MAQAO
Performance Analysis and Optimization Tool

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http://www.maqao.org

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MAQAO Framework and Toolsuite

R&D Team: develop performance evaluation and optimization tools

Open Source software (LGPL 3)
- Currently only binary release (source => ongoing)
- Profilers (generic and MPI) work on any LSB/Most Unix
- Code quality analysis and hardware counters support only available for Intel x86-64 and Xeon Phi

Funded by UVSQ, Intel and CEA (French department of energy)

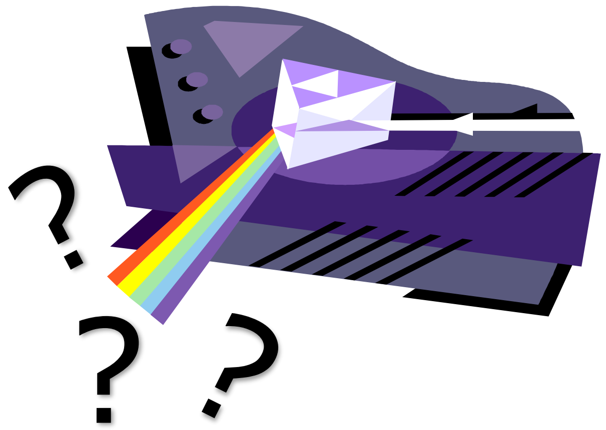
Establish partnerships:
- Optimize industrial applications
- Provide building blocks (framework services) to other tools:
  - TAU tool *tau_rewrite*: binary rewrtting feature (MIL)
  - ATOS/BULL tool *bullxprof* : binary rewrtting feature (MIL)

Introduction
Performance analysis (1/2)

- Characterize the performance of an application
  - Complex multicore CPUs and memory systems
  - How well does it behaves on a given machine

- Generally a multifaceted problem
  - What are the issues (numerous but finite) ?
  - Which one(s) dominates ?
  - Maximizing the number of views
  - => Need for specialized tools

- Three main classes of issues
  - Find/Select relevant algorithms
  - Work sharing/decomposition
  - Exploiting performance available at CPU level



Introduction
Performance analysis (2/2)

Motivating example: loop ~10% walltime

```
do j = ni+nvalue1,nato
    nj1 = ndim3d*j + nc ; nj2 = nj1 + nvalue1 ; nj3 = nj2 + nvalue1
    u1 = x11 - x(nj1) ; u2 = x12 - x(nj2) ; u3 = x13 - x(nj3)
    rtest2 = u1*u1 + u2*u2 + u3*u3 ; cnij = eci*qEold(j)
    rij = demi*(rvwi+rvwalc1(j))
    drtest2 = cnij/(rtest2 + rij) ; drtest = sqrt(drtest2)
    Eq = qq1*qq(j)*drtest
    ntj = nti + ntype(j)
    Ed = ceps(ntj)*drtest2*drtest2*drtest2
    Eqc = Eqc + Eq ; Ephob = Ephob + Ed
    gE = (c6*Ed + Eq)*drtest2 ; virt = virt + gE*rtest2
    u1g = u1*gE ; u2g = u2*gE ; u3g = u3*gE
    g1c = g1c - u1g ; g2c = g2c - u2g ; g3c = g3c - u3g
    gr(nj1,thread_num) = gr(nj1,thread_num) + u1g
    gr(nj2,thread_num) = gr(nj2,thread_num) + u2g
    gr(nj3,thread_num) = gr(nj3,thread_num) + u3g
end do
```

Variable number of iterations

Non-unit stride accesses

High number of statements vector versus calar

DIV/SQRT

Indirect accesses

Reductions

Non-unit stride accesses

Source code and associated issues:

1) High number of statements
2) Non-unit stride accesses
3) Indirect accesses
4) DIV/SQRT
5) Reductions
6) Vector vs Scalar

Introduction
MAQAO: working at binary level (1/2)

Why ???

Most of the time the compiler changes source code

Some source code instrumentation may prevent the compiler from applying transformation
- i.e.: loop interchange

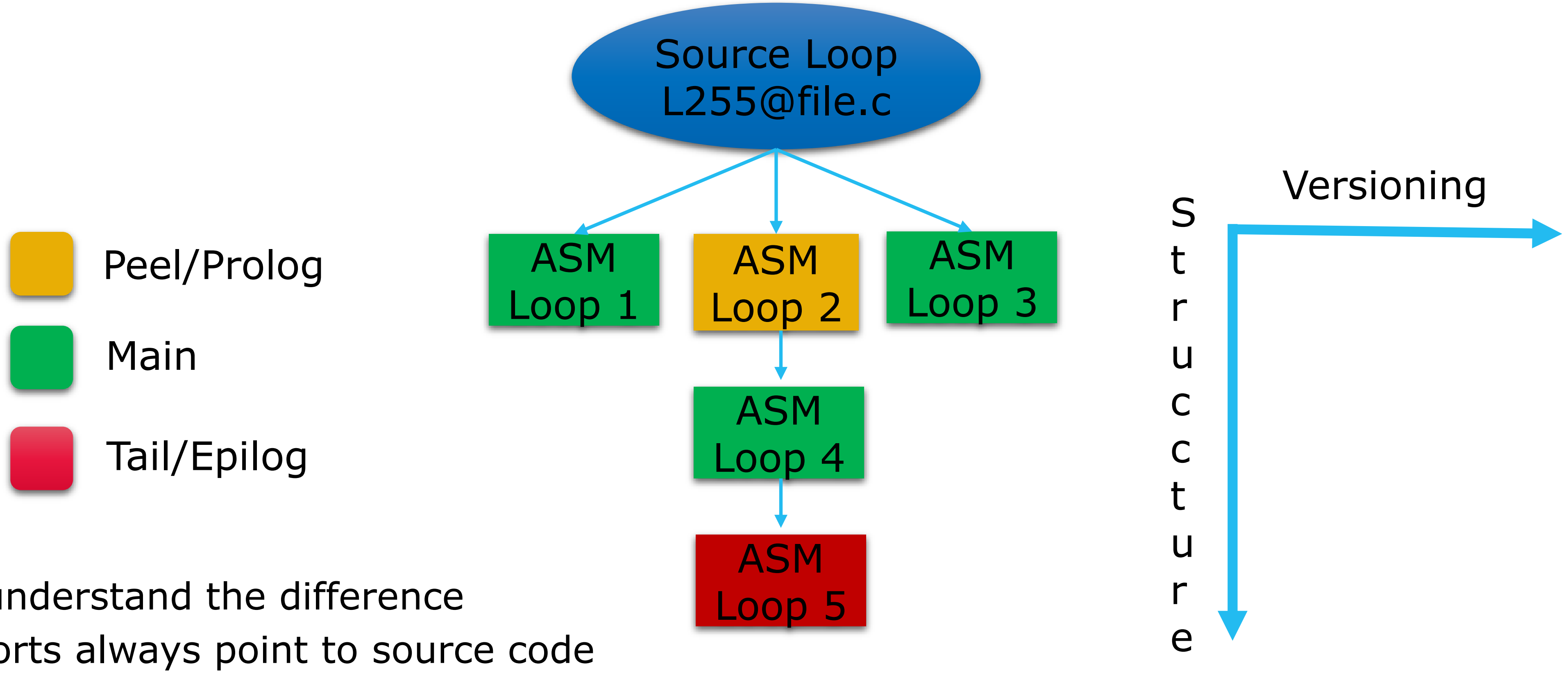
We want to evaluate the “real” executed code

We are able to reconstruct an abstract vue with functions and loops in order to be able to correlate with your source code.

One little difference is understanding loops at assembly level

Introduction
MAQAO: working at binary level (2/2)

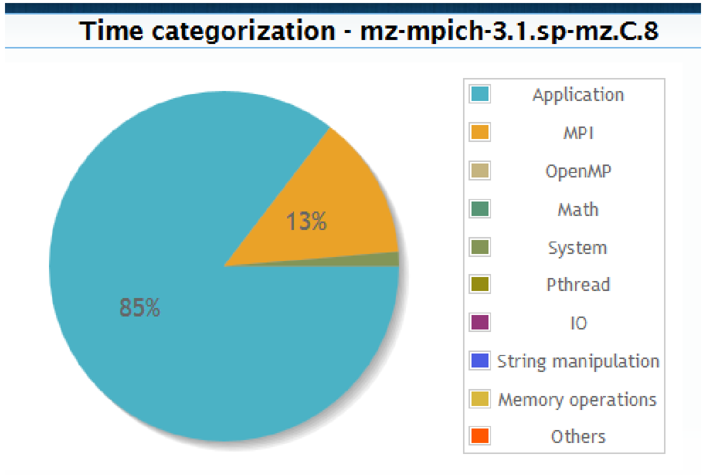
Source level V.S. Assembly level

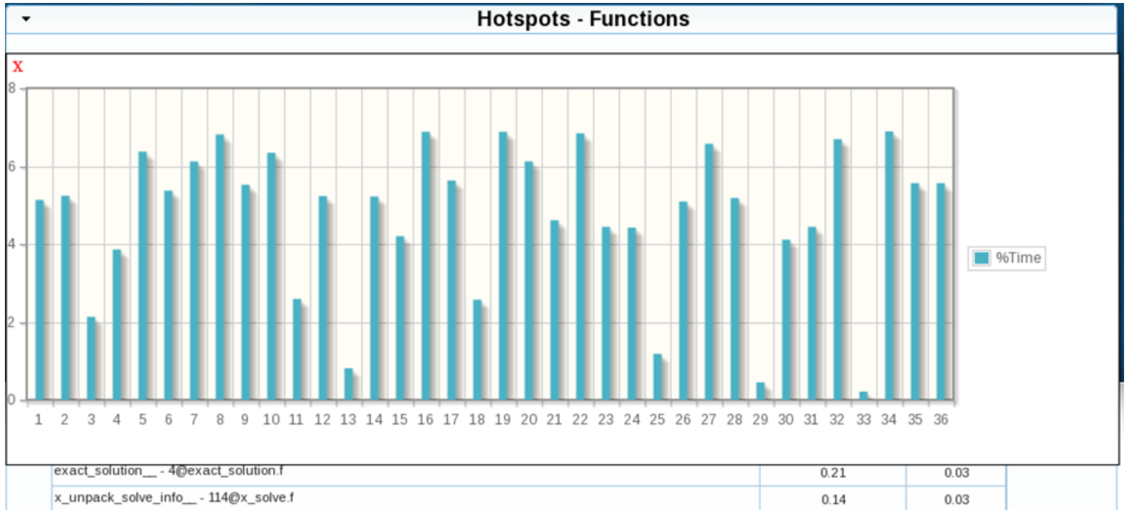


You just need to understand the difference

But our tools' reports always point to source code

MAQAO Perf: locating hotspots





MAQAO Perf: locating hotspots
Introduction

Locating most time consuming hotspots is the first step you want to accomplish.

Multiple measurement methods available:

- Why is it important to know this ?
- Instrumentation
  - Through binary rewriting
  - High overhead / More precision
- Sampling
  - Hardware counters (through perf_event_open system call)
  - Linux kernel timers
  - No instrumentation / Very low overhead / less details (i.e. function calls count)
- Default method: Sampling using hardware counters (if available) or timers

Runtime-agnostic: Only system processes and threads are considered

Where is time spent ? Which one(s) should I investigate first ?

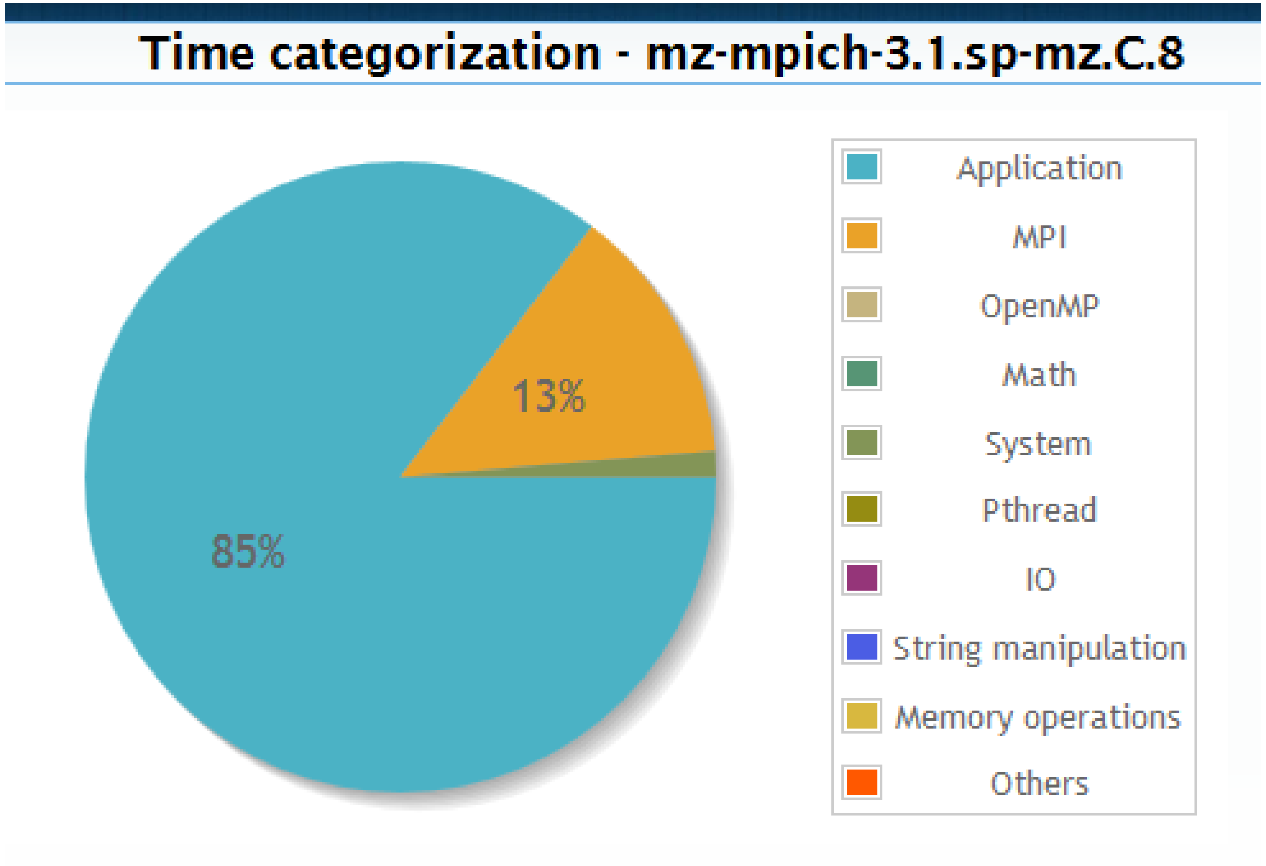
MAQAO Perf: locating hotspots
Time categorization

Sadly, executing an application is not just doing the science you are supposed to !

Work sharing/splitting
- Shared: Pthreads, OpenMP, etc …
- Distributed: MPI, etc…

Programming
- IO
- String manipulation
- Memory management
- Math (external librarires)

Doing actual science (Application)
- Functions
- Loops



MAQAO Perf: locating hotspots
Function and loop hotspots (1/3)

Lets focus on science !

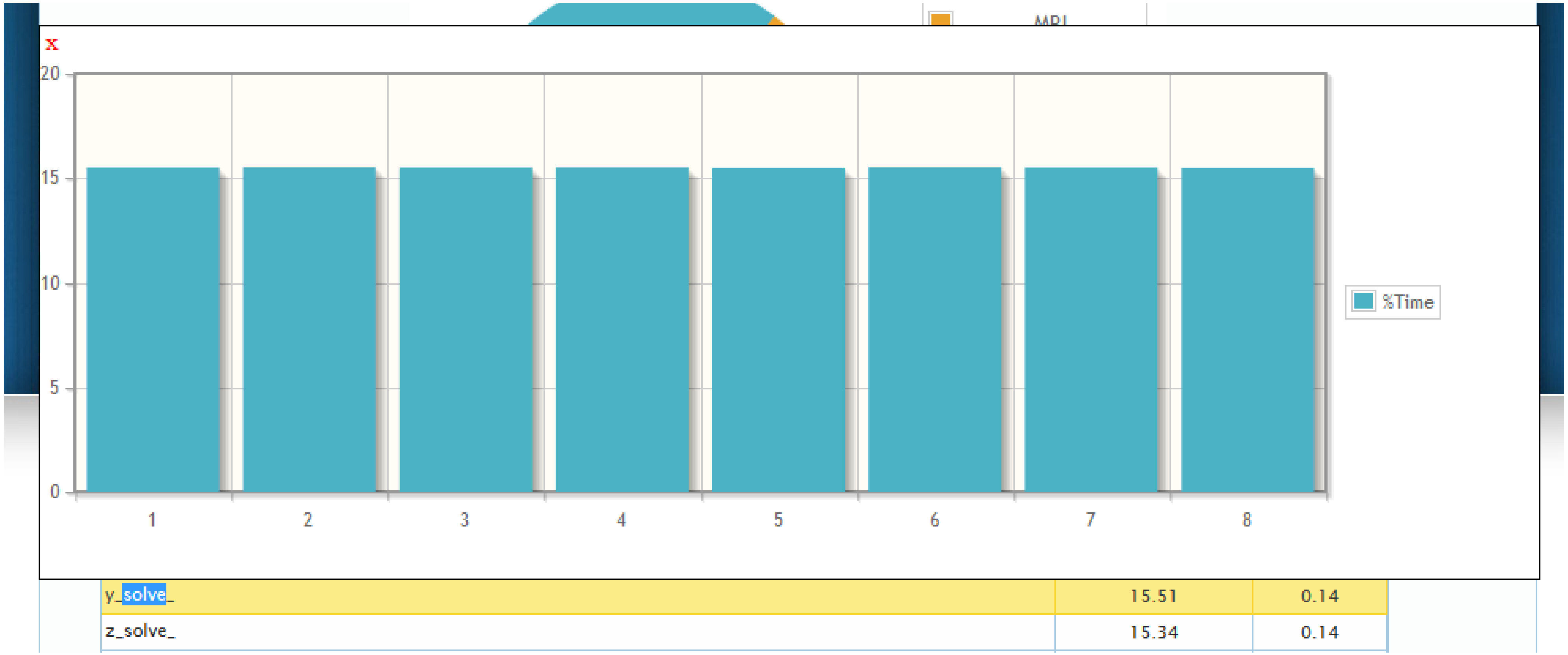
First we want to check function hotspots load balancing vue at (multi)node level

- For the same function
- Does it behave the same way on all the nodes ?

Hotspots - Functions

Name	Median Excl %Time	Deviation
compute_rhs_	30.88	0.14
y_solve_	15.51	0.14
z_solve_	15.34	0.14
x_solve_	15.07	0.14
MPIDI_CH3I_Progress	5.61	0.14

MAQAO Perf: locating hotspots
Function and loop hotspots (2/3)



MAQAO Perf: locating hotspots
Function and loop hotspots (3/3)

Then analyse time spent in loops:

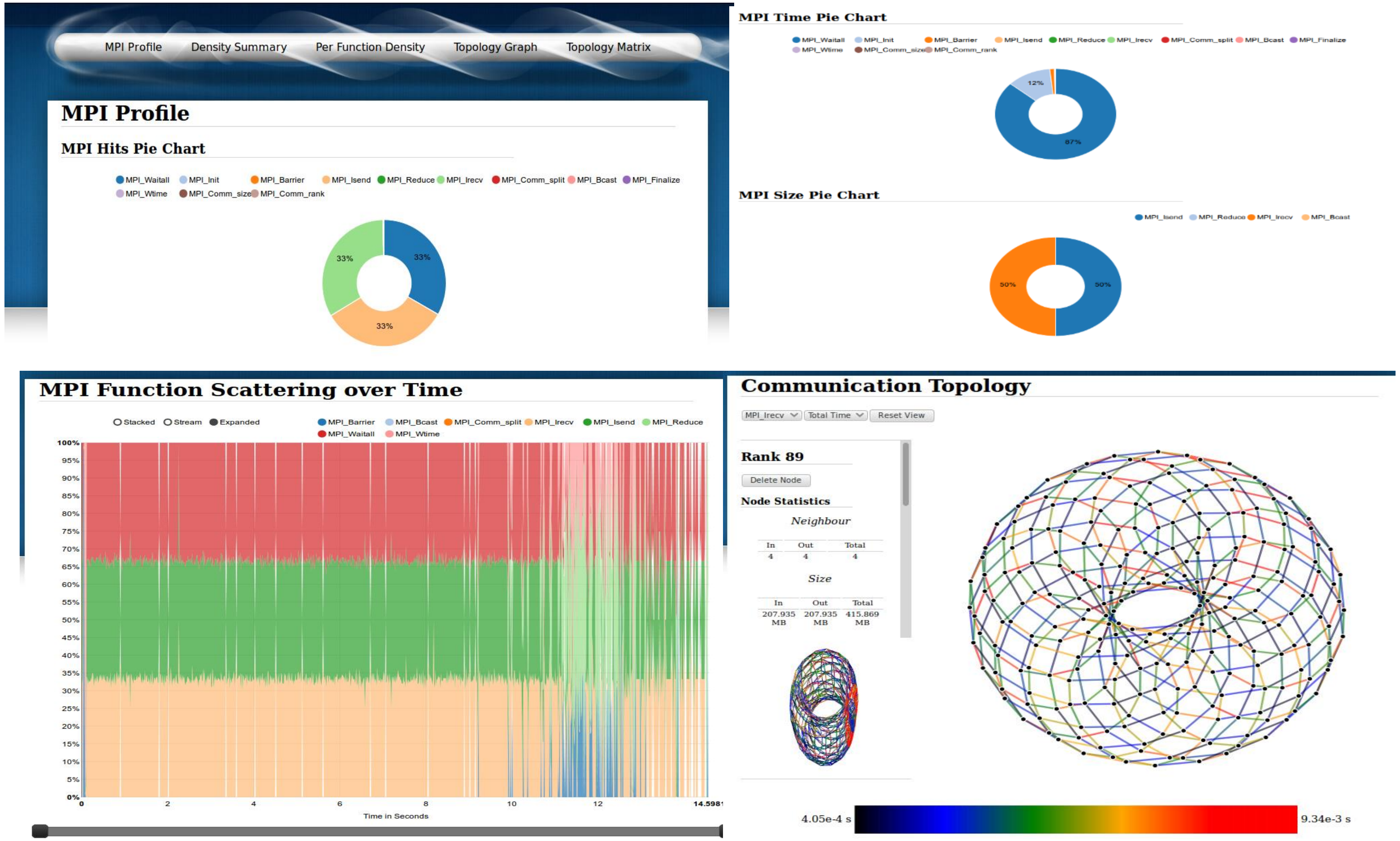
- Time spent in loop w.r.t. function

dauvergne - Process #14213 - Thread #14201

Name	Excl %Time	Excl Time (s)
binvcrhs - 206@solve_subs.f	17.27	2.23
MPIDI_CH3I_Progress	15.24	1.96
poll_active_fboxes	13.71	1.77
y_solve_.omp_fn.0 - 45@y_solve.f	8.47	1.09
loops	8.47	
Loop 121 - y_solve.f@45	0	
Loop 122 - y_solve.f@45	0.16	
Loop 124 - y_solve.f@45	0.14	
Loop 125 - y_solve.f@145	5.12	
Loop 126 - y_solve.f@55	2.03	
Loop 123 - y_solve.f@45	1.02	
x_solve_.omp_fn.0 - 48@x_solve.f	8.23	1.06
loops	8.23	

- Use MAQAO CQA tool to analyse loops of interest

MAQAO Perf/MPI: MPI characterization



MAQAO Perf/MPI: MPI characterization
Introduction (1/2)

The previous profiler module only provided a global figure about time spent in the MPI runtime (X%)

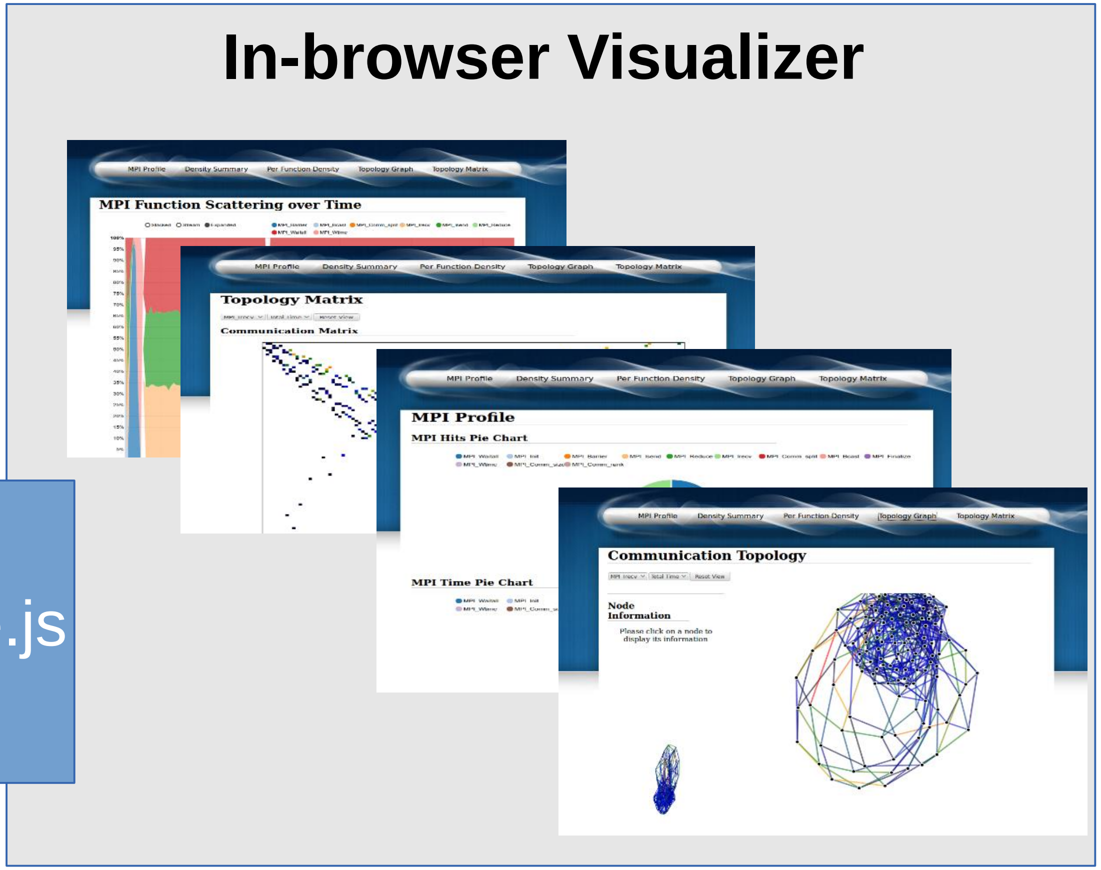
We want the same kind of insight but dealing with MPI primitives

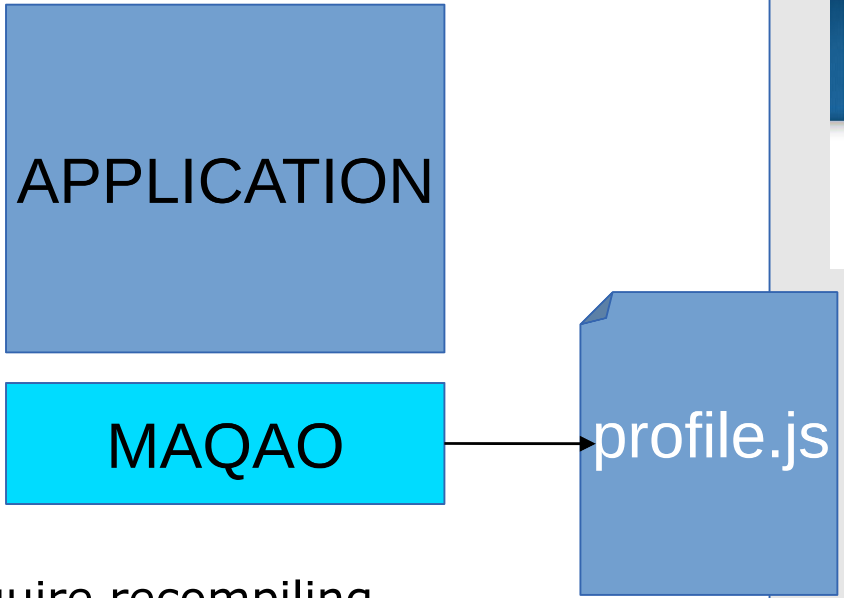
Our methodology:
- Coarse grain: overview, global trends/patterns => cheapest possible cost/overhead
- Fine grain: filtering precise issues => accept to pay higher cost/overhead if worth

Online profiling:
- No traces to void IO wall: no IOs (only one result file with pre-processed data)
- Avoid memory : reduced memory footprint thanks to aggregated metrics
- Scalable on 1000+ MPI processes

MAQAO Perf/MPI: MPI characterization
Introduction (2/2)

Summary: Perf/MPI is a simple MPI profiling tool targeting lightweight metrics which can be reduced online (no trace required).

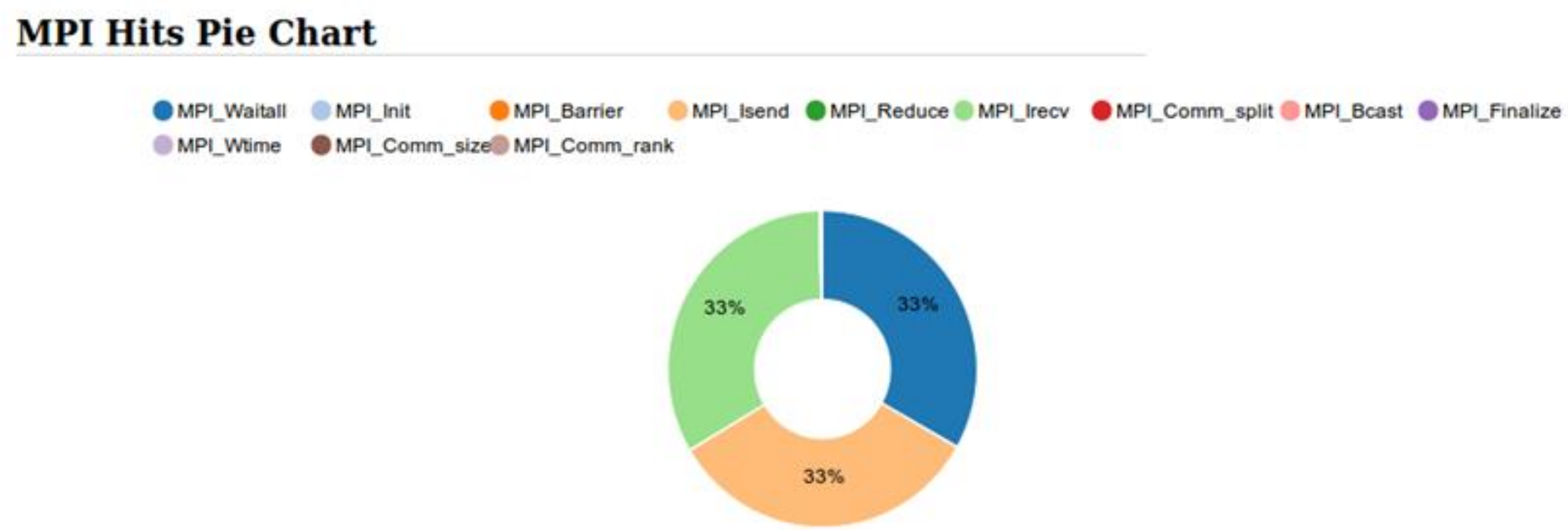




Does not require recompiling

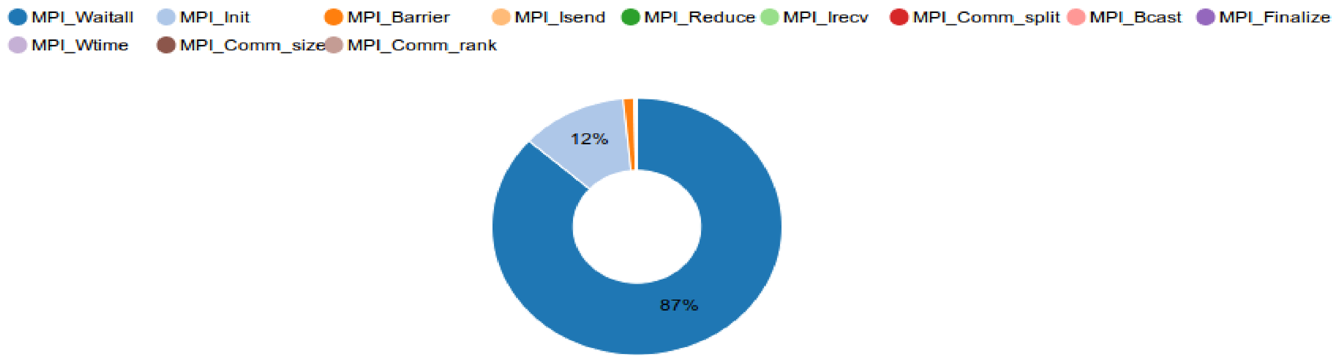
MAQAO Perf/MPI: MPI characterization
Global profile (1/3)

Summary vue: MPI primitives classified by hits (calls), time and size (if applicable)

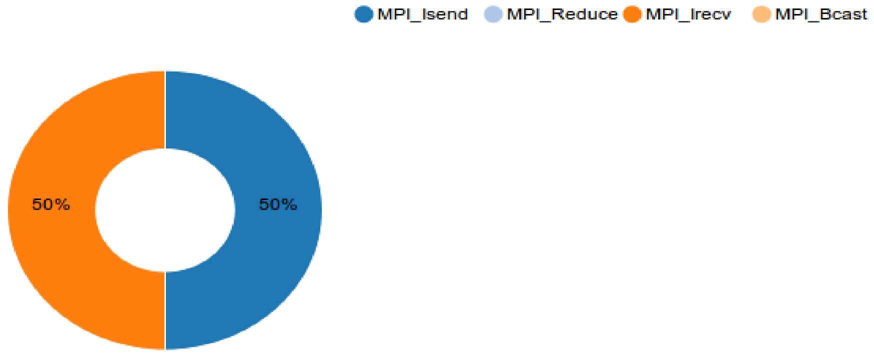


MAQAO Perf/MPI: MPI characterization
Global profile (2/3)

MPI Time Pie Chart



MPI Size Pie Chart

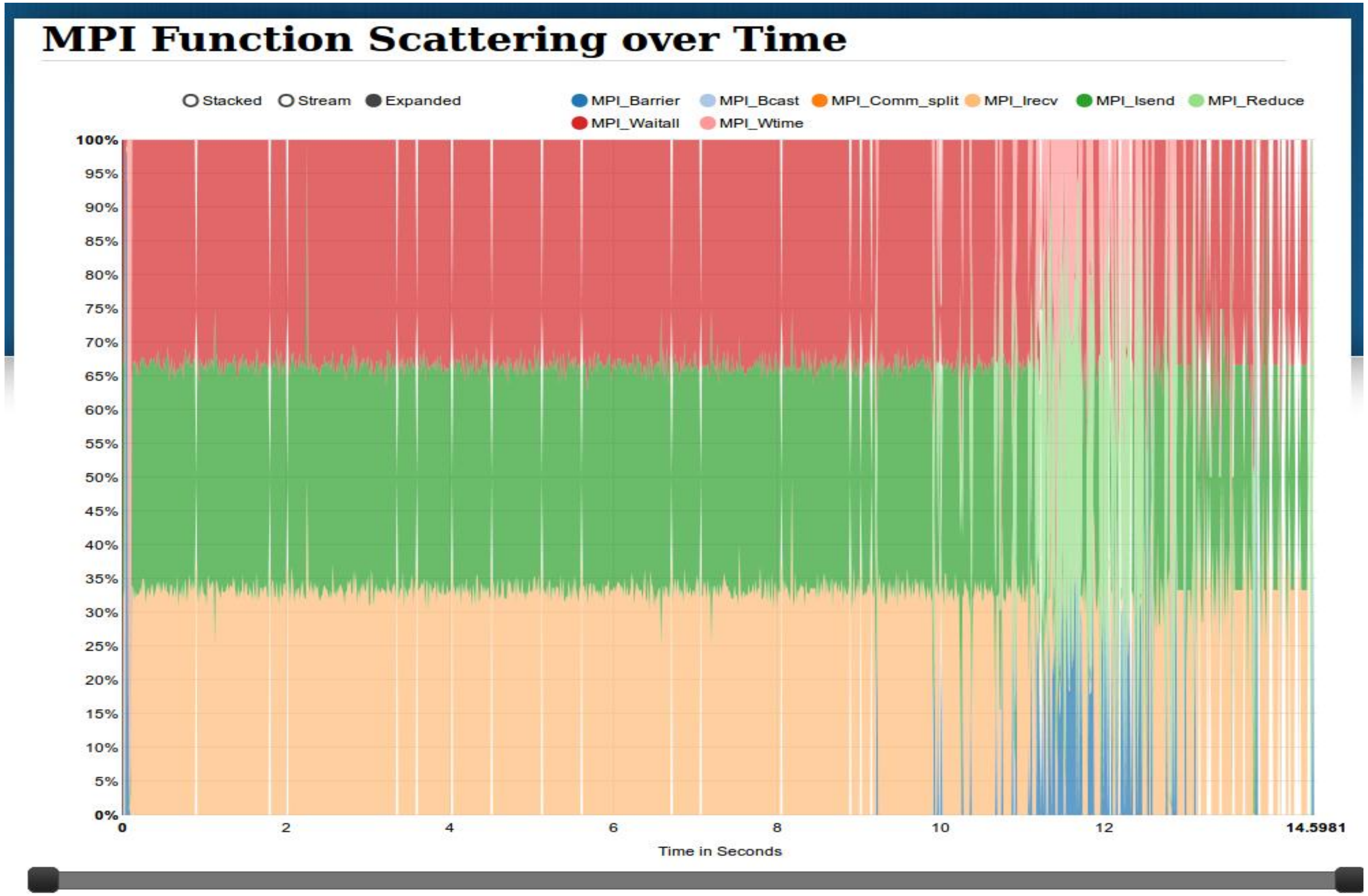


MAQAO Perf/MPI: MPI characterization
Global profile: flat vue (3/3)

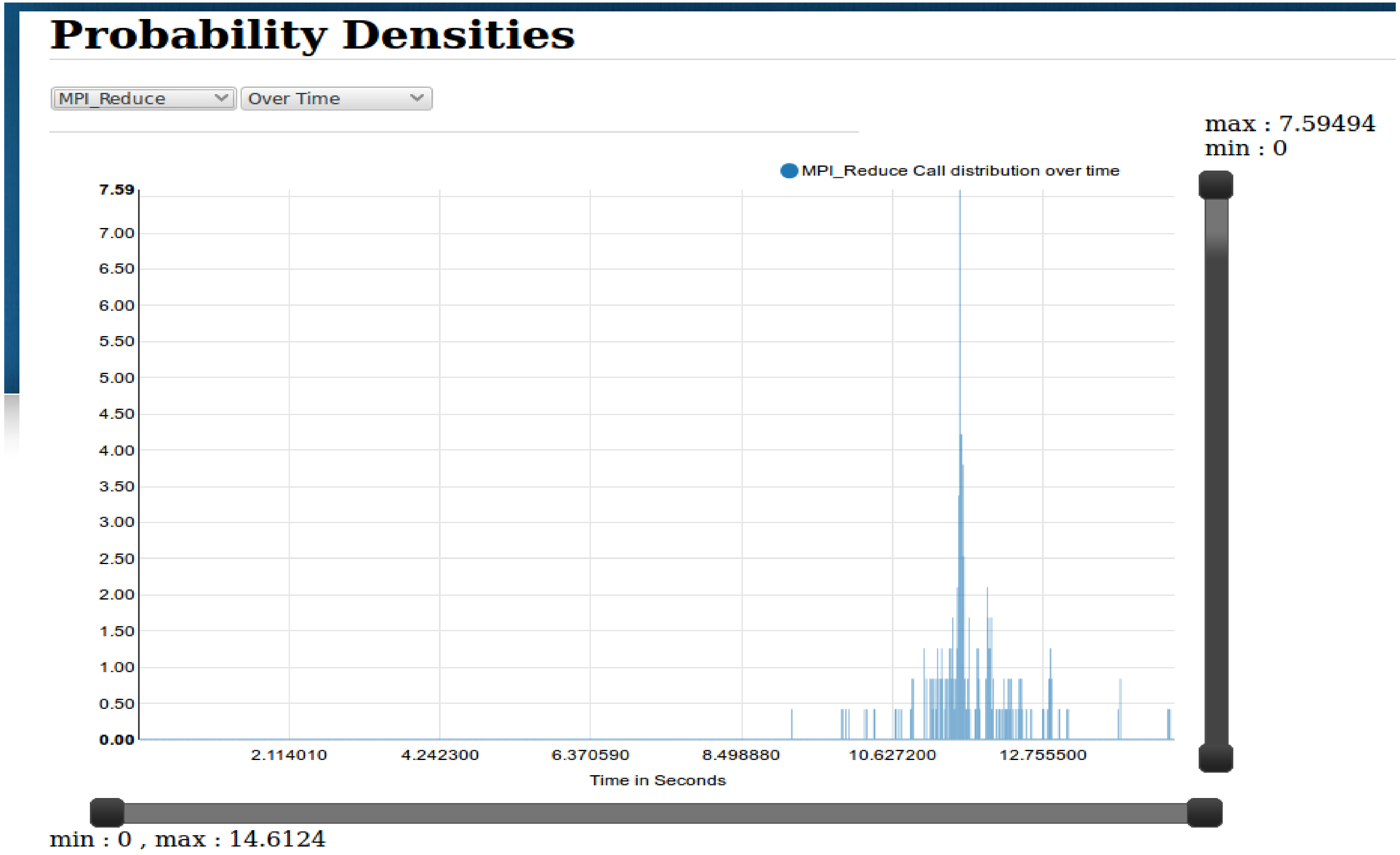
MPI Profile

Function	Hits	Time	Size	Walltime %
MPI_Waitall	192960	13 m 1.51 s	0 B	52.333%
MPI_Init	128	1 m 46.60 s	0 B	7.138%
MPI_Barrier	256	10.88 s	0 B	0.729%
MPI_Isend	192960	1.47 s	4.568 GB	0.098%
MPI_Reduce	384	5.36e-1 s	11.000 KB	0.036%
MPI_Irecv	192960	4.62e-1 s	4.568 GB	0.031%
MPI_Comm_split	128	4.05e-1 s	0 B	0.027%
MPI_Bcast	1152	3.12e-2 s	132.000 KB	0.002%
MPI_Finalize	128	2.07e-3 s	0 B	0.000%
MPI_Wtime	256	3.53e-4 s	0 B	0.000%
MPI_Comm_size	128	1.30e-4 s	0 B	0.000%
MPI_Comm_rank	256	4.28e-5 s	0 B	0.000%

MAQAO Perf/MPI: MPI characterization
Function scattering over time

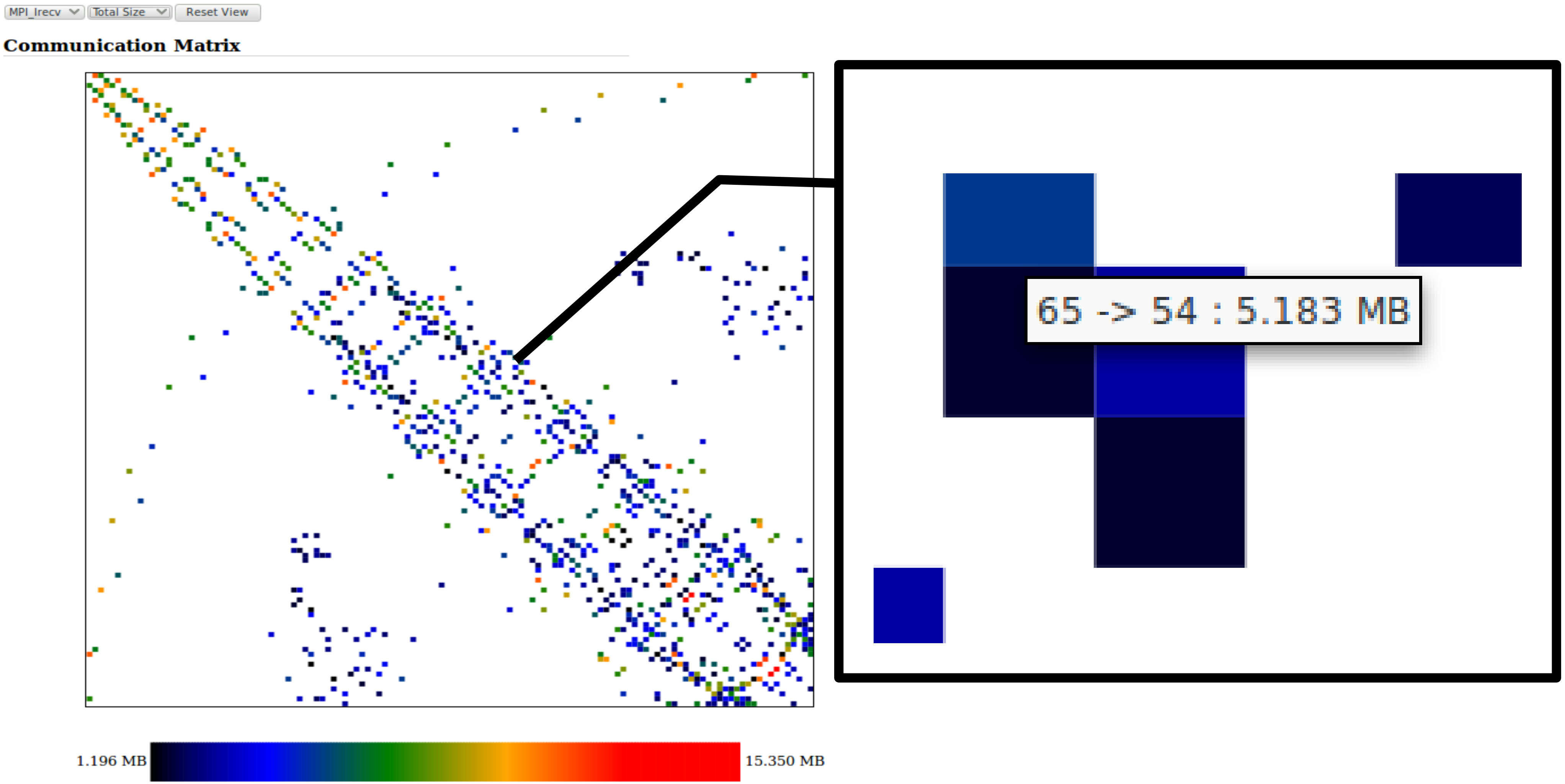


MAQAO Perf/MPI: MPI characterization
Probability densities: when and how long ?



MAQAO Perf/MPI: MPI characterization
2D communication matrix

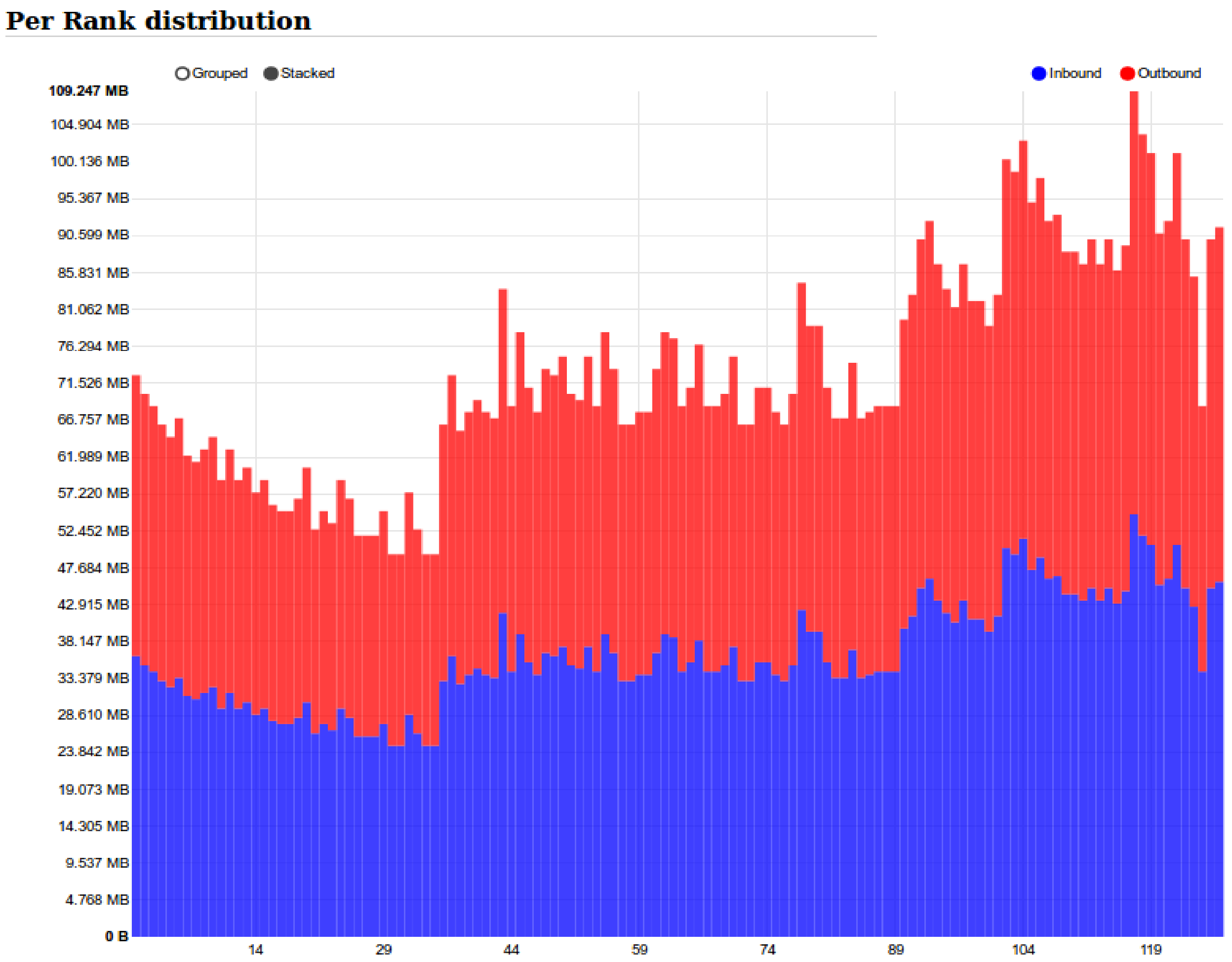
Hit, time, size



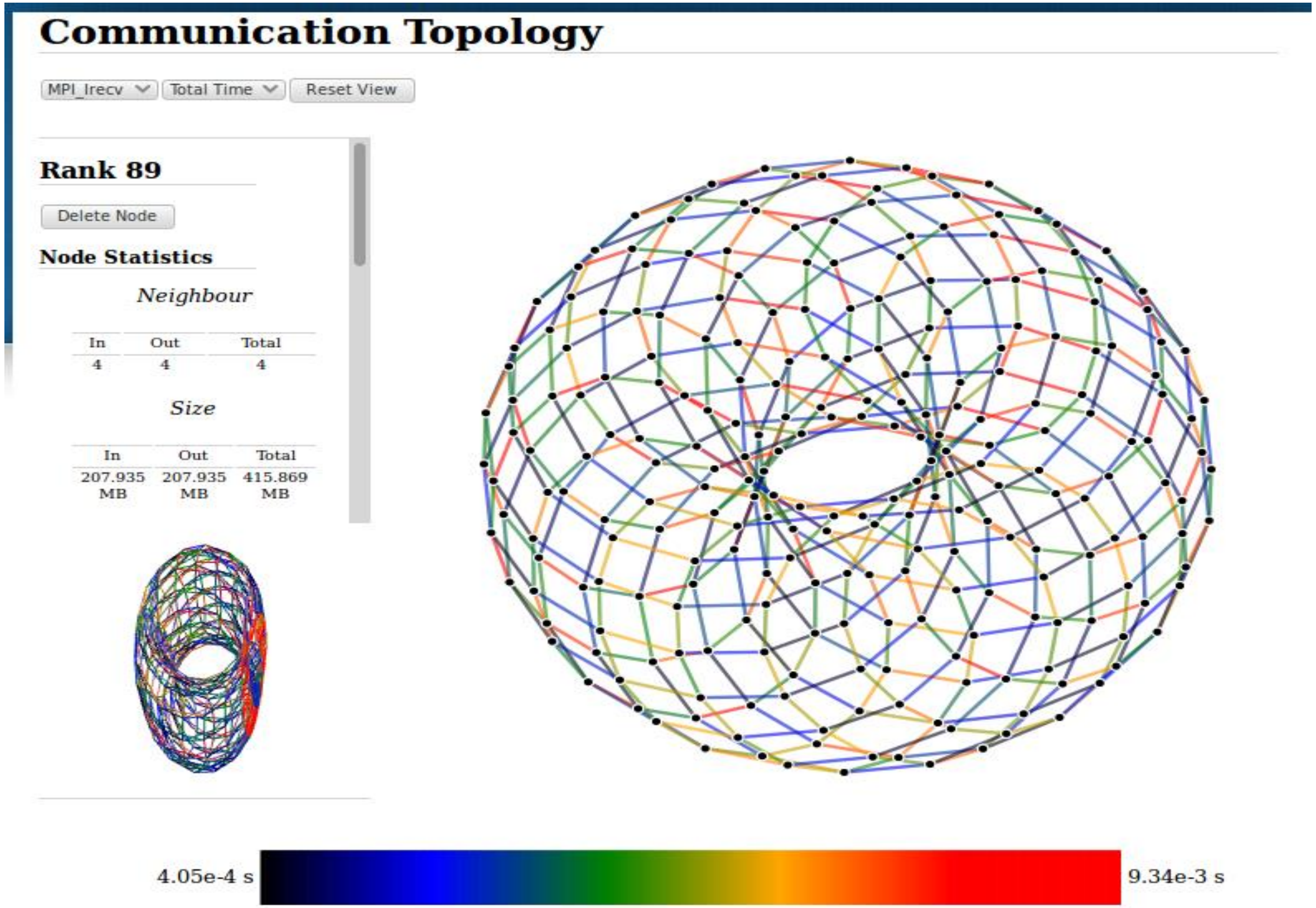
MAQAO Perf/MPI: MPI characterization
Per rank distribution

Hit, time, size

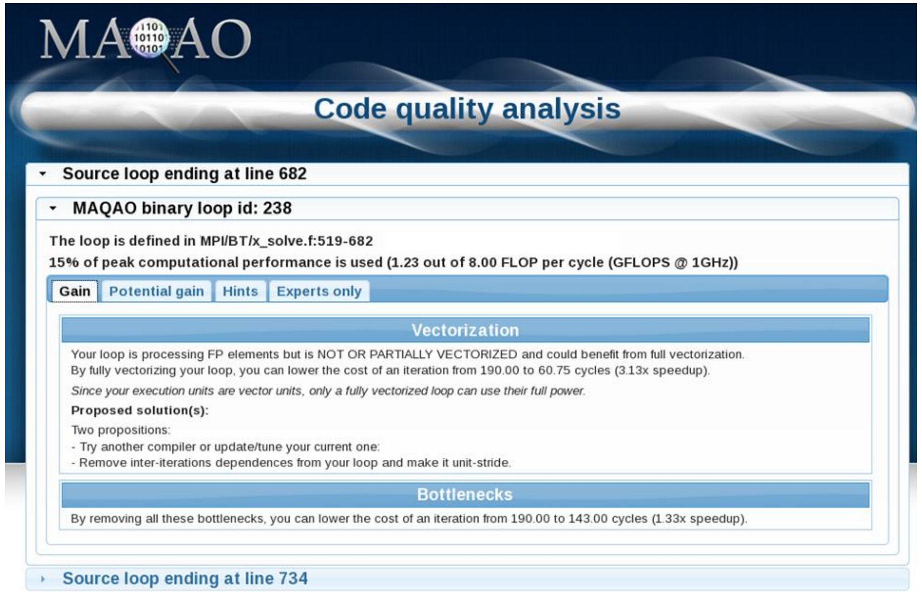
Check load balancing



MAQAO Perf/MPI: MPI characterization
3D Topology



MAQAO CQA: Analysing the code quality of your loops



MAQAO CQA: Analysing the code quality of your loops
Introduction

Main performance issues:

- Work sharing / communications / multicore interactions
- Core level

Most of the time core level is forgotten ! But that's were science is computed

CQA works at (assembly) loop level:

- In HPC most of the time is spent in loops (V.S. functions)
- Assess the quality of code generated by the compiler
- Take into account processor's (micro)architecture via simulation
- Hints and workarounds to improve static performance

Compute bound :

- this tool is not meant for optimizing memory issues
- It assumes that you have fixed them

MAQAO CQA: Analysing the code quality of your loops
Goal: how will it help you ?

Produce reports:

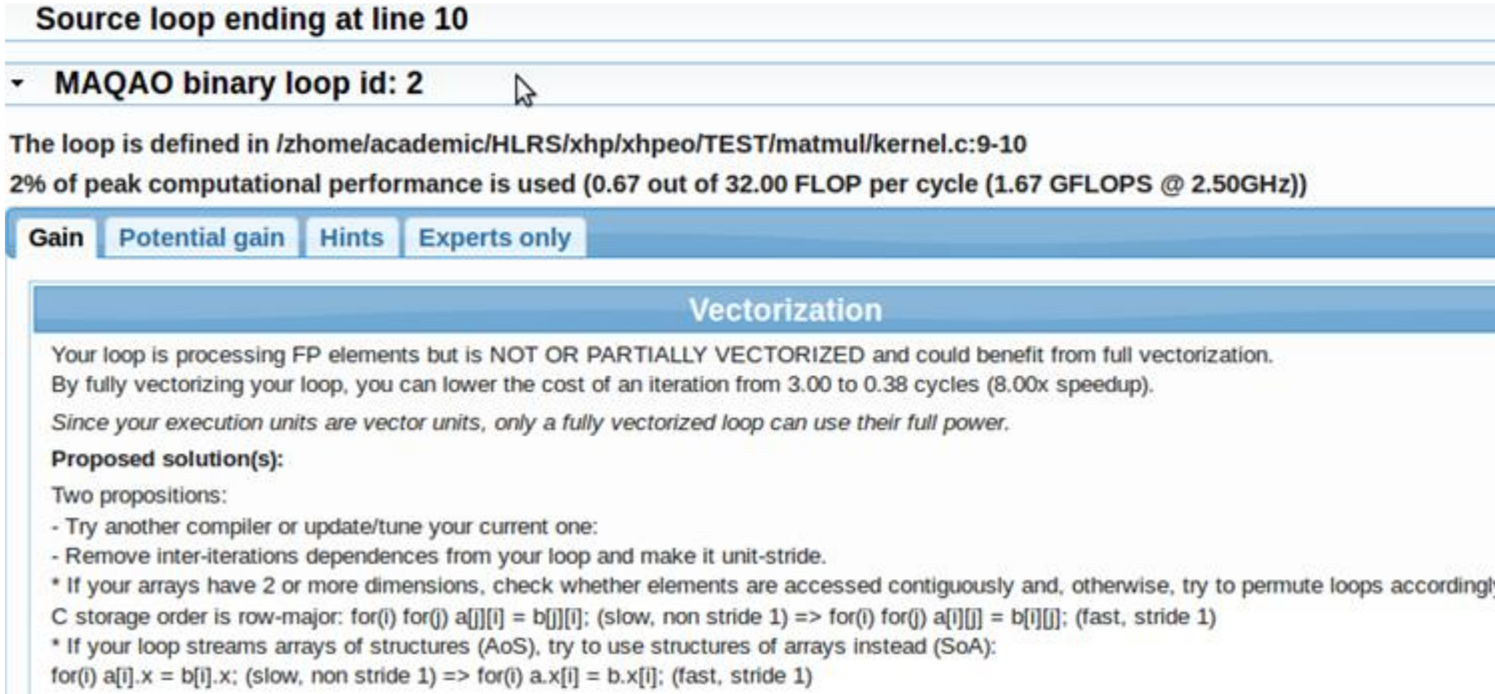
- We deal with low level details (assembly, microarchitecture details)
- You get high level reports

Provide high level reports:

- Provide source loop context when available (-g or equivalent)
- Describing a pathology/bottleneck
- Suggesting workarounds to improve static performance
- Reports categorized by confidence level:
  - gain, potential gain, hint and expert

No runtime cost/overhead:

- Your don't need to execute your app
- Static analysis



MAQAO CQA: Analysing the code quality of your loops
Processor Architecture: Core level

Maybe you want an efficient code that gets the best out of available computing resources ?

Concepts:
- Peak performance, TOP500/LINPACK
- Execution pipeline
- Ressources/Functional units

Most of the time applications only exploit at best 5% to 10% of the peak performance

Same instruction – Same cost

Process up to 8X (SP) data

Key performance levers:
- Vectorization
- Get rid of high latency instructions if possible
- Make the compiler generated an efficient code

MAQAO CQA: Analysing the code quality of your loops
The compiler

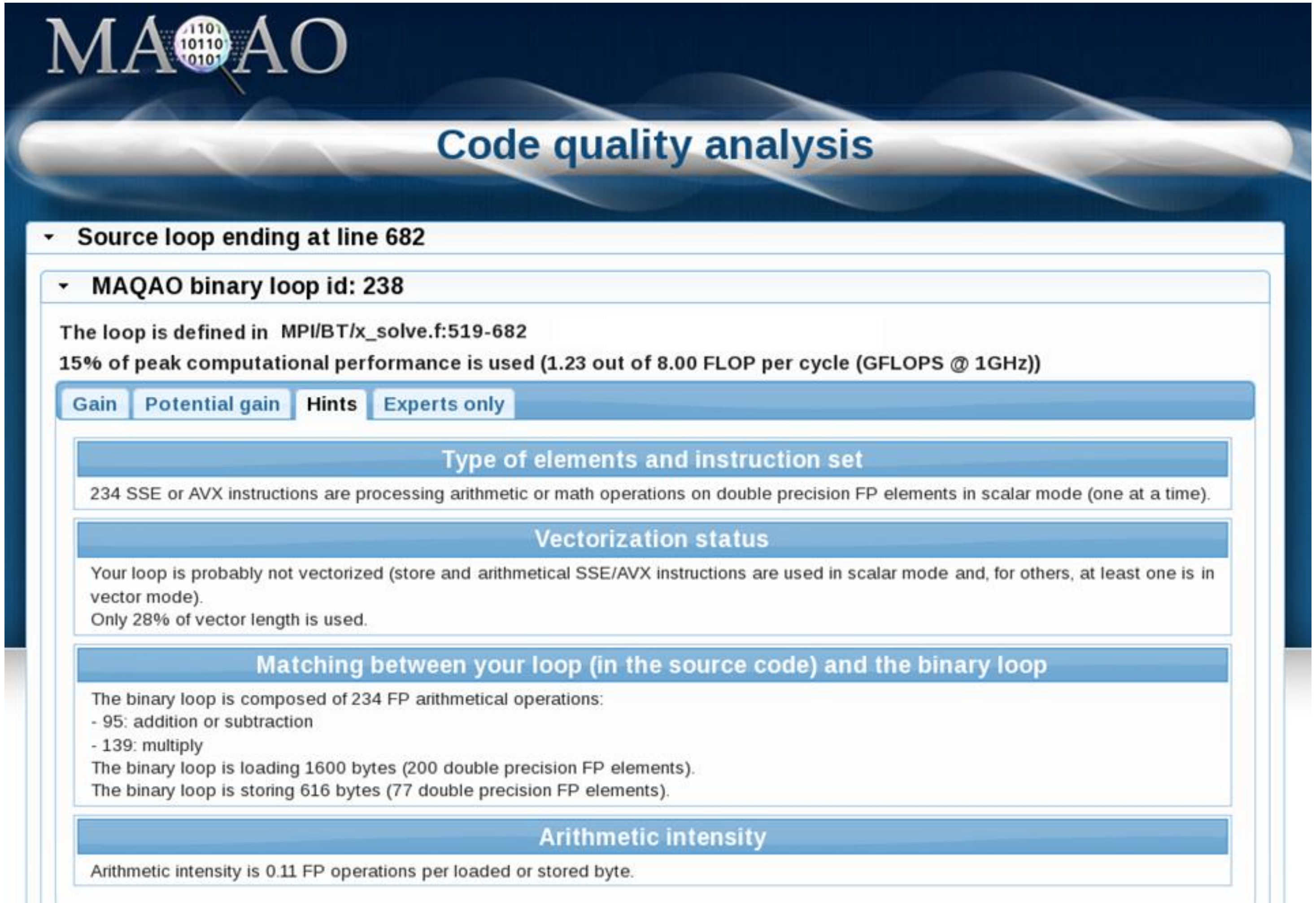
Compiler remains our best friend

Be sure to select proper flags
- Know default flags (e.g., -xHost on AVX capable machines)
- Bypass conservative behavior when possible (e.g., 1/X precision)

Pragmas:
- Vectorization, Alignement, Unrolling, etc…
- Portable transformations

MAQAO CQA: Analysing the code quality of your loops
GUI sample (1/2)

MAQAO CQA: Analysing the code quality of your loops
GUI sample (2/2)



Thank you for your attention

Questions