Code Profiling Tools

Shirley Moore
Innovative Computing Laboratory
University of Tennessee
shirley@cs.utk.edu

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

Available Profiling Tools

- prof, gprof
- PAPI (profiling based on timers or on any PAPI hardware counter metric)
- Dynaprof (requires dyninst or DPCL)
- GuideView (OpenMP) (being phased out)
- Vampir (MPI)
- TAU (OpenMP, MPI, MPI/OpenMP)
- SvPablo
- HPCView
- Vprof
- Vendor specific tools (e.g., SGI IRIX perfex and ssrun, IBM tprof and trace, Cray PAT)

prof, gprof

- Available on many Unix platforms (e.g., IBM AIX, Sun Solaris, HP/Compaq Tru64)
- Produces "flat" profile (prof) or "call graph" profile (gprof)
- Compile with special flag or set environment variable or rewrite executable to enable instrumentation and produce profile data file
- Collect profile data by periodically sampling the program counter during execution and/or calling monitoring routines
- See
  man prof
  man gprof

prof Profile of FSPX Benchmark

%time	cumulative	self	calls	ms/call	tot/call	name
21.71	18.93	18.93	6080	3.11	3.11	flux_
19.99	36.36	17.43	9124	1.91	3.91	proflux_
8.26	43.56	7.20	6080	1.18	1.18	pde_
8.11	50.63	7.07	6080	1.16	4.17	phase_
7.96	57.57	6.94	100061386	0.00	0.00	cplintg_
7.46	64.08	6.51	100061388	0.00	0.00	cpsintg_
6.05	69.36	5.28	49807360	0.00	0.00	tsofx_
5.60	74.24	4.88	49807362	0.00	0.00	tlofx_
4.07	77.79	3.55	62202877	0.00	0.00	cpl_
2.44	79.92	2.13	37371906	0.00	0.00	cps_
1.67	81.38	1.46	37371904	0.00	0.00	hl_
1.43	82.63	1.25	37371904	0.00	0.00	hs_
1.07	83.56	0.93	24903681	0.00	0.00	elqds_
0.89	84.34	0.78	37371904	0.00	0.00	aks_

IBM Profiling Utilities

- In addition to man pages, see the AIX 5 Performance Management Guide
- prof
- gprof
- tprof

SGI Profiling Utilities

- ssrun
  - Collects Speedshop and Workshop performance data
  - Types of experiments: totaltime, usertime, pcsamp, ideal, hardware counter
- prof
  - Analyzes and displays SpeedShop performance data generated by ssrun
- perfex
  - Runs program and collects hardware counter data

HP/Compaq Profiling Utilities

- prof
  - Displays profiling data from –p or pixie
- pixie
  - Instruction-counting profiler
- gprof
  - Displays profiling data from –pg or hiprof
- hiprof
  - Creates instrumented version of program for call-graph profiling
- uprofile
  - Profiles a program with Alpha on-chip performance counters

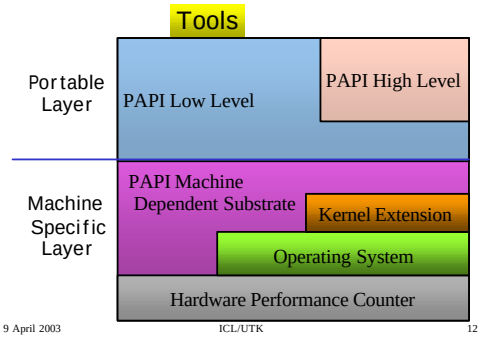
Overview of **PAPI**

- **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
- Being installed and supported at the DoD HPC Centers as part of PET CE004

PAPI Counter Interfaces

- PAPI provides three interfaces to the underlying counter hardware:
  1. The low level interface manages hardware events in user defined groups called *EventSets*.
  2. The high level interface simply provides the ability to start, stop and read the counters for a specified list of events.
  3. Graphical tools to visualize information.

PAPI Implementation



PAPI Preset Events

- Proposed standard set of events deemed most relevant for application performance tuning
- Defined in papiStdEventDefs.h
- Mapped to native events on a given platform
  - Run tests/avail to see list of PAPI preset events available on a platform

High-level Interface

- Meant for application programmers wanting coarse-grained measurements
- Not thread safe
- Calls the lower level API
- Allows only PAPI preset events
- Easier to use and less setup (additional code) than low-level

High-level API

- C interface
  PAPI_start_counters
  PAPI_read_counters
  PAPI_stop_counters
  PAPI_accum_counters
  PAPI_num_counters
  PAPI_flops
- Fortran interface
  PAPIF_start_counters
  PAPIF_read_counters
  PAPIF_stop_counters
  PAPIF_accum_counters
  PAPIF_num_counters
  PAPIF_flops

PAPI_flops

- int PAPI_flops(float *real_time, float *proc_time, long_long * flpins, float * mflops)
  - Only two calls needed, PAPI_flops before and after the code you want to monitor
  - real_time is the wall-clocktime between the two calls
  - proc_time is the "virtual" time or time the process was actually executing between the two calls (not as fine grained as real_time but better for longer measurements)
  - flpins is the total floating point instructions executed between the two calls
  - mflops is the Mflop/s rating between the two calls

Low-level Interface

- Increased efficiency and functionality over the high level PAPI interface
- About 40 functions
- Obtain information about the executable and the hardware
- Thread-safe
- Fully programmable
- Callbacks on counter overflow

Callbacks on Counter Overflow

- PAPI provides the ability to call user-defined handlers when a specified event exceeds a specified threshold.
- For systems that do not support counter overflow at the OS level, PAPI sets up a high resolution interval timer and installs a timer interrupt handler.

Statistical Profiling

- PAPI provides support for execution profiling based on any counter event.
- PAPI_profil() creates a histogram of overflow counts for a specified region of the application code.

PAPI_profil

int PAPI_profil(unsigned short *buf, unsigned int bufsiz, unsigned long offset, unsigned scale, int EventSet, int EventCode, int threshold, int flags)

- buf – buffer of bufsiz bytes in which the histogram counts are stored
- offset – start address of the region to be profiled
- scale – contraction factor that indicates how much smaller the histogram buffer is than the region to be profiled

What is DynaProf?

- A portable tool to instrument a running executable with *Probes* that monitor application performance.
- Simple command line interface.
- Open Source Software
- A work in progress…

No source code required

DynaProf Methodology

- Make collection of run-time performance data easy by:
  - Avoiding instrumentation and recompilation
  - Using the same tool with different probes
  - Providing useful and meaningful probe data
  - Providing different kinds of probes
  - Allowing custom probes

No source code required!

Why the “Dyna”?

- Instrumentation is selectively inserted directly into the program’s address space.
- Why is this a better way?
  - No perturbation of compiler optimizations
  - Complete language independence
  - Multiple Insert/Remove instrumentation cycles

DynaProf Design

- GUI, command line & script driven user interface
- Uses GNU readline for command line editing and command completion.
- Instrumentation is done using:
  - Dyninst on Linux, Solaris and IRIX
  - DPCL on AIX

DynaProf Commands

load <executable>
list [module pattern]
use <probe> [probe args]
instr module <module> [probe args]
instr function <module> <function> [probe args]
stop
continue
run [args]
Info
unload

Dynaprof Probes

- papiprobe
- wallclockprobe
- perfometerprobe

DynaProf Probe Design

- Can be written in any compiled language
- Probes export 3 functions with a standardized interface.
- Easy to roll your own (<1day)
- Supports separate probes for MPI/OpenMP/Pthreads

Future development

- GUI development
- Additional probes
  - Perfex probe
  - Vprof probe
  - TAU probe
- Better support for parallel applications

fspx Cycles & Instrs.

Exclusive Profile of Metric PAPI_TOT_INS.

Name	Percent	Total	Calls
TOTAL	100	3.031e+11	1
unknown	53.81	1.631e+11	1
proflux_	27.75	8.411e+10	9124
phase_	15.44	4.68e+10	6080
flux_	2.507	7.598e+09	6080
pde_	0.4884	1.48e+09	6080

Inclusive Profile of Metric PAPI_TOT_INS.

Name	Percent	Total	SubCalls
TOTAL	100	3.031e+11	0
proflux_	59.31	1.797e+11	2.242e+08
phase_	37.69	1.142e+11	1.247e+08
flux_	2.507	7.598e+09	0
pde_	0.4884	1.48e+09	0

1-Level Inclusive Call Tree of Metric PAPI_TOT_INS.

Parent/-Child	Percent	Total	Calls
TOTAL	100	3.031e+11	1
proflux_	100	1.797e+11	9124
- akl_	8.504	1.529e+10	3.737e+07
- aks_	8.4	1.51e+10	3.737e+07
- cpl_	8.525	1.532e+10	3.737e+07
- cps_	8.525	1.532e+10	3.737e+07
- hl_	9.689	1.742e+10	3.737e+07
- hs_	9.564	1.719e+10	3.737e+07
flux_	100	7.598e+09	6080
pde_	100	1.48e+09	6080
phase_	100	1.142e+11	6080
- tsofx_	11.72	1.339e+10	2.40e+07
- tlofx_	11.49	1.312e+10	2.40e+07
- esld_	12.88	1.471e+10	2.40e+07
- elgds_	12.69	1.449e+10	2.40e+07
- tinsol_	4.999e-07	571	1
- timmush_	1.114	1.273e+09	7.271e+04
- xsoft_	0.121	1.383e+08	7.271e+04
- xloft_	0.1031	1.178e+08	7.271e+04
- cpl_	0.913	1.018e+10	2.483e+07

Exclusive Profile of Metric PAPI_TOT_CYC.

Name	Percent	Total	Calls
TOTAL	100	5.017e+11	1
unknown	53.62	2.69e+11	1
proflux_	27.75	1.393e+11	9124
phase_	14.9	7.475e+10	6080
flux_	3.096	1.554e+10	6080
pde_	0.6356	3.189e+09	6080

Inclusive Profile of Metric PAPI_TOT_CYC.

Name	Percent	Total	SubCalls
TOTAL	100	5.017e+11	0
proflux_	57.32	2.876e+11	2.242e+08
phase_	38.92	1.953e+11	1.247e+08
flux_	3.096	1.554e+10	0
pde_	0.6356	3.189e+09	0

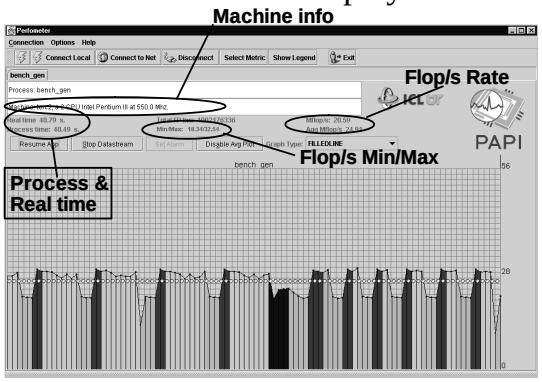
1-Level Inclusive Call Tree of Metric PAPI_TOT_CYC.

Parent/-Child	Percent	Total	Calls
TOTAL	100	5.017e+11	1
proflux_	100	2.876e+11	9124
- akl_	7.945	2.285e+10	3.737e+07
- aks_	7.871	2.264e+10	3.737e+07
- cpl_	8.84	2.542e+10	3.737e+07
- cps_	8.705	2.503e+10	3.737e+07
- hl_	9.252	2.661e+10	3.737e+07
- hs_	8.967	2.579e+10	3.737e+07
flux_	100	1.554e+10	6080
pde_	100	3.189e+09	6080
phase_	100	1.953e+11	6080
- tsofx_	12.42	2.425e+10	2.40e+07
- tlofx_	12.42	2.425e+10	2.40e+07
- esld_	13.41	2.618e+10	2.40e+07
- elgds_	13.41	2.62e+10	2.40e+07
- tinsol_	1.013e-06	1978	1
- timmush_	1.716	3.351e+09	7.271e+04
- xsoft_	0.1749	3.415e+08	7.271e+04
- xloft_	0.151	2.95e+08	7.271e+04
- cpl_	8.032	1.569e+10	2.483e+07

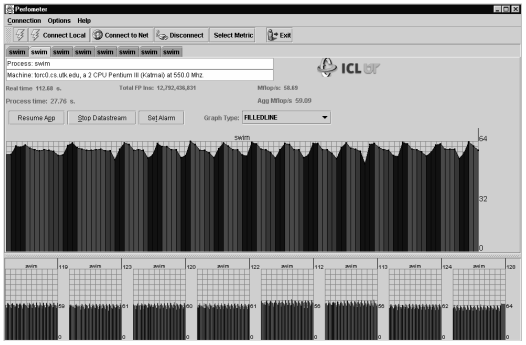
Perfometer

- Application is instrumented with PAPI
  - call perfometer()
  - call mark_perfometer(int color, char *label)
- Application is started. At the call to perfometer, signal handler and a timer are set up to collect and send the information to a Java applet containing the graphical view.
- Sections of code that are of interest can be designated with specific colors
- Real-time display or trace file

Perfometer Display



Perfometer Parallel Interface



KAP/Pro Toolset

- http://www.kai.com/
- Set of tools for developing parallel scientific software using OpenMP
- Components
  - Guide OpenMP compiler
  - Assure OpenMP debugger
  - GuideView performance analyzer
  - Utilities for translating older directives to OpenMP
- Licensed at ERDC MSRC and ARL MSRC
- Being phased out by Intel/KSL

GuideView

- Intuitive, color-coded display of parallel performance bottlenecks
- Regions of code are identified where improving local performance will have the greatest impact on overall performance.
- Configuration file Gvproperties.txt controls GUI features (fonts, colors, window sizes and locations, etc.)
- Online help system under Help menu
- Use kmp_set_parallel_name to name parallel regions so that name will be displayed by GuideView

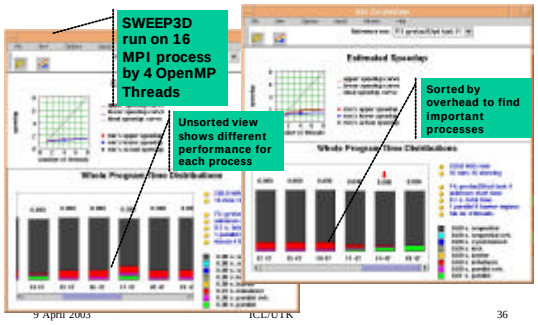
Guide Instrumentation Options

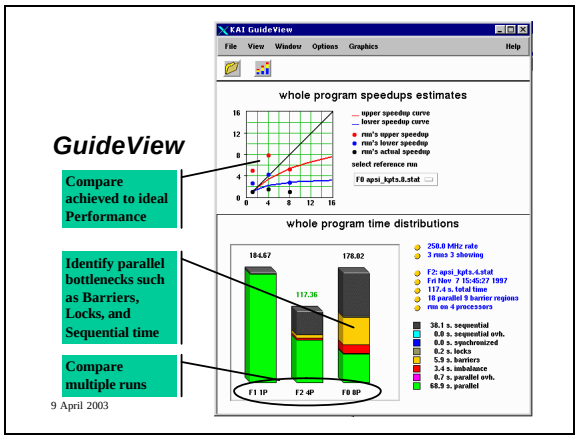
-WGnoopenmp
- Enable profiling but no OpenMP

-WGprof
- Activates profiling for Vampir and GuideView; implies –WGstats

-WGprof_leafprune=<integer>
- Sets the minimum size of procedures to retain in Vampir or GuideView profiles to <integer> lines
- Use to reduce instrumentation overhead and tracefile size

GuideView – OpenMP Profile



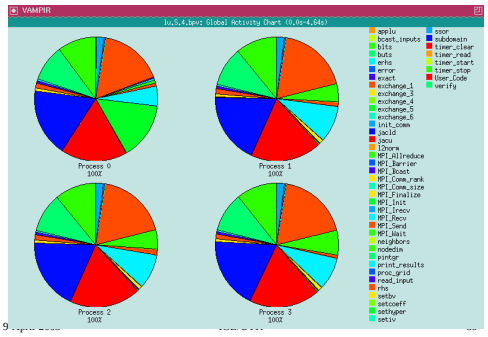


9 April 2003

Vampir

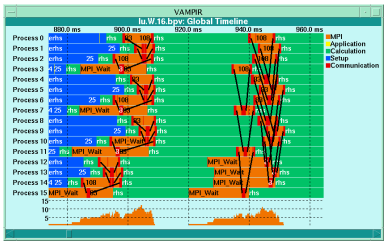
- http://www.pallas.com/e/products/vampir/index.htm
- Primarily a tracing tool but also generates and displays profiling statistics
- Version 3 will support OpenMP and mixed MPI/OpenMP
- Version 3 will use PAPI to access hardware counter data
- Licensed at ERDC MSRC, ARL MSRC, and ARSC

Vampir Statistics Display (also available in text form)



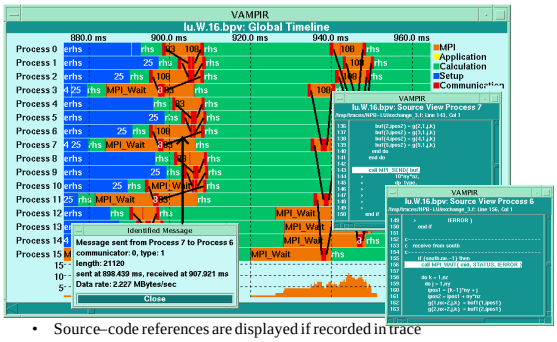
Vampir: Timeline Diagram

- Functions organized into groups
- Coloring by group
- Message lines can be colored by tag or size



- Information about states, messages, collective, and I/O operations available by clicking on the representation

Vampir: Timeline Diagram (Message Info)



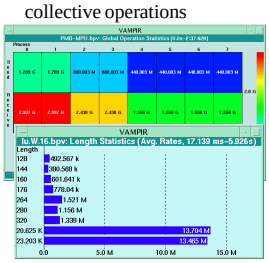
- Source–code references are displayed if recorded in trace

Vampir: Profile Statistics Displays

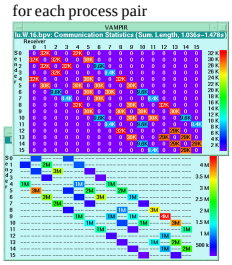
- Aggregated profiling information: execution time, # calls, inclusive/exclusive
- Available for all/any group (activity)
- Available for all routines (symbols)
- Available for any trace part (select in timeline diagram)

Vampir: Communication Statistics Displays

- Bytes sent/received for collective operations

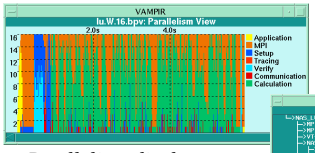


- Byte and message count, min/max/avg message length and min/max/avg bandwidth for each process pair

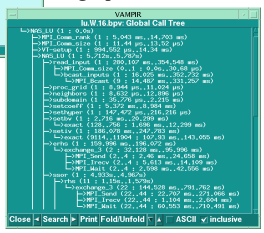


- Message length statistics
- Available for any trace part

Vampir: Other Features

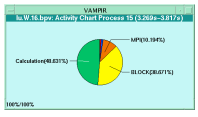


- ❒ Dynamic global call graph tree

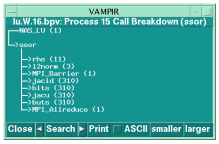


- Parallelism display
- Powerful filtering and trace comparison features
- All diagrams highly customizable (through context menus)

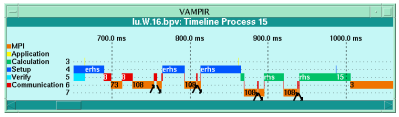
Vampir: Process Displays



- Activity chart

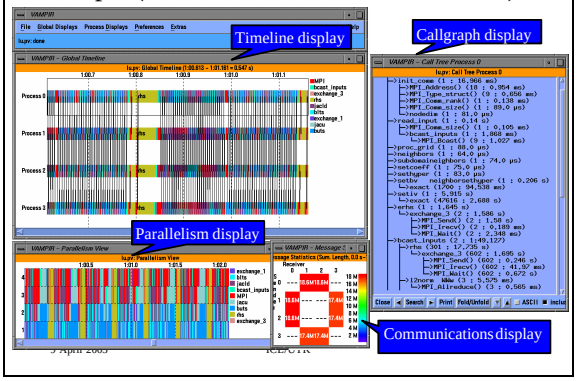


- ❒ Call tree

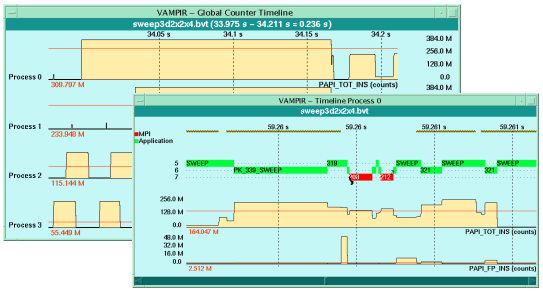


- ❒ Timeline
- ❒ For all selected processes in the global displays

Vampir (NAS Parallel Benchmark – LU)



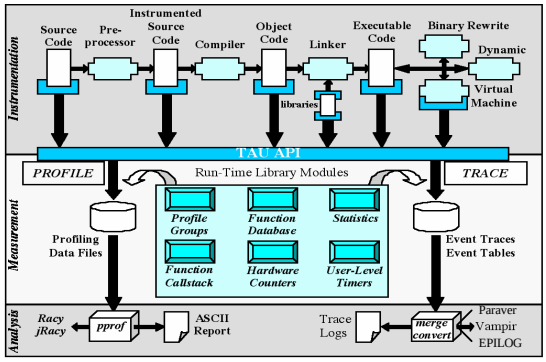
Vampir v3.x: Hardware Counter Data



TAU

- Tuning and Analysis Utilities
- http://www.cs.uoregon.edu/research/paracomp/tau/
- Portable profiling and tracing toolkit for performance analysis of parallel programs
  - Fortran 77/90, C, C++, Java
  - OpenMP, Pthreads, MPI, mixed mode
- In use at DOE ASCI Labs and at NCSA
- Being installed and supported at DoD HPC Centers as part of PET CE002

TAU Performance System Architecture



TAU Instrumentation

- Manually using TAU instrumentation API
- Automatically using
  - Program Database Toolkit (PDT)
  - MPI profiling library
  - Opari OpenMP rewriting tool
- Uses PAPI to access hardware counter data

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 Components

- Language front end
  - Edison Design Group (EDG): C, C++
  - Mutek Solutions Ltd.: F77, F90
  - 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

PDT Status

- Program Database Toolkit (Version 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
  - TAU instrumentor (C/C++/F90)
  - Program analysis support for SILOON and CHASM
- Platforms
  - SGI, IBM, Compaq, SUN, HP, Linux (IA32/IA64), Apple, Windows, Cray T3E, Hitachi

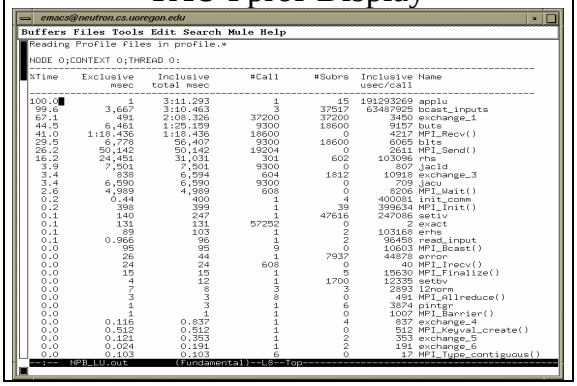
OPARI: Basic Usage (f90)

- 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

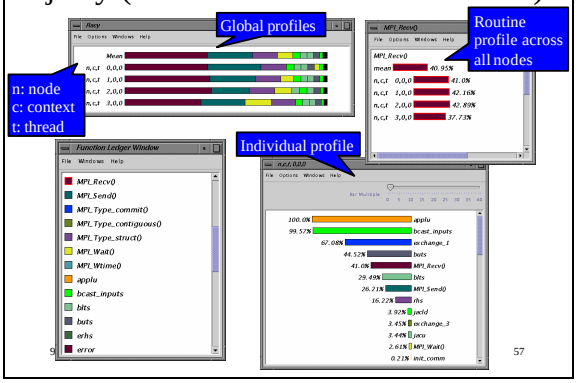
TAU Analysis

- Profile analysis
  - pprof
    - parallel profiler with text-based display
  - racy
    - graphical interface to pprof (Tcl/Tk)
  - jracy
    - Java implementation of Racy
- Trace analysis and visualization
  - Trace merging and clock adjustment (if necessary)
  - Trace format conversion (ALOG, SDDF, Vampir)
  - Vampir (Pallas) trace visualization
  - Paraver (CEPBA) trace visualization

TAU Pprof Display



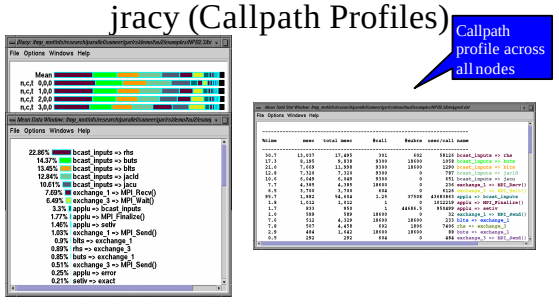
jracy (NAS Parallel Benchmark – LU)



1-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 1-level callpath used as its key
    - "a( )=>b( )" : name for time spent in "b" when called by "a"
- Map returns pointer to callpath profile structure
  - 1-level callpath is profiled using this profiling data
- Build upon TAU's performance mapping technology
- Measurement is independent of instrumentation
- Use –PROFILECALLPATH to configure TAU

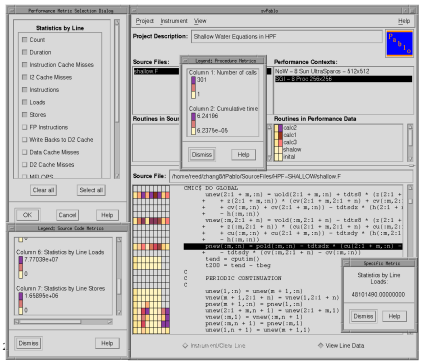
jracy (Callpath Profiles)



SvPablo

- Sourceview Pablo
- http://www-pablo.cs.uiuc.edu/Project/SVPablo/SVPabloOverview.htm
- Collects profile data and maps it to constructs in the original source code
- Automatic and interactive instrumentation of Fortran 77/90, C, MPI, OpenMP
- Uses PAPI to access hardware counter data
- In use at DOE sites and at NCSA

SvPablo



HPCView

- http://www.cs.rice.edu/~dsystem/hpcview/
- Combines multiple set of program profile data
- Correlates profile data with source code
- Computes derived performance metrics
- Generates browsable database
- Uses ssrun, uprofile, and PAPI to collect profile data
- In use at DOE ASCI Labs and at NCSA

VProf

- Visual Profiler
- http://aros.ca.sandia.gov/~cljanss/perf/vprof/
- Generate profiling data sorted by file, function, line
- Display using vprof GUI or cprof command-line utility
- Ported to Linux/IA-32/IA-64, AIX/RS6000, Linux/Alpha
- In use at DOE ASCI sites and at NCSA

vprof