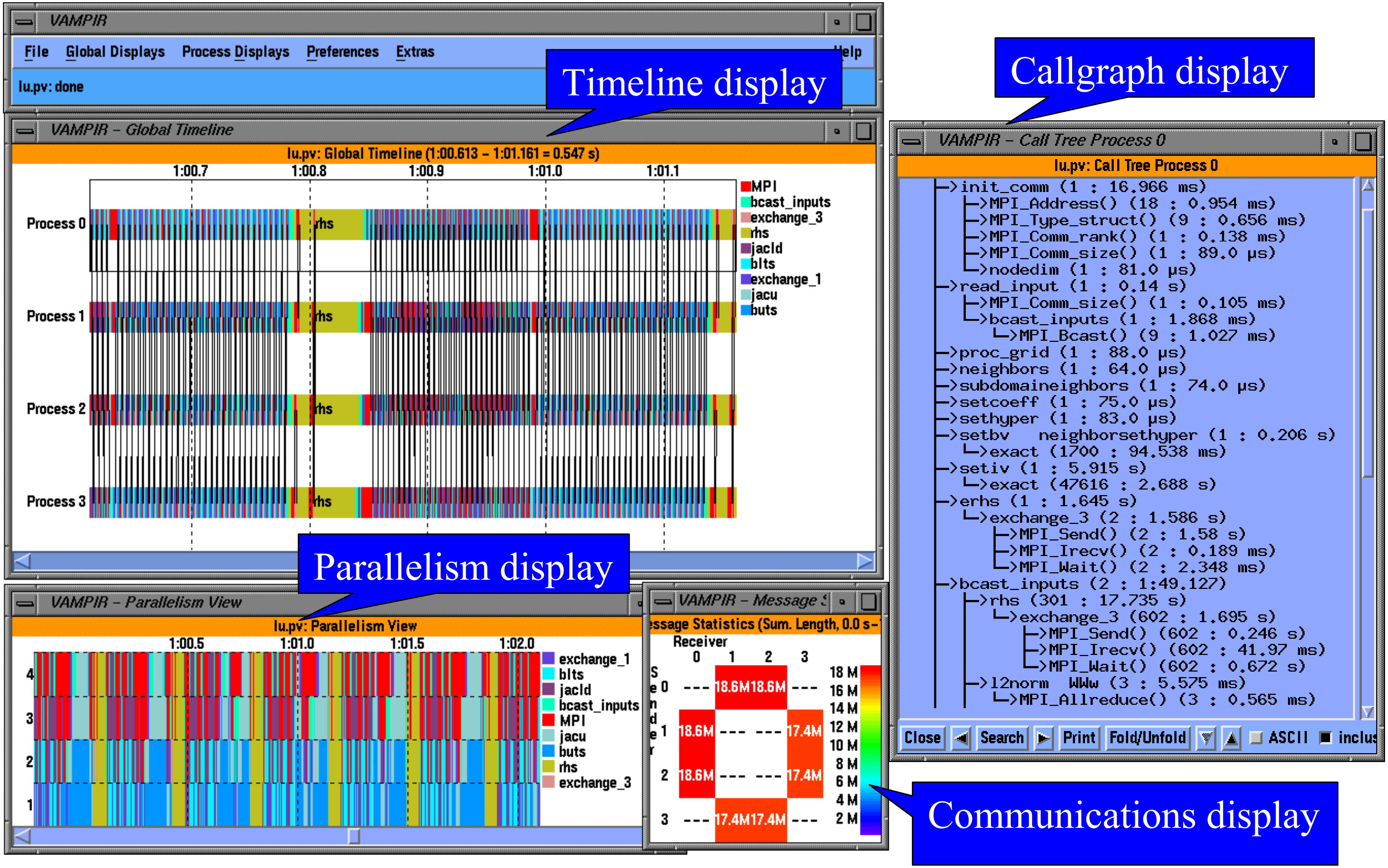
Vampir Trace Visualization Tool

- 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`**

Vampir (NAS Parallel Benchmark – LU)



TAU Performance System Status

- Computing platforms
  - IBM SP, SGI Origin 2K/3K, ASCI Red, Apple, Cray T3E, HP/Compaq SC, HP Superdome, Sun, Windows, Linux (IA-32, IA-64, Alpha…), NEC, Hitachi, …
- Programming languages
  - C, C++, Fortran 77/90, HPF, Java, Python
- Communication libraries
  - MPI, PVM, Nexus, Tulip, ACLMPL, MPIJava
- Thread libraries
  - pthreads, Java,Windows, Tulip, SMARTS, OpenMP
- Compilers
  - KAI, PGI, GNU, Fujitsu, Sun, Microsoft, SGI, Cray, IBM, Compaq, NEC, Hitachi

TAU Performance System Status (continued)

- TAU full distribution (Version 2.12, web download)
  - Measurement library and profile analysis tools
  - Automatic software installation
  - Performance analysis examples
  - Extensive TAU User’s Guide

PDT Status

- Program Database Toolkit (Version 2.2.2, web download)
  - EDG C++ front end (Version 2.45.2)
  - Mutek Fortran 90 front end (Version 2.4.1)
  - C++ and Fortran 90 IL Analyzer
  - DUCTAPE library
  - Standard C++ system header files (KCC Version 4.0f)
- PDT-constructed tools
  - Automatic TAU performance instrumentation
    - C, C++, Fortran 77, and Fortran 90
  - XMLGEN – PDB to XML translation tool
  - Program analysis support for SILOON and CHASM

Information

- TAU (http://www.cs.uoregon.edu/research/paracomp/tau)
- PDT (http://www.cs.uoregon.edu/research/paracomp/pdtoolkit)
- PAPI (http://icl.cs.utk.edu/projects/papi/)
- OPARI (http://www.fz-juelich.de/zam/kojak/)
- Vampir (http://www.pallas.de)

Support Acknowledgement

- TAU and PDT support:
  - Department of Engegy (DOE)
    - DOE 2000 ACTS contract
    - DOE MICS contract
    - DOE ASCI Level 3 (LANL, LLNL)
  - DARPA
  - NSF National Young Investigator (NYI) award

Hands-on session

- On seaborg.nersc.gov, copy files from <training dir>
- Load modules

  % module load tau

  % module load java

  % module load tcltk

  % module load kap
- Examine the Makefile.
- Type "make" in each directory; then execute the program
- Type "paraprof" or "vampir" based on profile/trace

Examples

The training directory contains example programs that illustrate the use of TAU instrumentation and measurement options.

instrument -	This contains a simple C++ example that shows how TAU's API can be used for manually instrumenting a C++ program. It highlights instrumentation for templates and user defined events.
threads -	A simple multi-threaded program that shows how the main function of a thread is instrumented. Performance data is generated for each thread of execution. Configure with -pthread.
cthreads -	Same as threads above, but for a C program. An instrumented C program may be compiled with a C compiler, but needs to be linked with a C++ linker. Configure with -pthread.
pi -	An MPI program that calculates the value of pi and e. It highlights the use of TAU's MPI wrapper library. TAU needs to be configured with -mpiinc=<dir> and -mpilib=<dir>. Run using mpirun -np <procs> cpi <iterations>.
papi -	A matrix multiply example that shows how to use TAU statement level timers for comparing the performance of two algorithms for matrix multiplication. When used with PAPI or PCL, this can highlight the cache behaviors of these algorithms. TAU should be configured with -papi=<dir> or -pcl=<dir> and the user should set PAPI_EVENT or PCL_EVENT respective environment variables, to use this.

Examples - (cont.)

papithreads - Same as papi, but uses threads to highlight how hardware performance counters may be used in a multi-threaded application. When it is used with PAPI, TAU should be configured with -papi=<dir> -pthread

autoinstrument - Shows the use of Program Database Toolkit (PDT) for automating the insertion of TAU macros in the source code. It requires configuring TAU with the -pdt=<dir> option. The Makefile is modified to illustrate the use of a source to source translator (tau_instrumentor).

NPB2.3 - The NAS Parallel Benchmark 2.3 [from NASA Ames]. It shows how to use TAU's MPI wrapper with a manually instrumented Fortran program. LU and SP are the two benchmarks. LU is instrumented completely, while only parts of the SP program are instrumented to contrast the coverage of routines. In both cases MPI level instrumentation is complete. TAU needs to be configured with -mpiinc=<dir> and -mpilib=<dir> to use this.