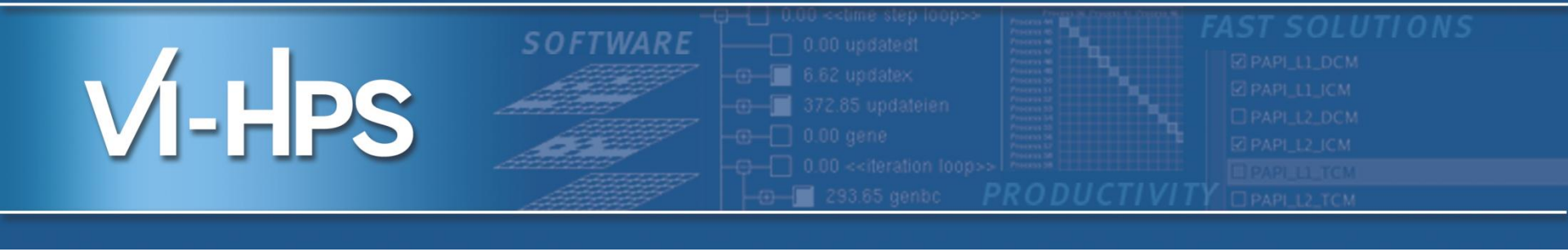


# Hands-on Practical Hybrid Parallel Application Performance Engineering

***EuroMPI Conference, Vienna, Austria, September 23, 2012***

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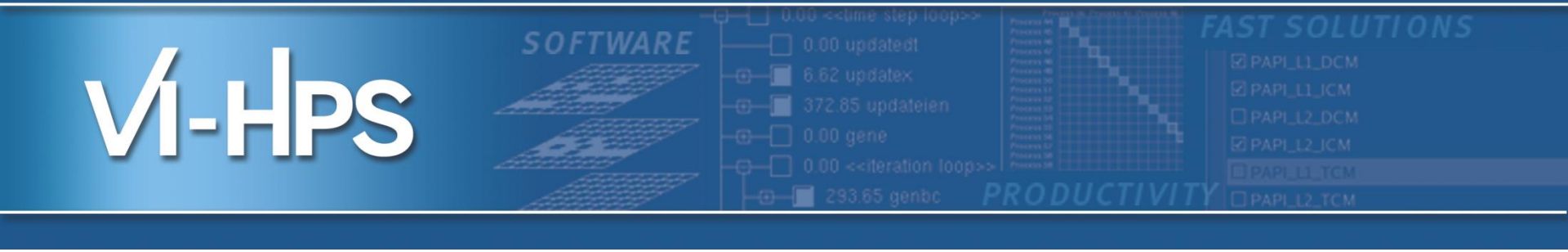
# Tutorial Agenda

| Time | Topic | Speaker |
|---|---|---|
| 9:00 – 9:15 | Introduction to VI-HPS | Geimer |
| 9:15 – 9:45 | Introduction to performance engineering | Gerndt |
| 9:45 – 10:00 | VI-HPS Live-DVD | all |
| 10:00 – 10:30 | *Break* | |
| 10:30 – 11:00 | Profile examination with **CUBE** | Geimer |
| 11:00 – 11:30 | Profile examination with **TAU** ParaProf | Shende |
| 11:30 – 11:45 | Profile data mining with **TAU** PerfExplorer | Shende |
| 11:45 – 12:30 | Interactive trace analysis with **Vampir** | Wesarg |
| 12:30 – 14:00 | *Lunch* | |
| 14:00 – 15:00 | Instrumentation & measurement with **Score-P** | Wesarg / Geimer |
| 15:00 – 15:30 | Automatic trace analysis with **Scalasca** | Geimer |
| 15:30 – 16:00 | *Break* | |
| 16:00 – 16:45 | Online analysis with **Periscope** | Gerndt |
| 16:45 – 17:00 | Wrap-up & discussion | all |




# Introduction to VI-HPS

Markus Geimer
Jülich Supercomputing Centre

**Goal**: Improve the quality and accelerate the development process of complex simulation codes running on highly-parallel computer systems

- Start-up funding (2006–2011) by Helmholtz Association of German Research Centres


- Activities
  - Development and integration of HPC programming tools
    - Correctness checking & performance analysis
  - Training workshops
  - Service
    - Support email lists
    - Application engagement
  - Academic workshops

**http://www.vi-hps.org**

# VI-HPS partners (founders)




- Forschungszentrum Jülich
  - Jülich Supercomputing Centre
- RWTH Aachen University
  - Centre for Computing & Communication
- Technical University of Dresden
  - Centre for Information Services & HPC
- University of Tennessee (Knoxville)
  - Innovative Computing Laboratory

# VI-HPS partners (cont.)







- Barcelona Supercomputing Center
  - Centro Nacional de Supercomputación
- German Research School
  - Laboratory of Parallel Programming
- Lawrence Livermore National Lab.
  - Centre for Applied Scientific Computing
- Technical University of Munich
  - Chair for Computer Architecture
- University of Oregon
  - Performance Research Laboratory
- University of Stuttgart
  - HPC Centre
- University of Versailles St-Quentin
  - LRC ITACA

# Productivity tools

## Marmot/MUST

- MPI correctness checking

## PAPI

- Interfacing to hardware performance counters

## Periscope

- Automatic analysis via an on-line distributed search

## Scalasca

- Large-scale parallel performance analysis

## TAU

- Integrated parallel performance system

## Vampir/VampirTrace

- Event tracing and graphical trace visualization & analysis

## Score-P

- Common instrumentation & measurement infrastructure

# Productivity tools

## KCachegrind

- Callgraph-based cache analysis [x86 only]

## MAQAO

- Assembly instrumentation & optimization [x86 only]

## mpiP/mpiPview

- MPI profiling tool and analysis viewer

## ompP

- OpenMP profiling tool

## Open MPI

- Integrated memory checking

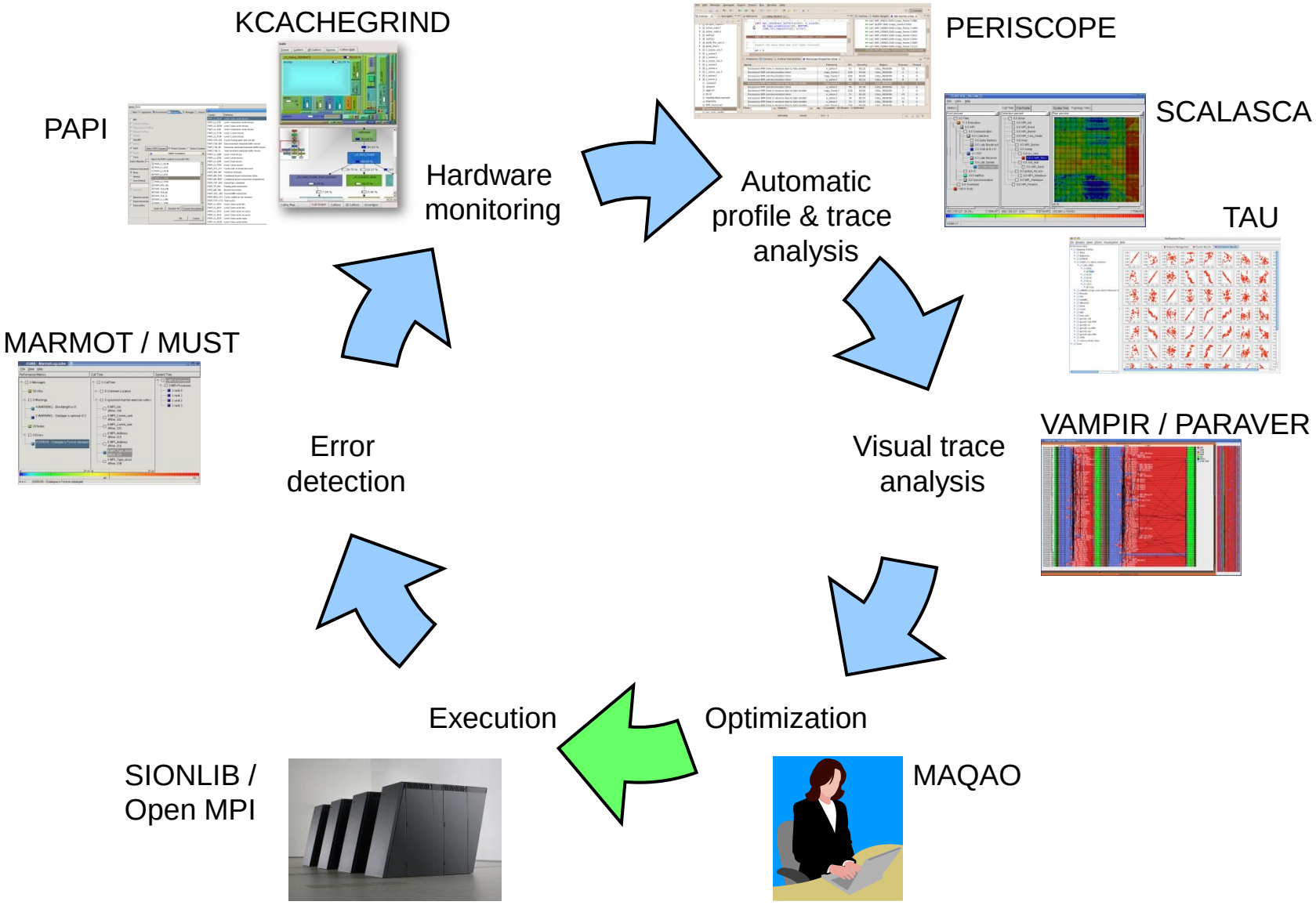
## Open|Speedshop

- Integrated parallel performance analysis environment

## Paraver/Extrae

- Event tracing and graphical trace visualization & analysis

# Technologies and their integration



Tools will ***not*** automatically make you, your applications or computer systems more *productive*.

However, they can help you understand ***how*** your parallel code executes and ***when / where*** it's necessary to work on *correctness* and *performance* issues.

# VI-HPS training & Tuning Workshops


- Goals
  - Give an overview of the programming tools suite
  - Explain the functionality of individual tools
  - Teach how to use the tools effectively
  - Offer hands-on experience and expert assistance using tools
  - Receive feedback from users to guide future development
- For best results, bring & analyze/tune your own code(s)!

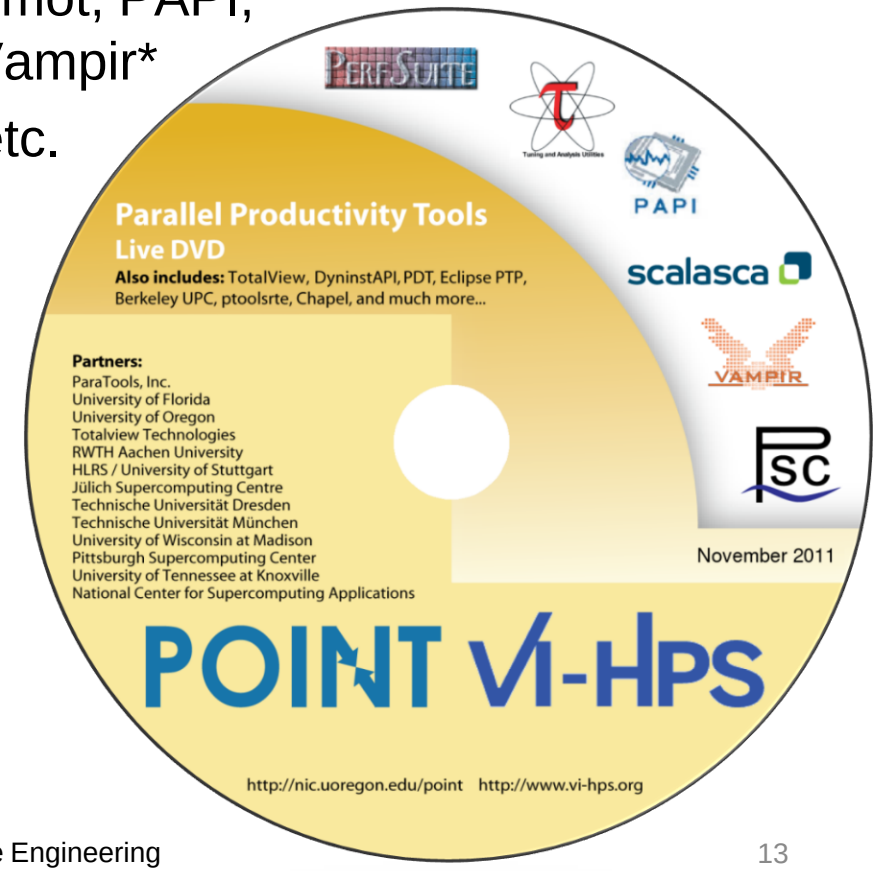
- VI-HPS Tutorial series
  - SC'08, ICCS'09, SC'09, Cluster'10, SC'10, SC'11, EuroMPI'12
- VI-HPS Tuning Workshop series
  - 2008 (Aachen & Dresden), 2009 (Jülich & Bremen), 2010 (Garching & Amsterdam), 2011 (Stuttgart & Aachen), 2012 (St-Quentin), **2012/10/16–19 (Garching)**

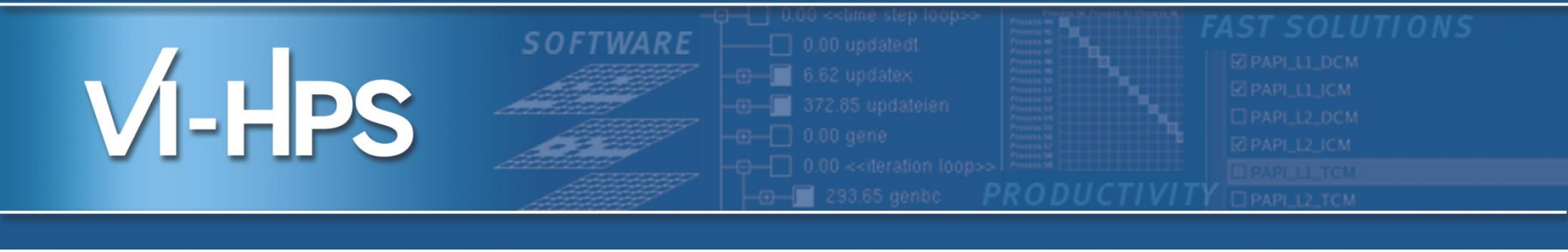
# Upcoming events

- 10th VI-HPS Tuning Workshop (16-19 Oct 2012)
  - Hosted by LRZ, Garching-bei-München, Germany
  - Using PRACE Tier-0 *SuperMUC* iDataPlex system
  - Scalasca, Vampir, TAU, Periscope, KCachegrind, MAQAO, ...
- Further events to be determined
  - (one-day) tutorials
    - With guided exercises usually using a Live-DVD
  - (multi-day) training workshops
    - With your own applications on real HPC systems
- Check www.vi-hps.org/training for announced events
- Contact us if you might be interested in hosting an event

# VI-HPS Linux Live DVD/ISO

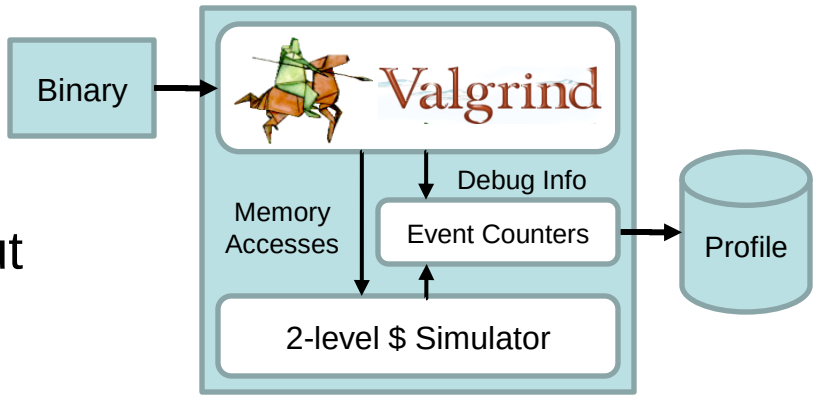
- Bootable Linux installation on DVD (or USB memory stick)
- Includes everything needed to try out our parallel tools on an 64-bit x86-architecture notebook computer
  - VI-HPS tools: KCachegrind, Marmot, PAPI, Periscope, Scalasca, TAU, VT/Vampir*
  - Also: Eclipse/PTP, TotalView*, etc.
    * time/capability-limited evaluation licences provided for commercial products
  - GCC (w/ OpenMP), OpenMPI
  - Manuals/User Guides
  - Tutorial exercises & examples
- Produced by U. Oregon PRL
  - Sameer Shende



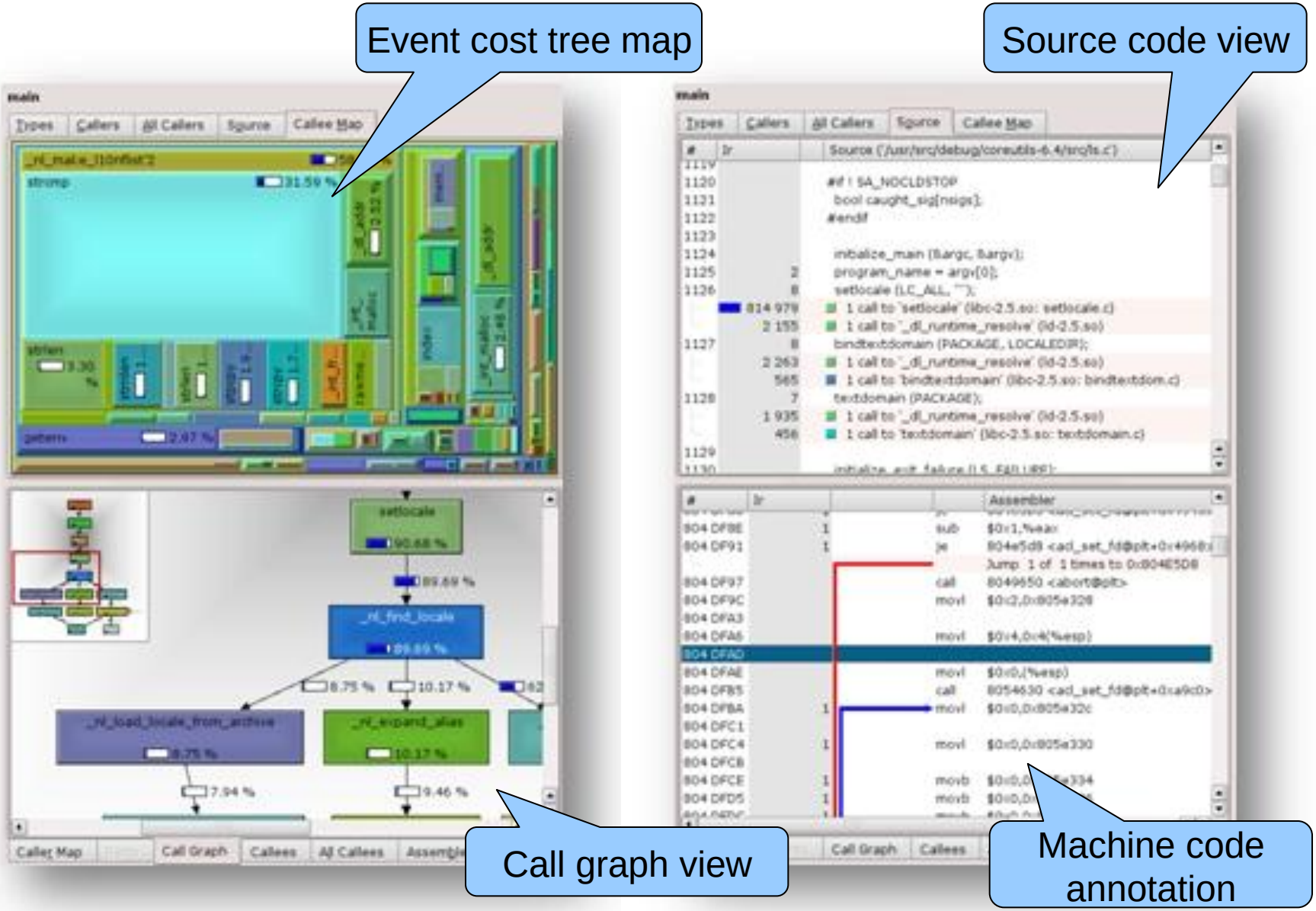



# VI-HPS productivity tools suite

- Cachegrind: cache analysis by simple cache simulation
  - Captures dynamic callgraph
  - Based on valgrind dynamic binary instrumentation
  - Runs on x86/PowerPC/ARM unmodified binaries
    - No root access required
  - ASCII reports produced
- [KQ]Cachegrind GUI
  - Visualization of cachegrind output
- Developed by TU Munich
  - Released as GPL open-source
  - http://kcachegrind.sf.net/



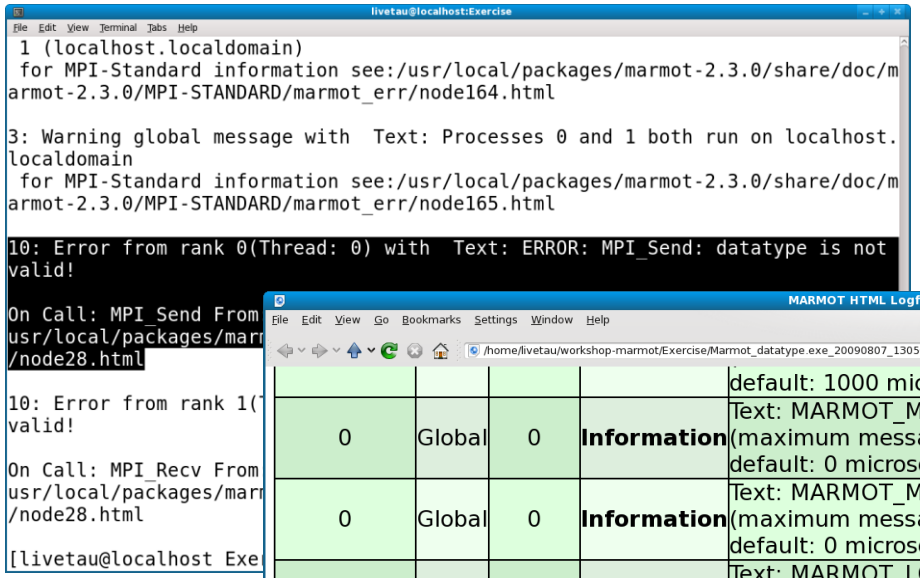
# KCachegrind GUI

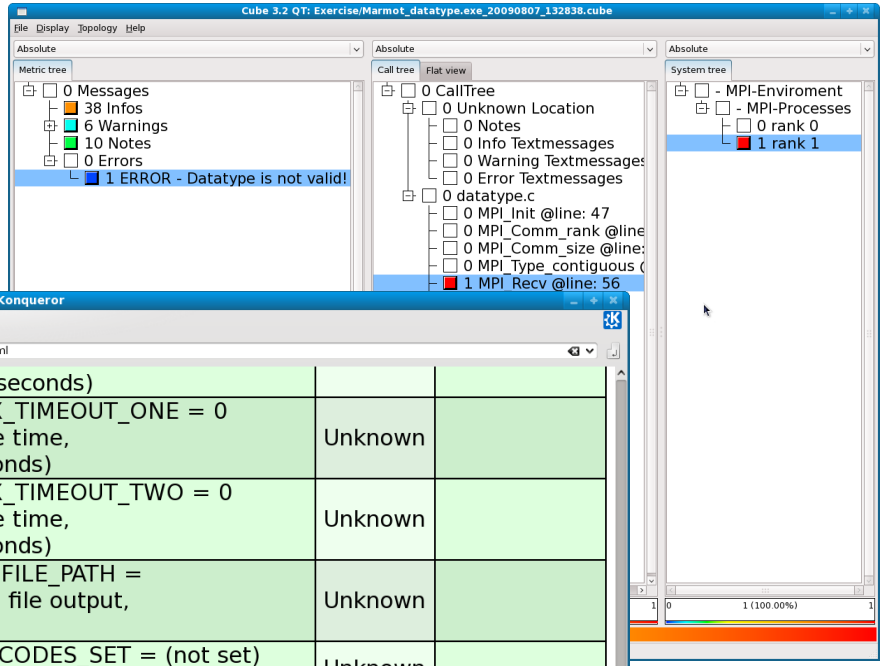


# Marmot


- Tool to check for correct MPI usage at runtime
  - Checks conformance to MPI standard
    - Supports Fortran & C bindings of MPI-1.2
  - Checks parameters passed to MPI
  - Monitors MPI resource usage
- Implementation
  - C++ library gets linked to the application
  - Does not require source code modifications
  - Additional process used as DebugServer
  - Results written in a log file (ASCII/HTML/CUBE)
- Developed by HLRS & TU Dresden
  - Released as open-source
  - http://www.hlrs.de/organization/av/amt/projects/marmot

# Marmot logfiles




MARMOT HTML Logfile - Konqueror

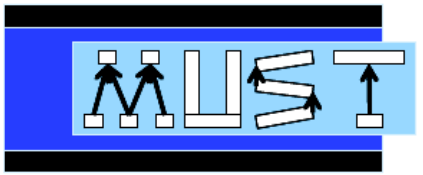
File Edit View Go Bookmarks Settings Window Help

/home/livetau/workshop-marmot/Exercise/Marmot_datatype.exe_20090807_130509.html

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | default: 1000 microseconds) | | |
| 0 | Global | 0 | **Information** | Text: MARMOT_MAX_TIMEOUT_ONE = 0 (maximum message time, default: 0 microseconds) | Unknown | |
| 0 | Global | 0 | **Information** | Text: MARMOT_MAX_TIMEOUT_TWO = 0 (maximum message time, default: 0 microseconds) | Unknown | |
| 0 | Global | 0 | **Information** | Text: MARMOT_LOGFILE_PATH = (path of Marmot log file output, default: ) | Unknown | |
| 0 | Global | 0 | **Information** | Text: MARMOT_ERRCODES_SET = (not set) (not functional yet) | Unknown | |
| 0 | Global | 0 | **Information** | Text: End of the environmental variables info. | Unknown | |
| 0 | Global | 0 | **Information** | Text: Thread Syncronisation is disabled.If you are using multiple threads errors might occur | Unknown | |
| 3 | Global | 0 | **Warning** | Text: Debugserver runs on same node as process 0 (localhost.localdomain) | Unknown | Infos see MPI-Standard |
| 3 | Global | 0 | **Warning** | Text: Debugserver runs on same node as process 1 (localhost.localdomain) | Unknown | Infos see MPI-Standard |
| 3 | Global | 0 | **Warning** | Text: Processes 0 and 1 both run on localhost.localdomain | Unknown | Infos see MPI-Standard |
| 10 | 0 | 0 | **Error** | Text: ERROR: MPI_Send: datatype is not valid!<br>Call: MPI_Send | datatype.c line: 53 | Infos see MPI-Standard |
| 10 | 1 | 0 | **Error** | Text: ERROR: MPI_Recv: datatype is not valid!<br>Call: MPI_Recv | datatype.c line: 56 | Infos see MPI-Standard |

- Next generation MPI runtime error detection tool
  - Successor of the Marmot and Umpire tools
  - Initial merge of Marmot's many local checks with Umpire's non-local checks
  - Improved scalability expected in future
  - Exploits CMake, GTI & PnMPI infrastructure

- Developed by TU Dresden, LLNL & LANL
  - BSD license open-source initial release in November 2011
  - http://tu-dresden.de/zih/must/



- Portable performance counter library & utilities
  - Configures and accesses hardware/system counters
  - Predefined events derived from available native counters
  - Core component for CPU/processor counters
    - instructions, floating point operations, branches predicted/taken, cache accesses/misses, TLB misses, cycles, stall cycles, …
    - performs transparent multiplexing when required
  - Extensible components for off-processor counters
    - InfiniBand network, Lustre filesystem, system hardware health, …
  - Used by multi-platform performance measurement tools
    - Periscope, Scalasca, TAU, VampirTrace, ...
- Developed by UTK-ICL
  - Available as open-source for most modern processors http://icl.cs.utk.edu/papi/

# PAPI preset counters (and their definitions)

- juropa$ ***papi_avail***
- Available events and hardware information.
  ---
  PAPI Version : 4.1.0.0
  Vendor string and code : GenuineIntel (1)
  Model string and code : Intel(R) Xeon(R) CPU X5570 @ 2.93GHz (26)
  CPU Revision : 5.000000
  CPUID Info : Family: 6 Model: 26 Stepping: 5
  CPU Megahertz : 1600.000000
  CPU Clock Megahertz : 1600
  Hdw Threads per core : 2
  Cores per Socket : 4
  NUMA Nodes : 2
  CPU's per Node : 8
  Total CPU's : 16
  Number Hardware Counters : 16
  Max Multiplex Counters : 512
  ---
  Name Code Avail Deriv Description
- **PAPI_L1_DCM** 0x80000000 Yes No
  Level 1 data cache misses
- **PAPI_L1_ICM** 0x80000001 Yes No
  Level 1 instruction cache misses
  ...
  ---
- Of 107 possible events, 35 are available, of which 9 are derived.

- juropa$ ***papi_avail -d***
- ...
  Symbol Event Code Count |Short Descr.|
  |Long Description|
  |Developer's Notes|
  |Derived|
  |PostFix|
  Native Code[n]: <hex> |name|
- **PAPI_L1_DCM** 0x80000000 1 |L1D cache misses|
  |Level 1 data cache misses|
  ||
  |NOT_DERIVED|
  ||
  Native Code[0]: 0x40002028 |*L1D:REPL*|
- **PAPI_L1_ICM** 0x80000001 1 |L1I cache misses|
  |Level 1 instruction cache misses|
  ||
  |NOT_DERIVED|
  ||
  Native Code[0]: 0x40001031 |*L1I:MISSES*|
- **PAPI_L2_DCM** 0x80000002 2 |L2D cache misses|
  |Level 2 data cache misses|
  ||
  |*DERIVED_SUB*|
  ||
  Native Code[0]: 0x40000437 |*L2_RQSTS:MISS*|
  Native Code[1]: 0x40002037 |*L2_RQSTS:IFETCH_MISS*|
- ...



# PAPI native counters (and qualifiers)

- juropa$ papi_native_avail
- Available native events and hardware information.
- ...
- Event Code Symbol | Long Description |

```
--------------------------------------------------------------------------------
0x40000000  UNHALTED_CORE_CYCLES  | count core clock cycles whenever the cloc |
        | k signal on the specific core is running (not halted). Alias to e |
        | vent CPU_CLK_UNHALTED:THREAD                                      |
--------------------------------------------------------------------------------
0x40000001  INSTRUCTION_RETIRED  | count the number of instructions at retire |
        | ment. Alias to event INST_RETIRED:ANY_P                           |
--------------------------------------------------------------------------------
...
```

- ```
  --------------------------------------------------------------------------------
  0x40000086  UNC_SNP_RESP_TO_REMOTE_HOME  | Remote home snoop response - LLC d |
          | oes not have cache line                                         |
    40000486  :I_STATE  | Remote home snoop response - LLC does not have cache  |
          | line                                                            |
    40000886  :S_STATE  | Remote home snoop response - LLC has  cache line in S |
          |  state                                                          |
    40001086  :FWD_S_STATE  | Remote home snoop response - LLC forwarding cache |
          |  line in S state.                                               |
    40002086  :FWD_I_STATE  | Remote home snoop response - LLC has forwarded a  |
          | modified cache line                                             |
    40004086  :CONFLICT  | Remote home conflict snoop response                |
    40008086  :WB  | Remote home snoop response - LLC has cache line in the M s |
          | tate                                                            |
    40010086  :HITM  | Remote home snoop response - LLC HITM                 |
  --------------------------------------------------------------------------------
  Total events reported: 135
  ```




  ```

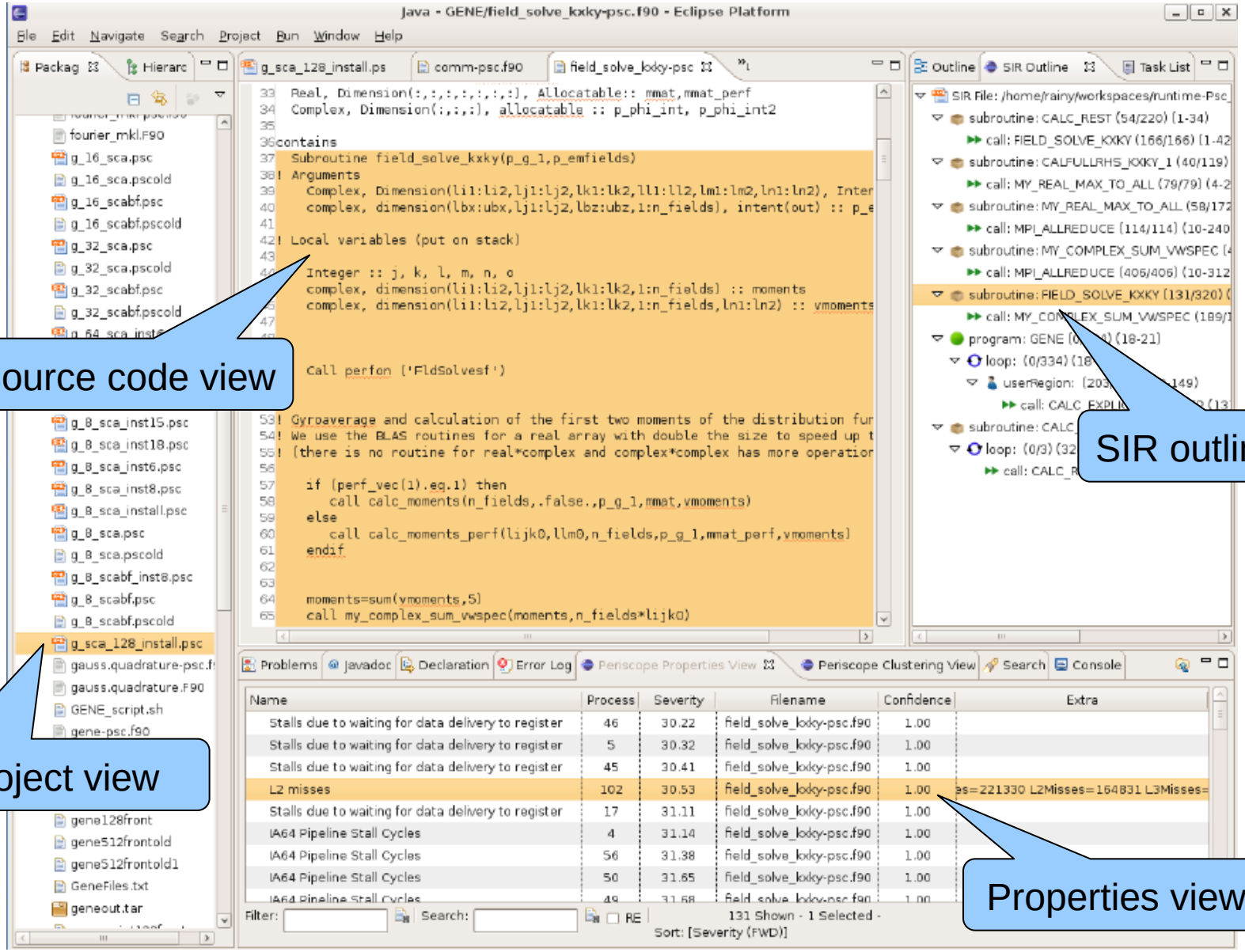
- Automated profile-based performance analysis
  - Iterative on-line performance analysis
    - Multiple distributed hierarchical agents
  - Automatic search for bottlenecks based on properties formalizing expert knowledge
    - MPI wait states, OpenMP overheads and imbalances
    - Processor utilization hardware counters
  - Clustering of processes/threads with similar properties
  - Eclipse-based integrated environment
- Supports
  - SGI Altix Itanium2, IBM Power and x86-based architectures
- Developed by TU Munich
  - Released as open-source
  - http://www.lrr.in.tum.de/periscope

# Periscope properties & strategies (examples)

- MPI
  - Excessive MPI communication time
  - Excessive MPI time due to many small messages
  - Excessive MPI time in receive due to late sender
  - …
- OpenMP
  - Load imbalance in parallel region/section
  - Sequential computation in master/single/ordered region
  - ...
- Hardware performance counters (platform-specific)
  - Cycles lost due to cache misses
    - High L1/L2/L3 demand load miss rate
  - Cycles lost due to no instruction to dispatch
  - ...

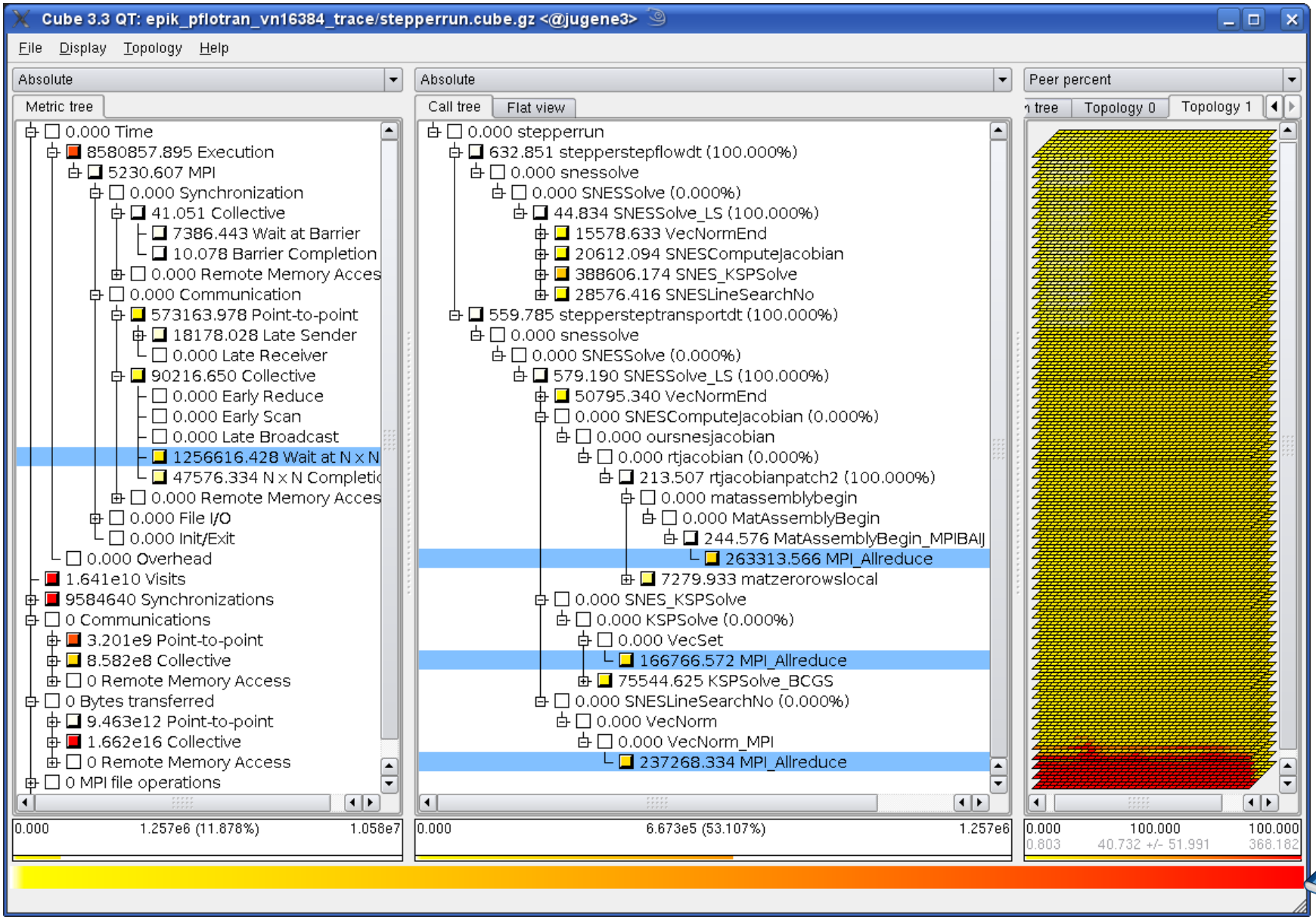


# Periscope plug-in to Eclipse environment

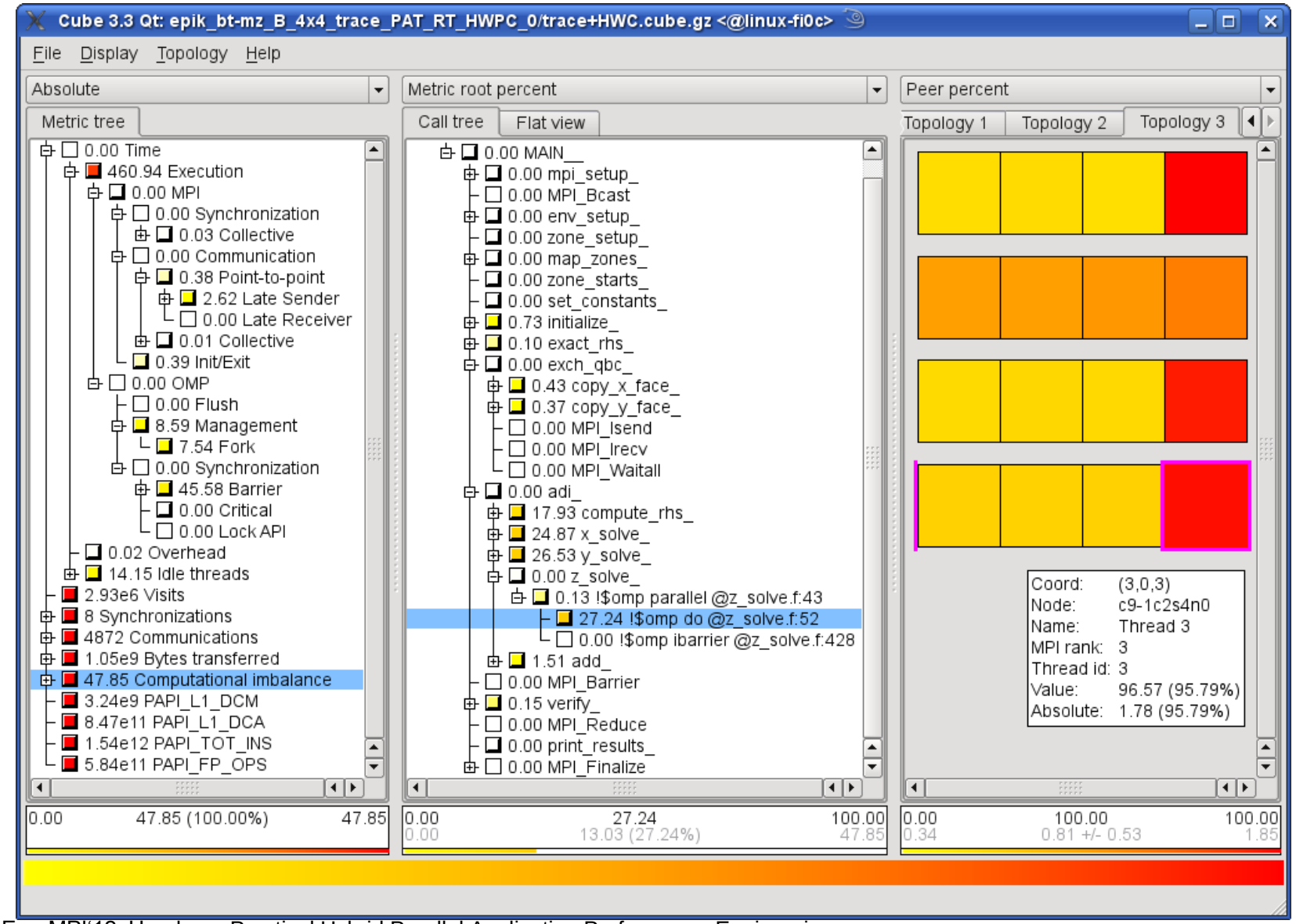


- Automatic performance analysis toolset
  - Scalable performance analysis of large-scale applications
    - particularly focused on MPI & OpenMP paradigms
    - analysis of communication & synchronization overheads
  - Automatic and manual instrumentation capabilities
  - Runtime summarization and/or event trace analyses
  - Automatic search of event traces for patterns of inefficiency
    - Scalable trace analysis based on parallel replay
  - Interactive exploration GUI and algebra utilities for XML callpath profile analysis reports
- Developed by JSC & GRS
  - Released as open-source
  - http://www.scalasca.org/

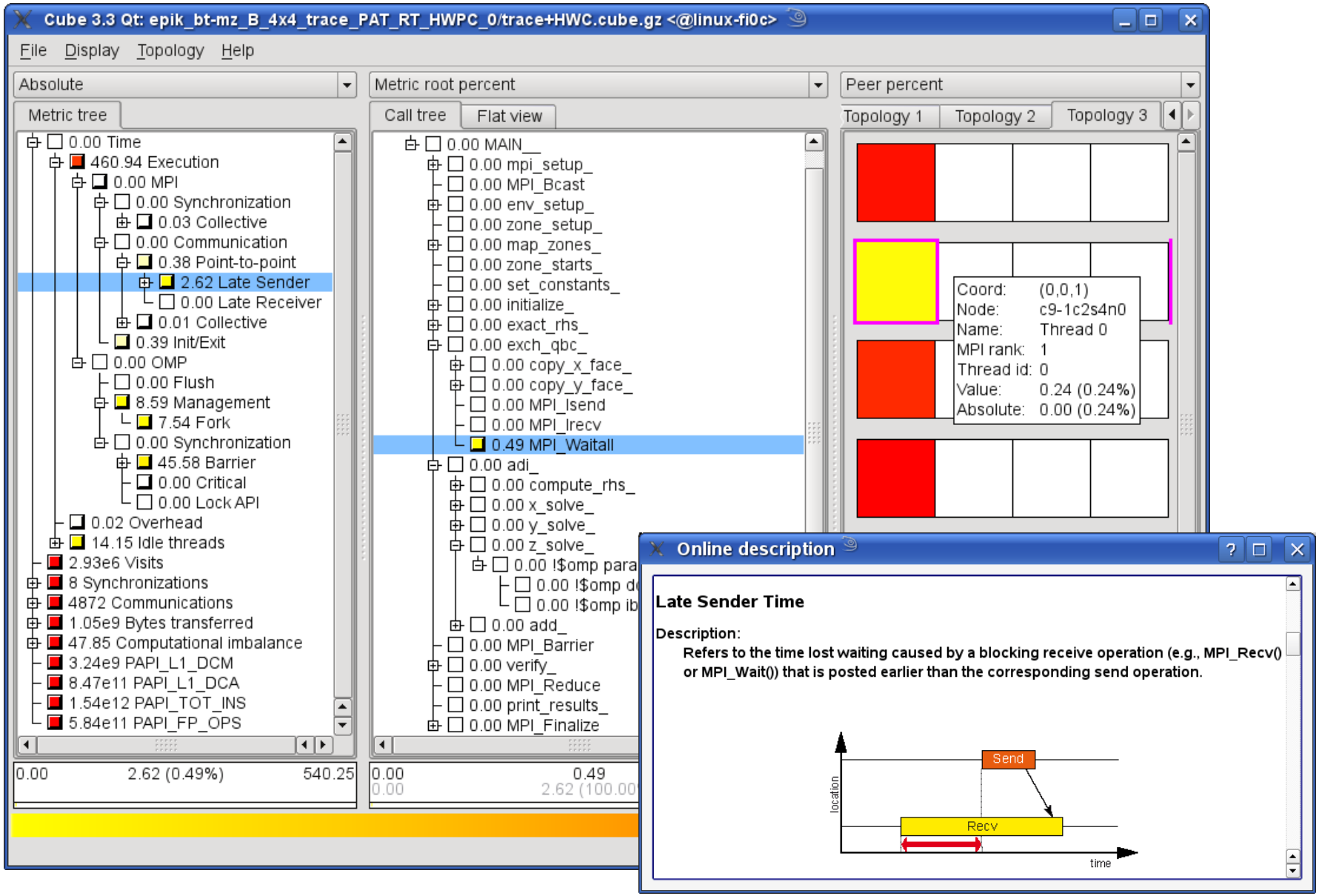
# Scalasca automatic trace analysis report



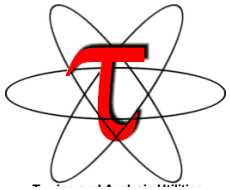
# Scalasca hybrid analysis report



# Scalasca automatic trace analysis report



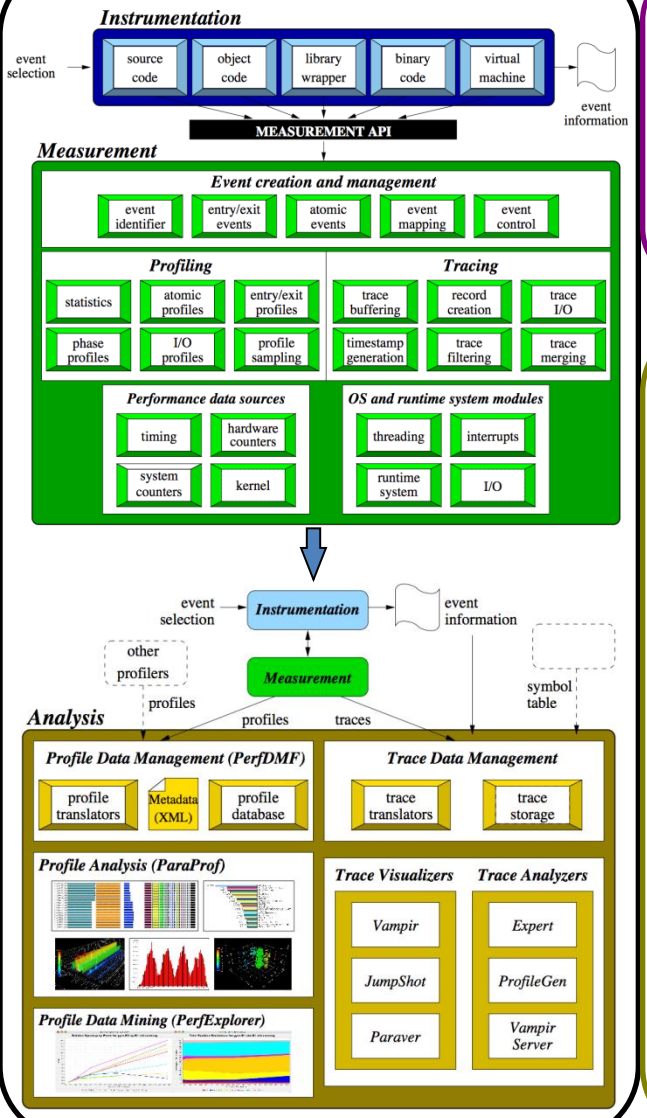
- Integrated performance toolkit
  - Instrumentation, measurement, analysis & visualization
    - Highly customizable installation, API, envvars & GUI
    - Supports multiple profiling & tracing capabilities
  - Performance data management & data mining
  - Targets all parallel programming/execution paradigms
    - Ported to a wide range of computer systems
  - Performance problem solving framework for HPC
  - Extensive bridges to/from other performance tools
    - PerfSuite, Scalasca, Vampir, ...
- Developed by U. Oregon/PRL
  - Broadly deployed open-source software
  - http://tau.uoregon.edu/



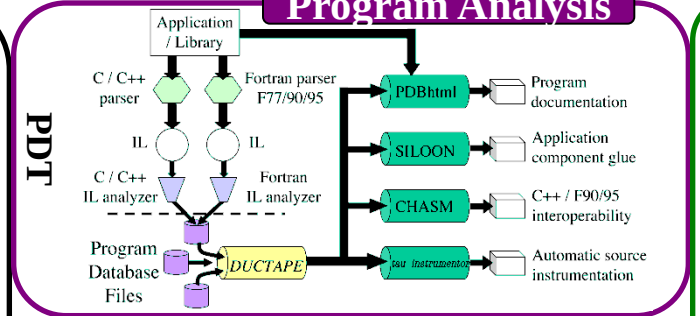
# TAU Performance System components

VI-HPS

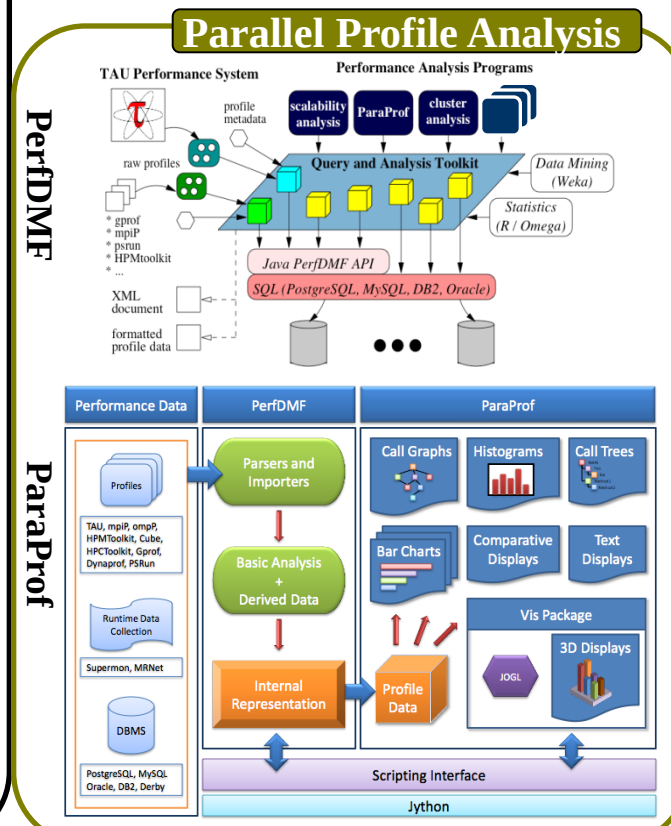
## TAU Architecture



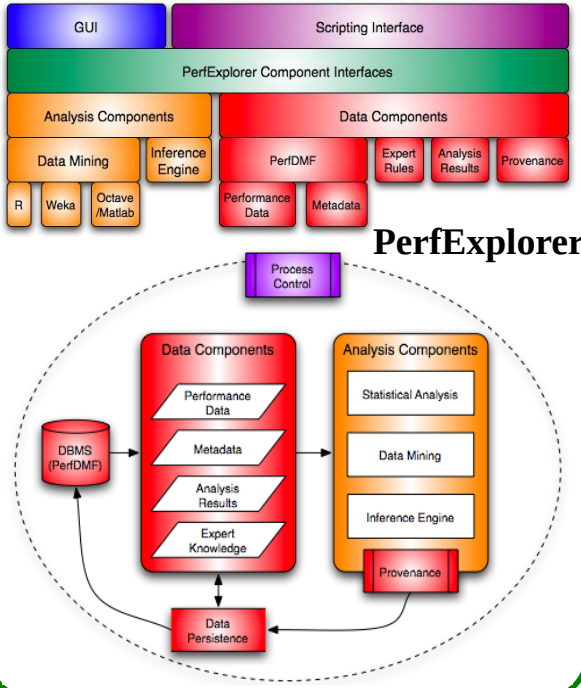

## Program Analysis



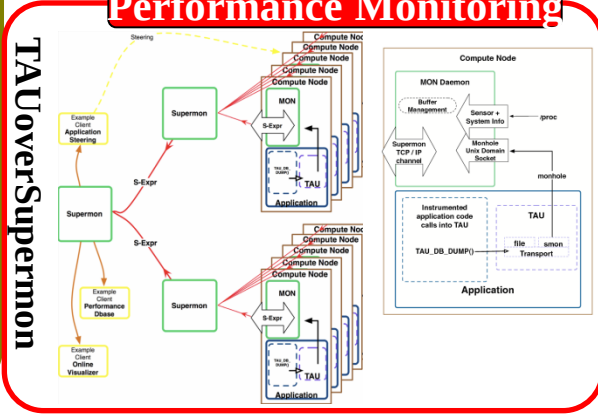

## Parallel Profile Analysis



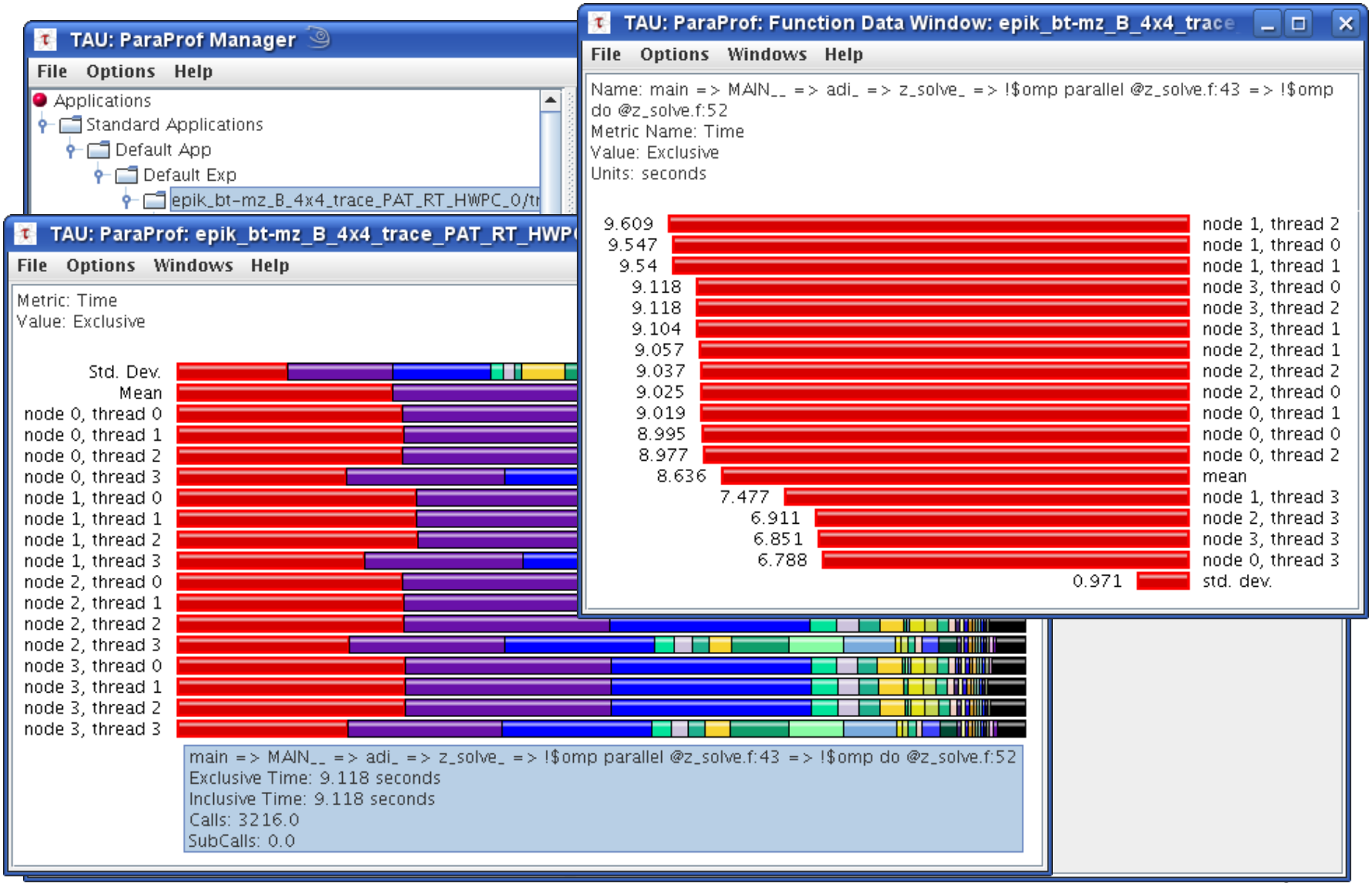

## Performance Data Mining



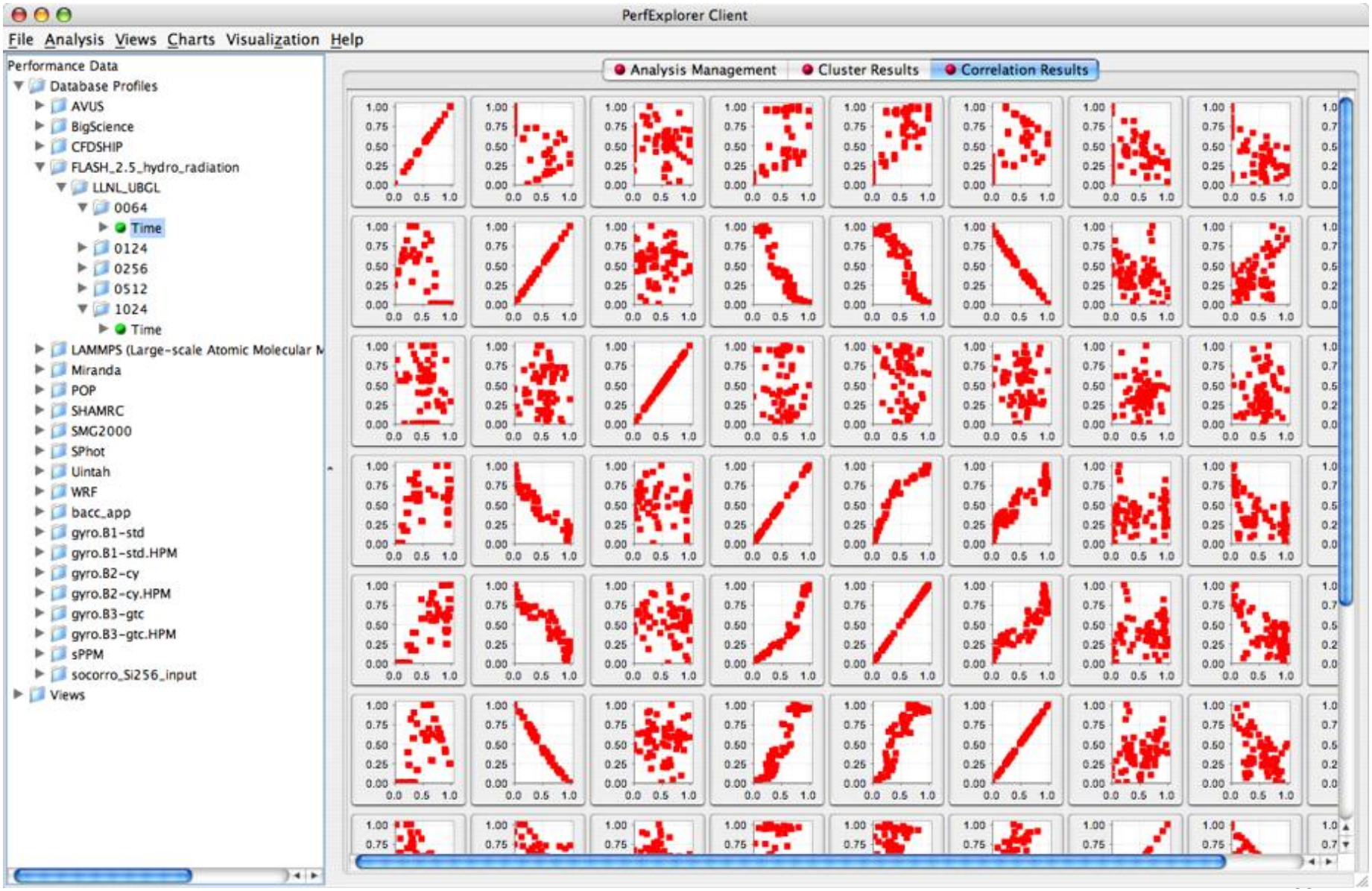

## Performance Monitoring



# TAU ParaProf GUI displays (selected)

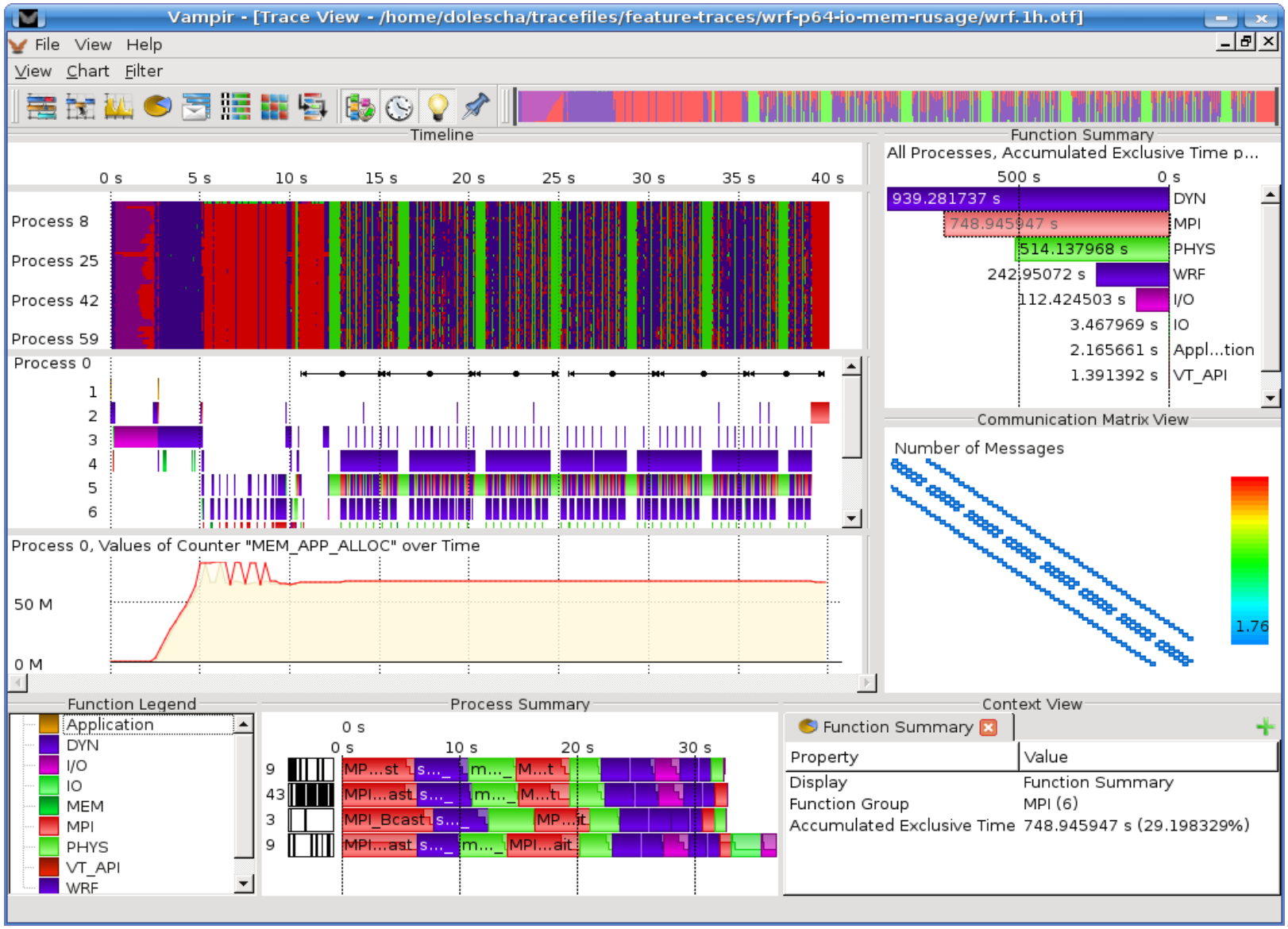


# TAU PerfExplorer data mining

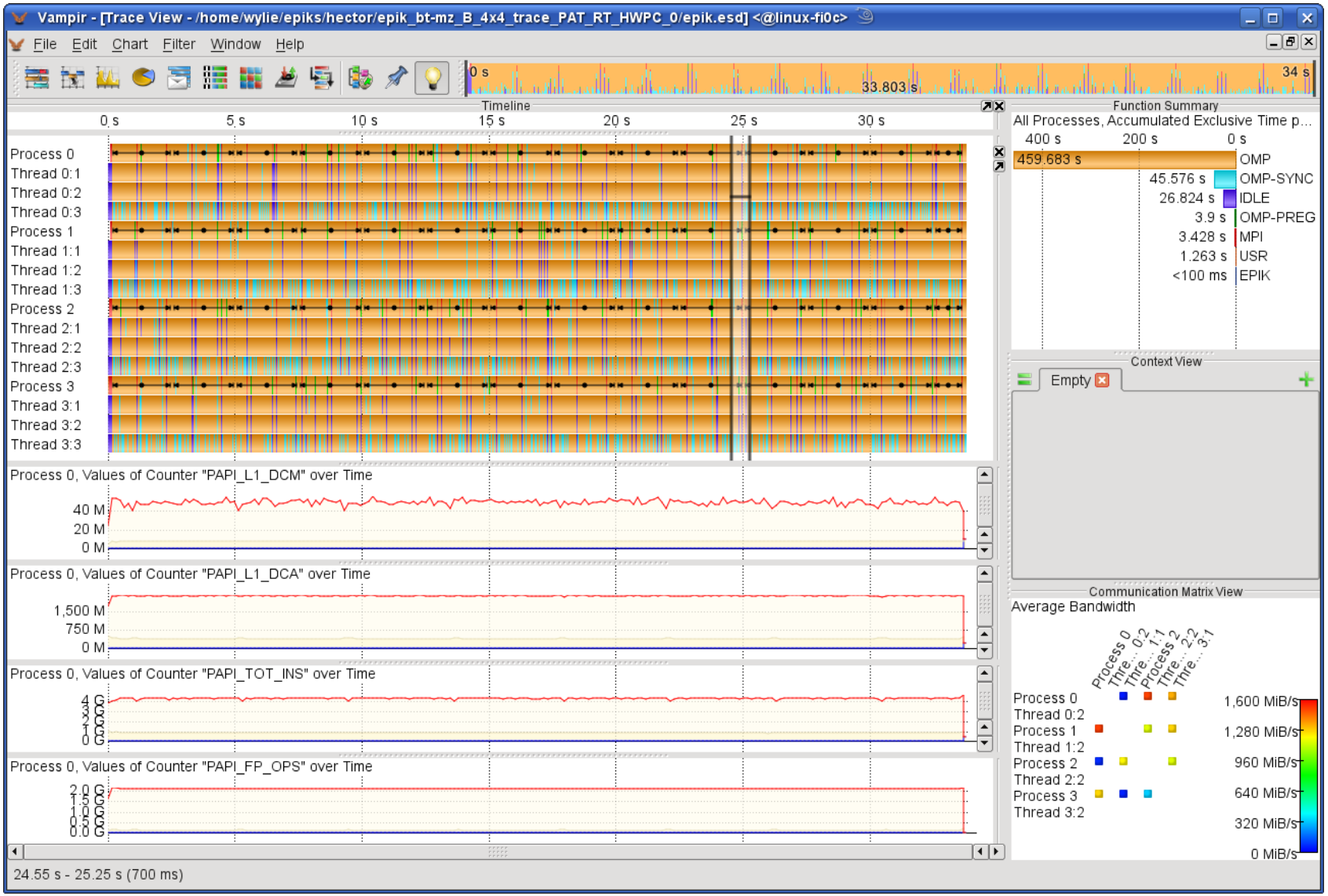


- Interactive event trace analysis
  - Alternative & supplement to automatic trace analysis
  - Visual presentation of dynamic runtime behaviour
    - event timeline chart for states & interactions of processes/threads
    - communication statistics, summaries & more
  - Interactive browsing, zooming, selecting
    - linked displays & statistics adapt to selected time interval (zoom)
    - scalable server runs in parallel to handle larger traces
- Developed by TU Dresden ZIH
  - Open-source VampirTrace library bundled with OpenMPI 1.3
  - http://www.tu-dresden.de/zih/vampirtrace/
  - Vampir Server & GUI have a commercial license
  - http://www.vampir.eu/

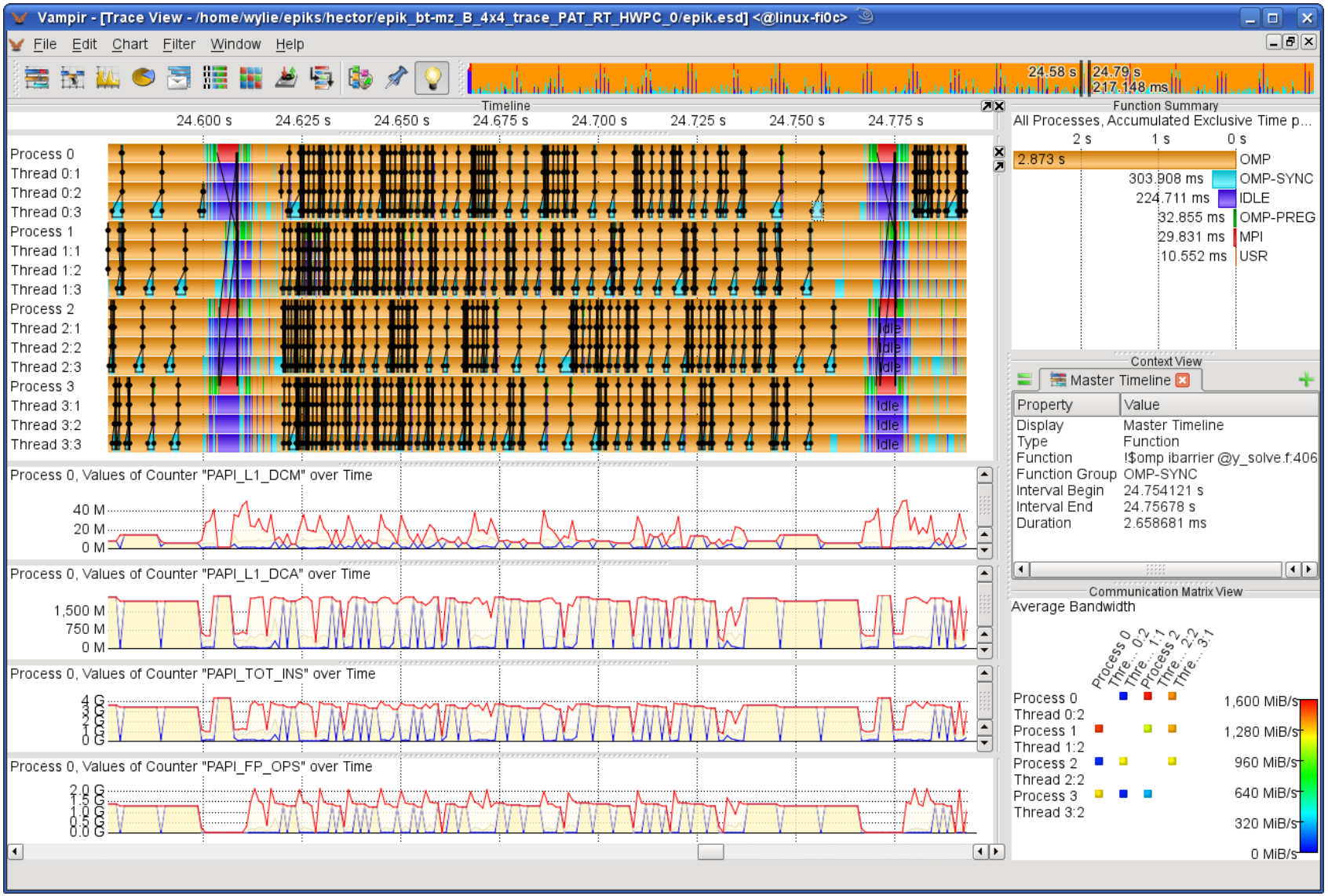
# Vampir interactive trace analysis GUI



# Vampir interactive trace analysis GUI



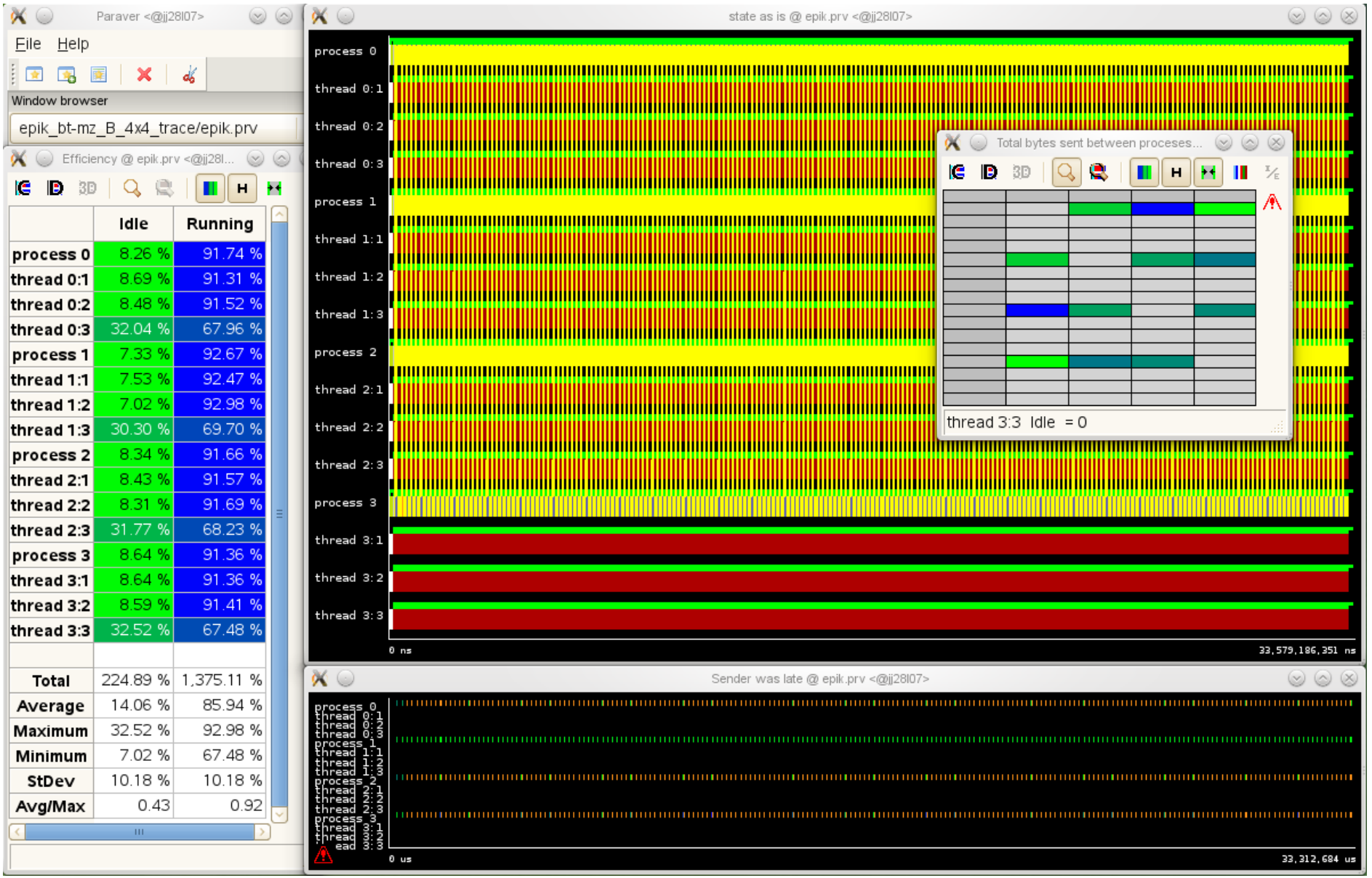
# Vampir interactive trace analysis GUI (zoom)



- Interactive event trace analysis
  - Visual presentation of dynamic runtime behaviour
    - event timeline chart for states & interactions of processes
    - Interactive browsing, zooming, selecting
  - Large variety of highly configurable analyses & displays
- Developed by Barcelona Supercomputing Center
  - Paraver trace analyser and Extrae measurement library
  - Open source available from http://www.bsc.es/paraver/



# Paraver interactive trace analysis GUI




| | Idle | Running |
|---|---|---|
| process 0 | 8.26 % | 91.74 % |
| thread 0:1 | 8.69 % | 91.31 % |
| thread 0:2 | 8.48 % | 91.52 % |
| thread 0:3 | 32.04 % | 67.96 % |
| process 1 | 7.33 % | 92.67 % |
| thread 1:1 | 7.53 % | 92.47 % |
| thread 1:2 | 7.02 % | 92.98 % |
| thread 1:3 | 30.30 % | 69.70 % |
| process 2 | 8.34 % | 91.66 % |
| thread 2:1 | 8.43 % | 91.57 % |
| thread 2:2 | 8.31 % | 91.69 % |
| thread 2:3 | 31.77 % | 68.23 % |
| process 3 | 8.64 % | 91.36 % |
| thread 3:1 | 8.64 % | 91.36 % |
| thread 3:2 | 8.59 % | 91.41 % |
| thread 3:3 | 32.52 % | 67.48 % |
| | | |
| Total | 224.89 % | 1,375.11 % |
| Average | 14.06 % | 85.94 % |
| Maximum | 32.52 % | 92.98 % |
| Minimum | 7.02 % | 67.48 % |
| StDev | 10.18 % | 10.18 % |
| Avg/Max | 0.43 | 0.92 |

- Modular Assembler Quality Analyzer & Optimizer
  - Framework for binary manipulation
    - using plugins and scripting language
  - Tool exploiting framework to produce reports
    - fast prototyping and batch interface
  - STAN static performance model
  - MIL instrumentation language for dynamic analysis
    - building custom performance evaluation tools using HWCs
    - instrumentation of functions, loops, blocks & instructions
- Developed by UVSQ Exascale Computing Research lab
  - Supports Intel x86_64 microarchitecture
  - Available from www.maqao.org

# VI-HPS component technologies

- Key tool components also provided as open-source
  - Program development environment
    - Eclipse PTP ETFw, UNITE
  - Program/library instrumentation
    - COBI, OPARI, PDToolkit
  - Runtime measurement systems
    - PnMPI, Score-P, UniMCI
  - Scalable I/O
    - SIONlib
  - Libraries & tools for handling (and converting) traces
    - EPILOG, OTF, PEARL
  - Analysis algebra & hierarchical/topological presentation
    - CUBE



- Scalable performance measurement infrastructure
  - Supports instrumentation, profiling & trace collection, as well as online analysis of HPC parallel applications
  - Works with Periscope, Scalasca, TAU & Vampir prototypes
  - Based on updated tool components
    - CUBE4 profile data utilities & GUI
    - OA online access interface to performance measurements
    - OPARI2 OpenMP & pragma instrumenter
    - OTF2 open trace format
- Created by German BMBF SILC & US DOE PRIMA projects
  - JSC, RWTH, TUD, TUM, GNS, GRS, GWT & UO PRL
  - Available as BSD open-source from http://www.score-p.org/



- Portable native parallel I/O library & utilities
  - Scalable massively-parallel I/O to task-local files
  - Manages single or multiple physical files on disk
    - optimizes bandwidth available from I/O servers by matching blocksizes/alignment, reduces metadata-server contention
  - POSIX-I/O-compatible sequential & parallel API
    - adoption requires minimal source-code changes
  - Tuned for common parallel filesystems
    - GPFS (BlueGene), Lustre (Cray), ...
  - Convenient for application I/O, checkpointing,
    - Used by Scalasca tracing (when configured)
- Developed by JSC
  - Available as open-source from
  - http://www.fz-juelich.de/jsc/sionlib/



- Uniform integrated tool environment
  - Manages installation & access to program development tools
    - based on software environment management “modules”
    - commonly used on most cluster and HPC systems
    - configurable for multiple MPI libraries & compiler suites
  - Specifies how & where tools packages get installed
    - including integrating tools where possible
  - Defines standard module names and different versions
  - Supplies pre-defined module files
  - Configurable to co-exist with local installations & policies
- Developed by JSC, RWTH & TUD
  - Available as open-source from http://www.vi-hps.org/projects/unite/