MAQAO
Performance Analysis and Optimization Tool

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VI-HPS 21st Garching – Germany – 18-22 April 2016

MAQAO Framework and Tool suite

R&D Team: develop performance evaluation and optimization tools

MAQAO main functionalities:
- Profiling and hardware counters collection
- Code quality analysis

LGPL3 Open Source software
- Source release of core components planned for 2016
- Binary release available on demand
- Support Intel x86-64 and Xeon Phi

Partnerships:
- Funded by UVSQ, Intel and CEA (French department of energy)
- Optimize industrial and academic HPC applications (Yales2, AVBP, Polaris…)
- Provide building blocks for other tools (TAU performance tools, ATOS bullxprof, Intel AmplifierXE)

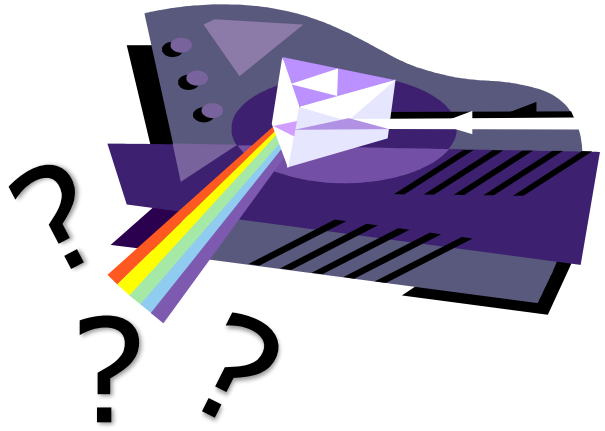
Introduction
Performance analysis (1/2)

Characterize application performance

- Application profiling
- Pinpoint the performance bottlenecks
  - Complex multicore and manycore CPUs
  - Complex memory hierarchy
- Best use of the machine features

Generally a multifaceted problem

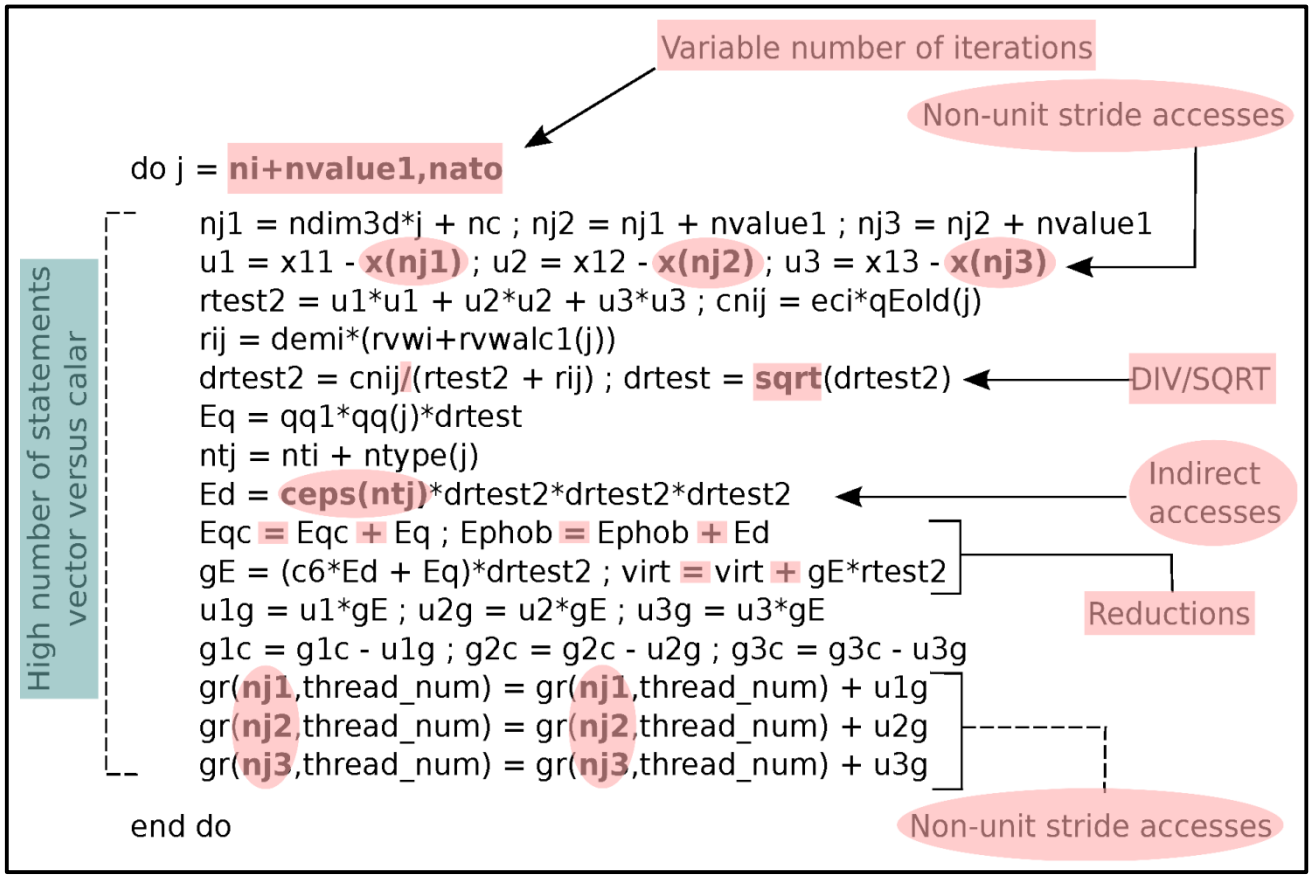
- How to determine the dominant issues?
  - Algorithms choice
  - Implementation
  - Parallelization
  - …
- Maximizing the number of views



=> Need for dedicated and complementary tools

Introduction
Performance analysis (2/2)

Motivating example: loop ~10% walltime



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: Analysis at the binary level

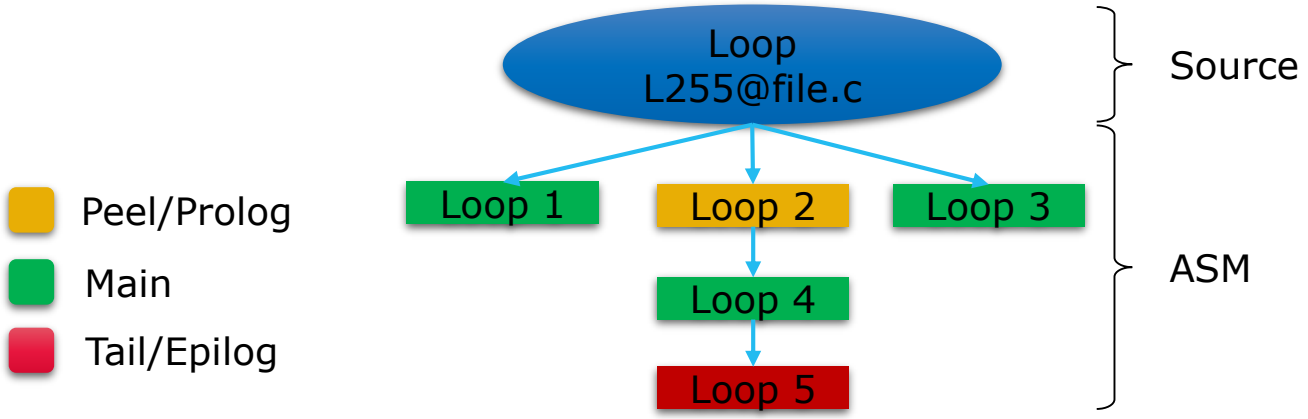
Advantages of binary analysis

- Compiler optimizations increase the distance between the executed code and the source
- Source code instrumentation may prevent the compiler from applying some transformations

We want to evaluate the "real" executed code: What You Analyze Is What You Run

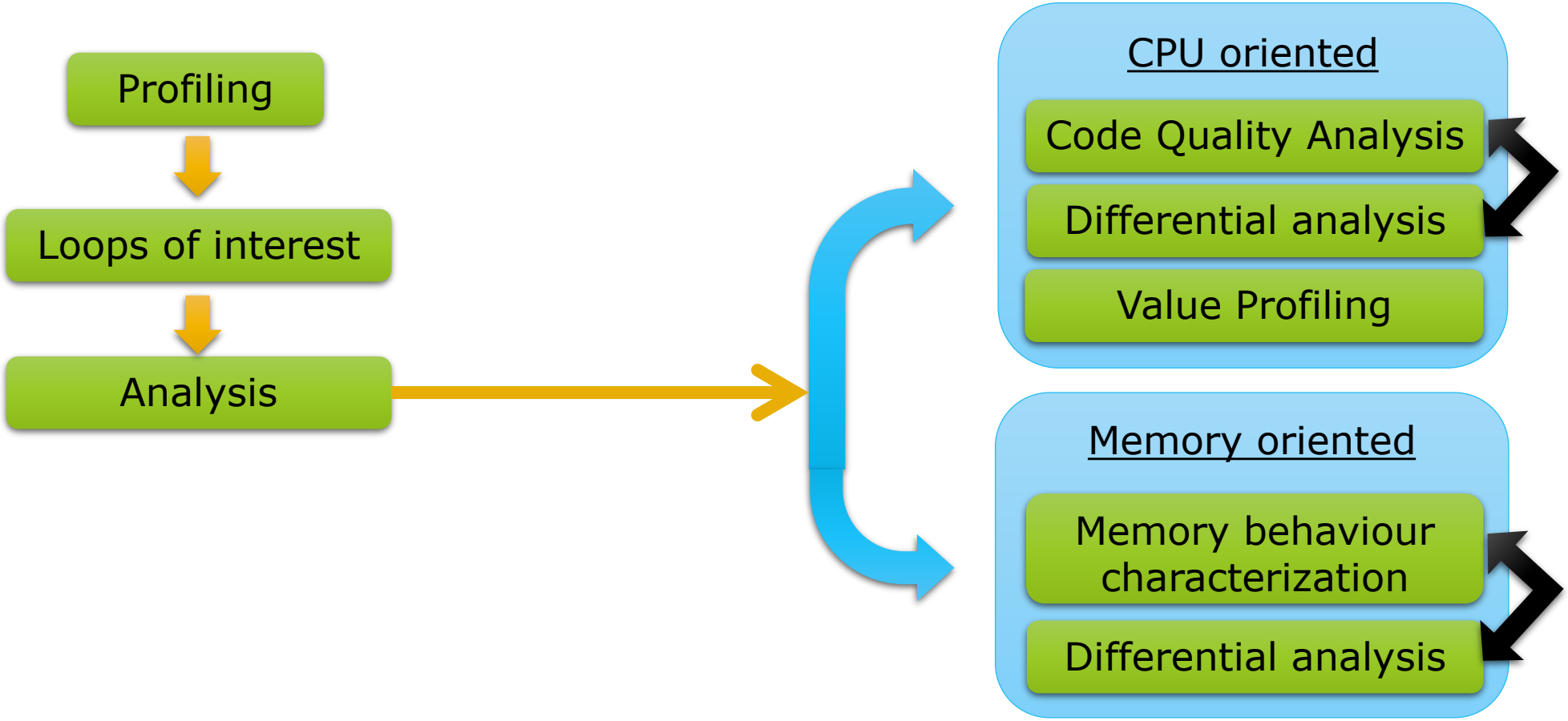
We are able to reconstruct the program structure

- Automatically relate the analyses to source code
  - A single source loop can be compiled as multiple assembly loops

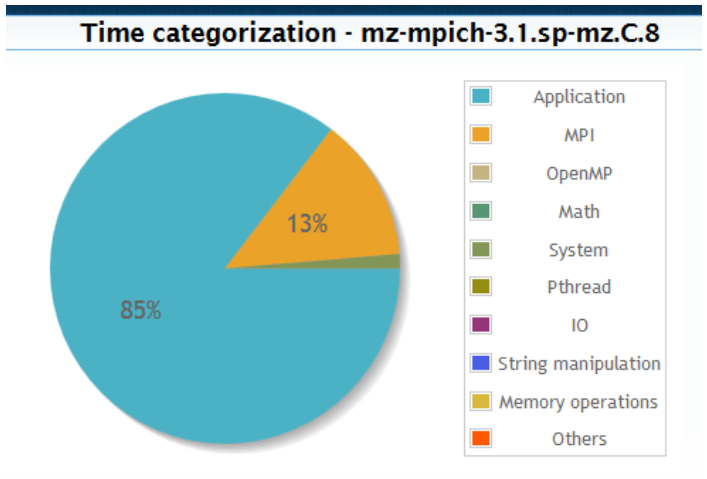


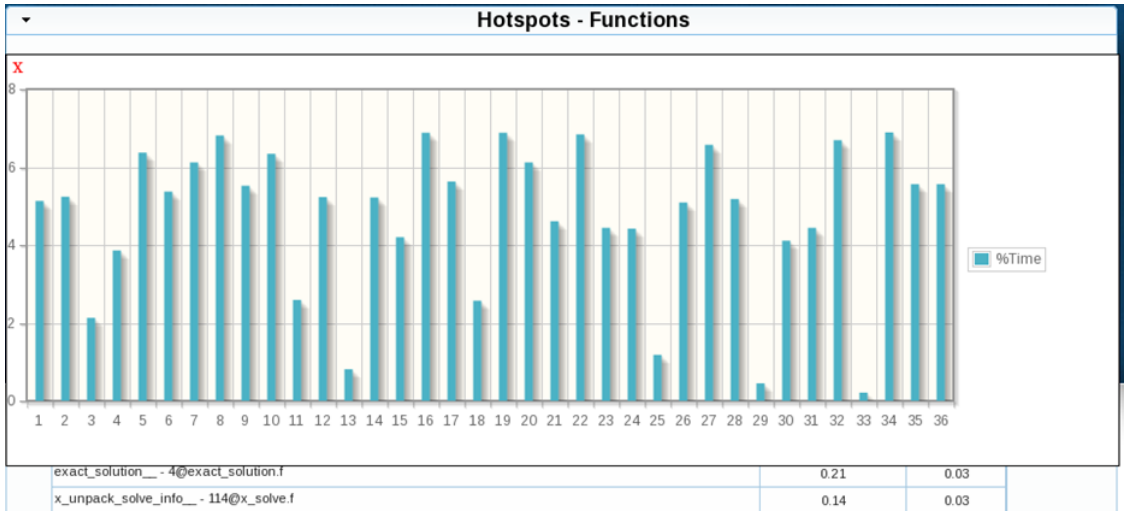
Introduction
MAQAO methodology

Decision tree



MAQAO LProf: Lightweight Profiler





MAQAO LProf: Lightweight Profiler
Introduction

Lightweight localization of application hotspots

Multiple measurement methods available:

- Sampling (default)
  - Hardware counters (through perf_event_open system call)
  - Non intrusive, low overhead
- Instrumentation
  - Through binary rewriting
  - Can target specific issues
  - Extra overhead

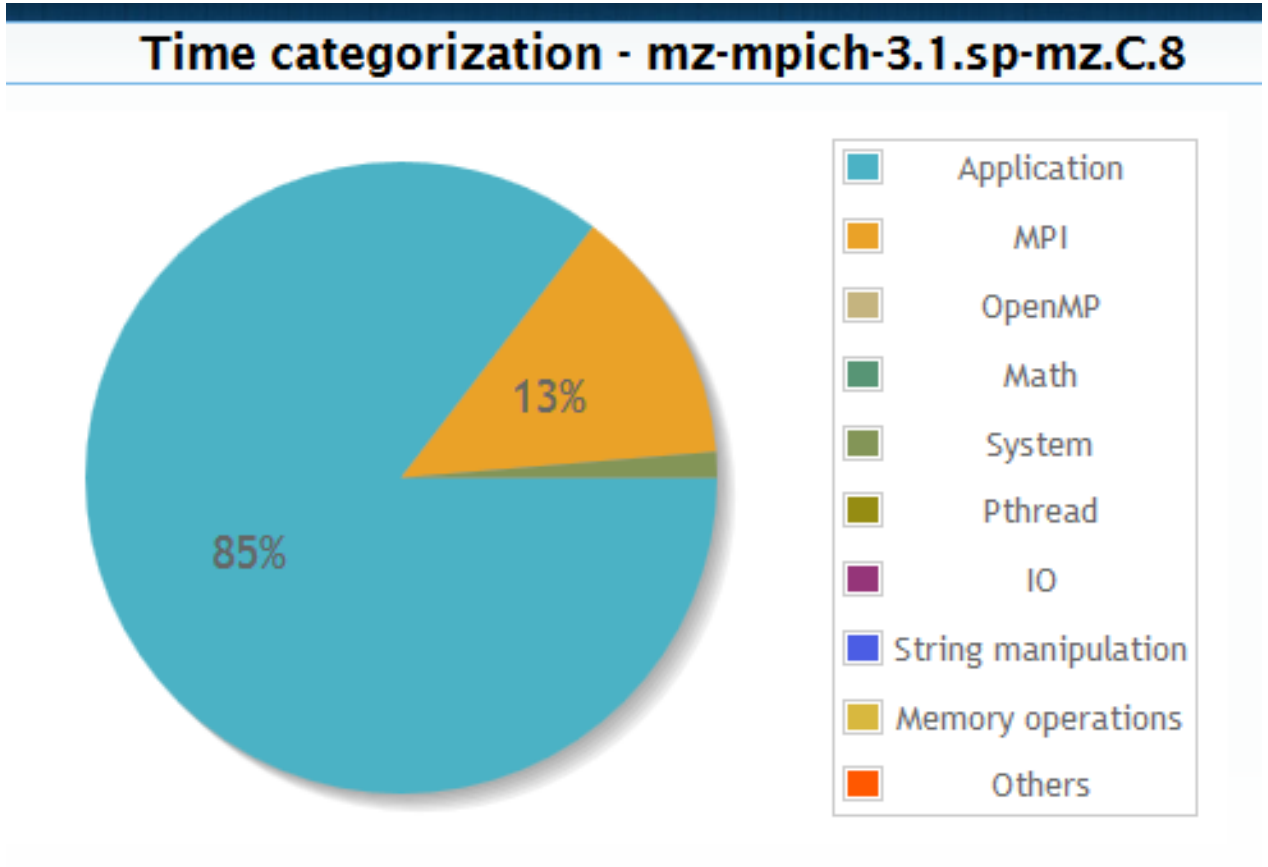
Runtime-agnostic

MAQAO LProf: Lightweight Profiler
Time categorization

Parallelization overhead
- Shared: Pthreads, OpenMP, etc …
- Distributed: MPI, etc…

Programming
- IO operations
- String operations
- Memory management
- External libraries such as libm / libmkl

User time breakdown
- Functions
- Loops



MAQAO LProf: Lightweight Profiler
Function and loop hotspots (1/3)

Focusing on user time

- Function hotspots
- Load balancing across the nodes

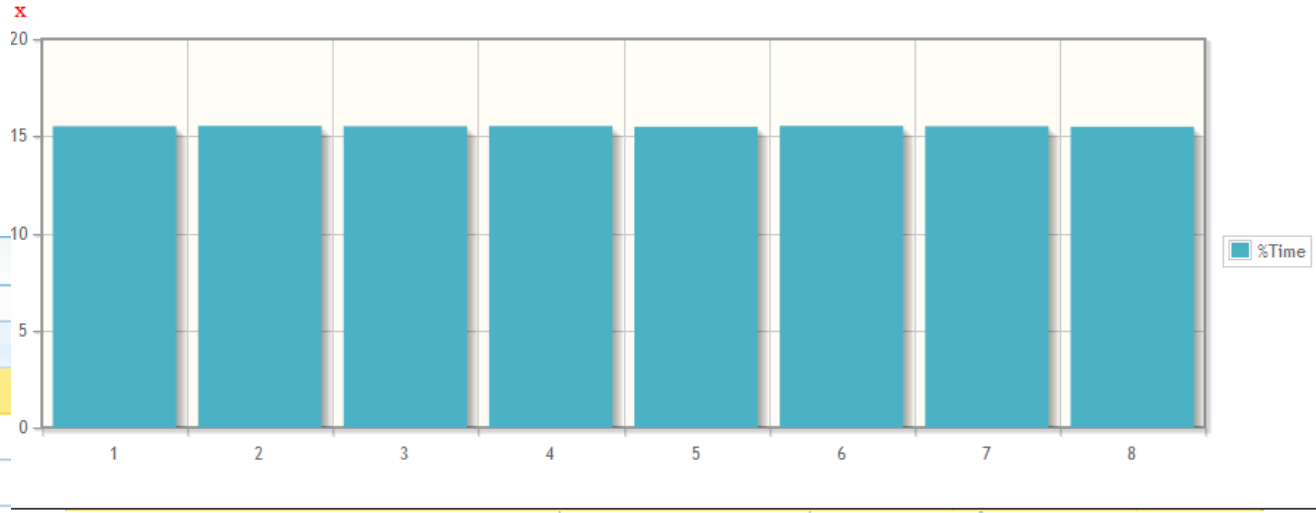
Hotspots - Functions

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 LProf: Lightweight Profiler
Function and loop hotspots (2/3)

Focusing on user time

- Function hotspots
- Load balancing across the nodes



Name		
compute_rhs_		
y_solve_		
z_solve_		
x_solve_	15.07	0.14
MPIDI_CH3I_Progress	5.61	0.14

MAQAO LProf: Lightweight Profiler
Function and loop hotspots (3/3)

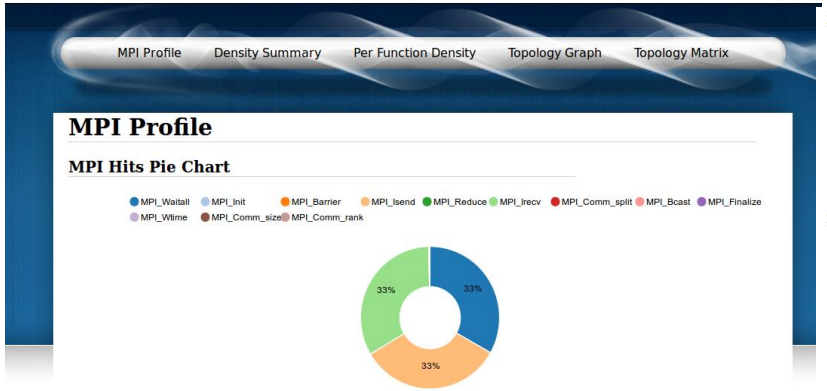
Analyze the time spent at loop level

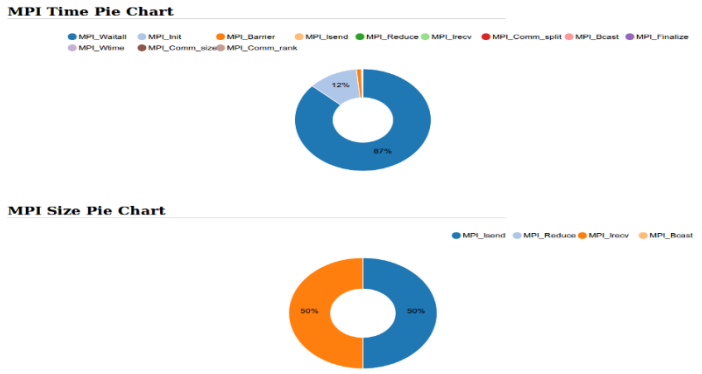
- Find the most time consuming
- Direct link to MAQAO CQA analyses

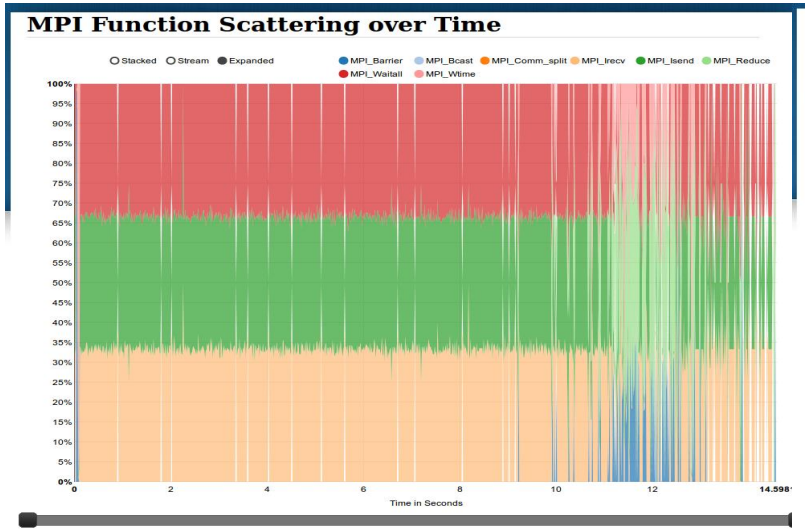
dauvergne - Process #14213 - Thread #14201

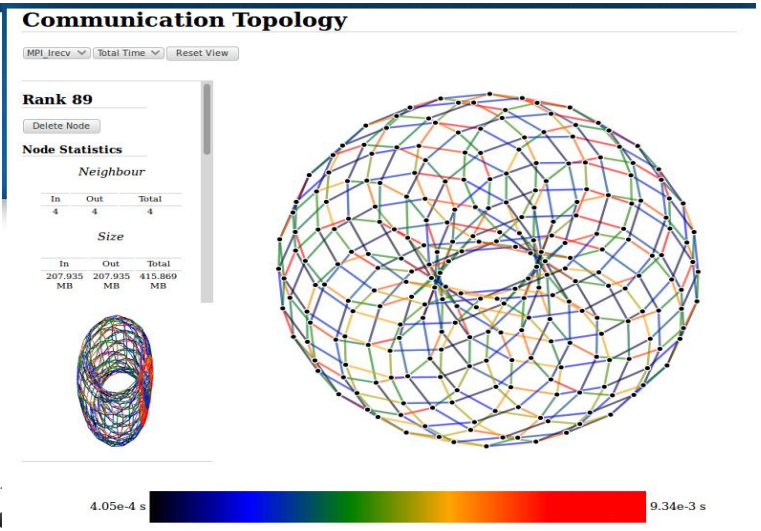
Name	Excl %Time	Excl Time (s)
binvcrhs - 206@solve_subs.f	17.27	2.23
MPIDI_CH3I_Progress	15.24	1.96
poll_active_fboxes	13.71	1.77
▼ y_solve_.omp_fn.0 - 45@y_solve.f	8.47	1.09
▼ loops	8.47	
▼ Loop 121 - y_solve.f@45	0	
▼ Loop 122 - y_solve.f@45	0.16	
○ Loop 124 - y_solve.f@45	0.14	
○ Loop 125 - y_solve.f@145	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	

MAQAO LProf/MPI: MPI characterization









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

Objective: profiling MPI runtime use.

- Coarse grain
  - Overview
  - Global trends/patterns
  - Low overhead
- Fine grain
  - Filtering precise issues
  - Higher overhead

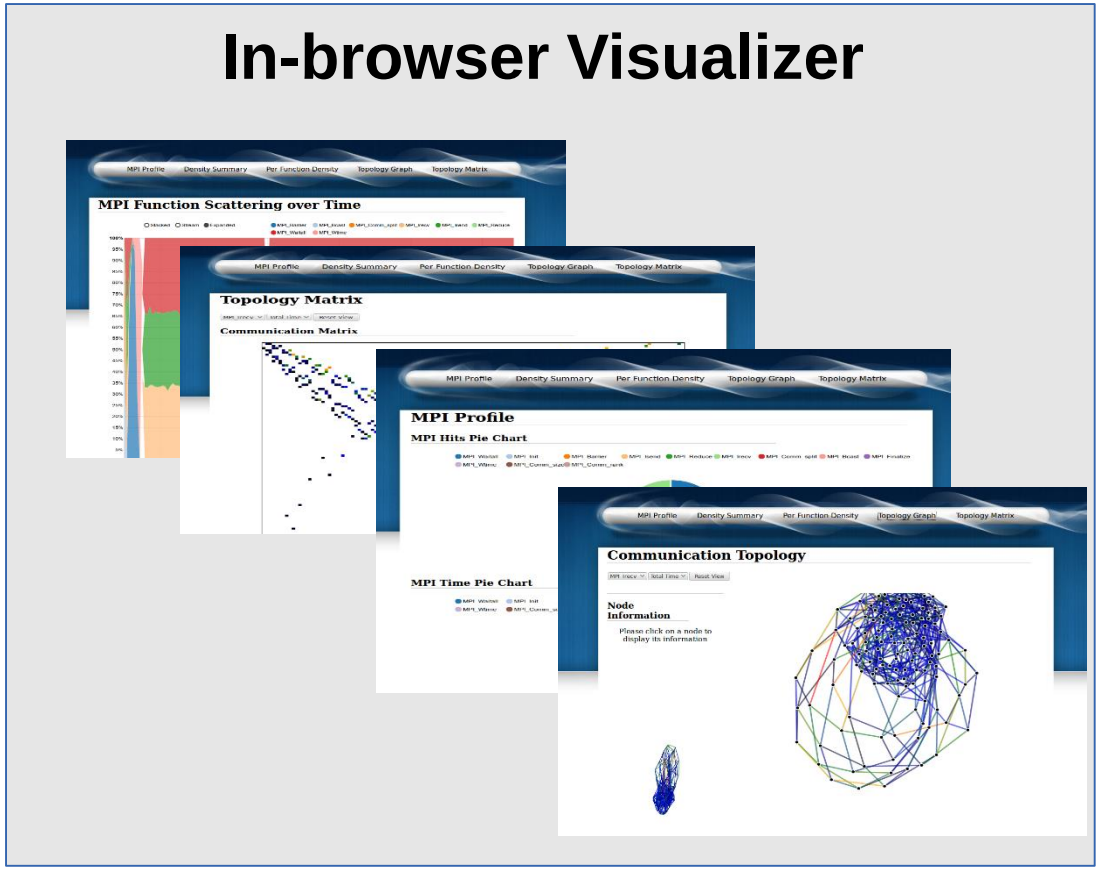
Online profiling:

- No IOs: only one result file with pre-processed data
- Reduced memory footprint thanks to aggregated metrics
- Scalable on 1000+ MPI processes

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

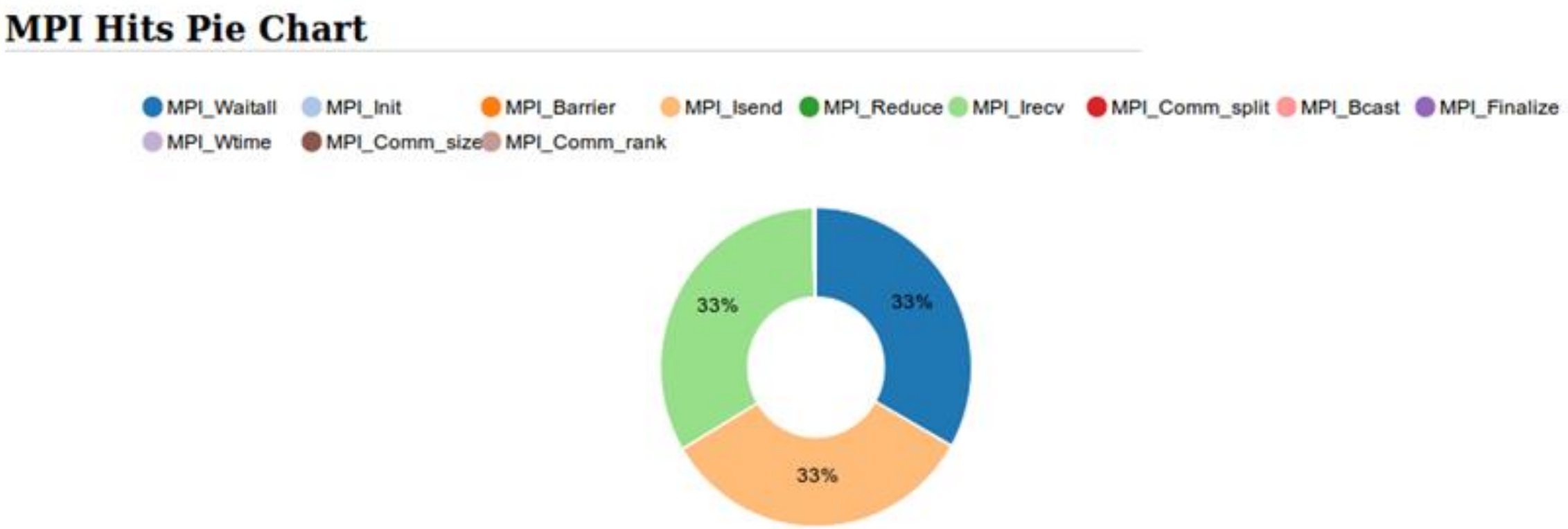
LProf/MPI is an MPI profiling tool targeting lightweight metrics that can be deduced online

- No trace required
- Does not require recompiling



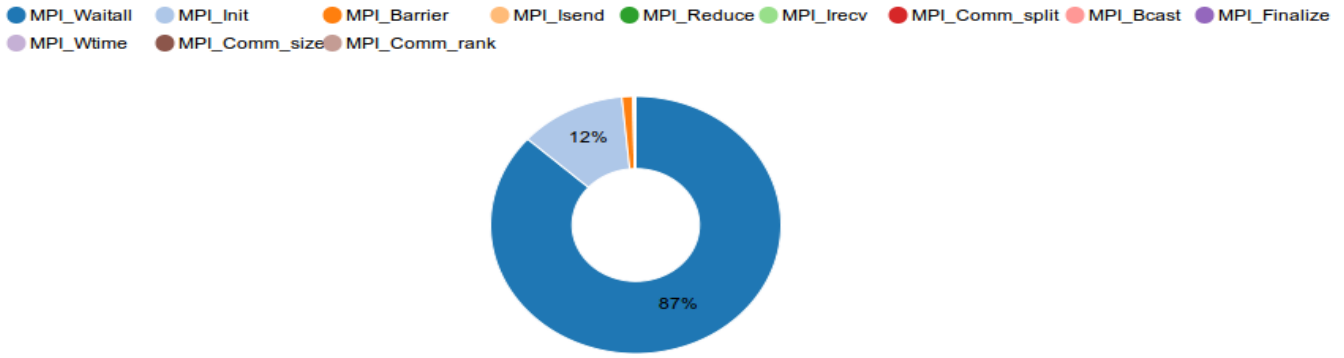
MAQAO LProf/MPI: MPI characterization
Global profile (1/3)

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

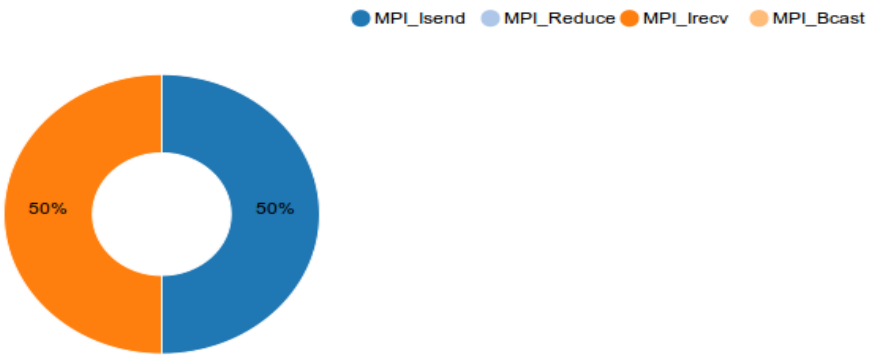


MAQAO LProf/MPI: MPI characterization
Global profile (2/3)

MPI Time Pie Chart



MPI Size Pie Chart

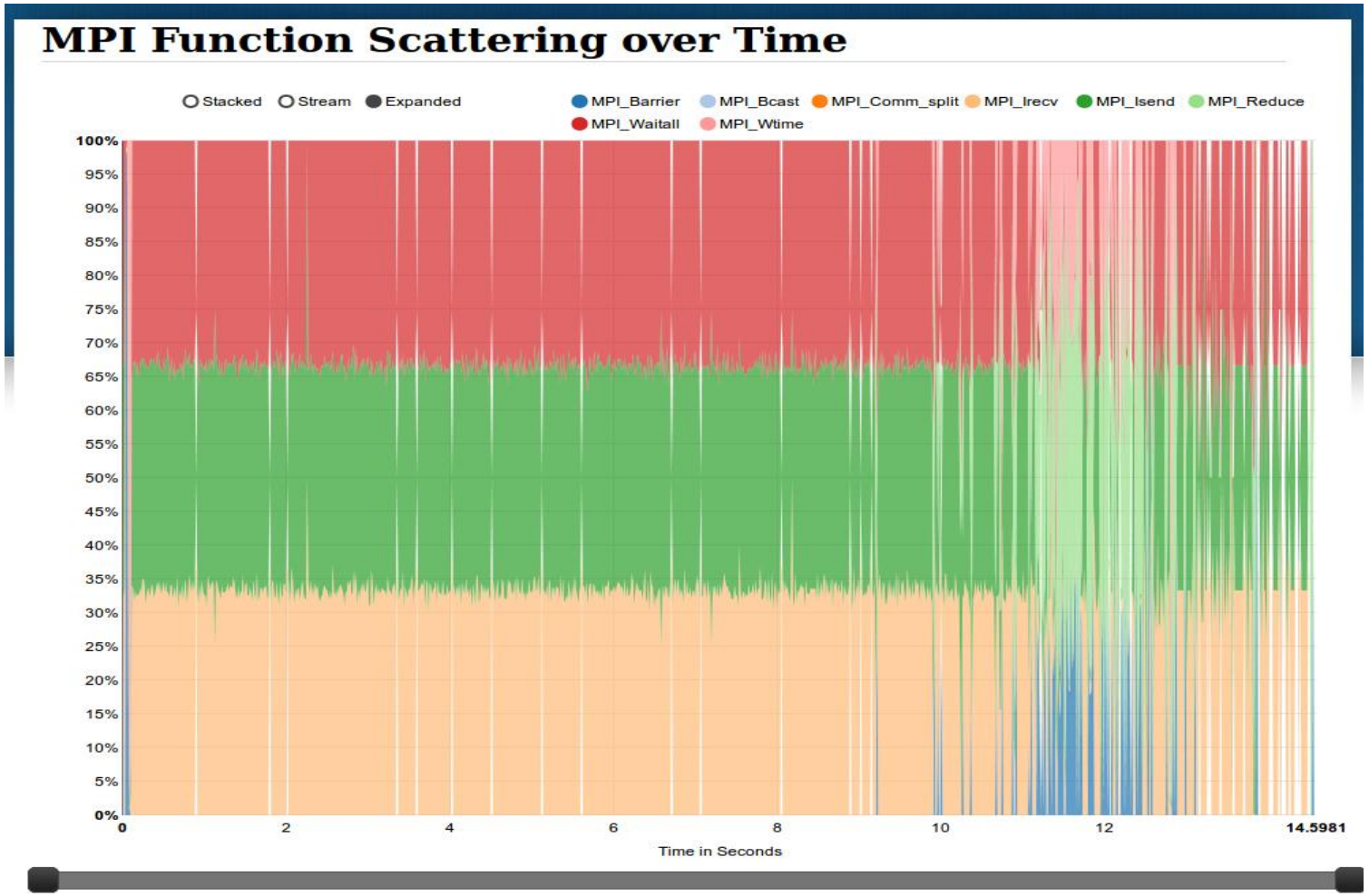


MAQAO LProf/MPI: MPI characterization
Global profile: flat view (3/3)

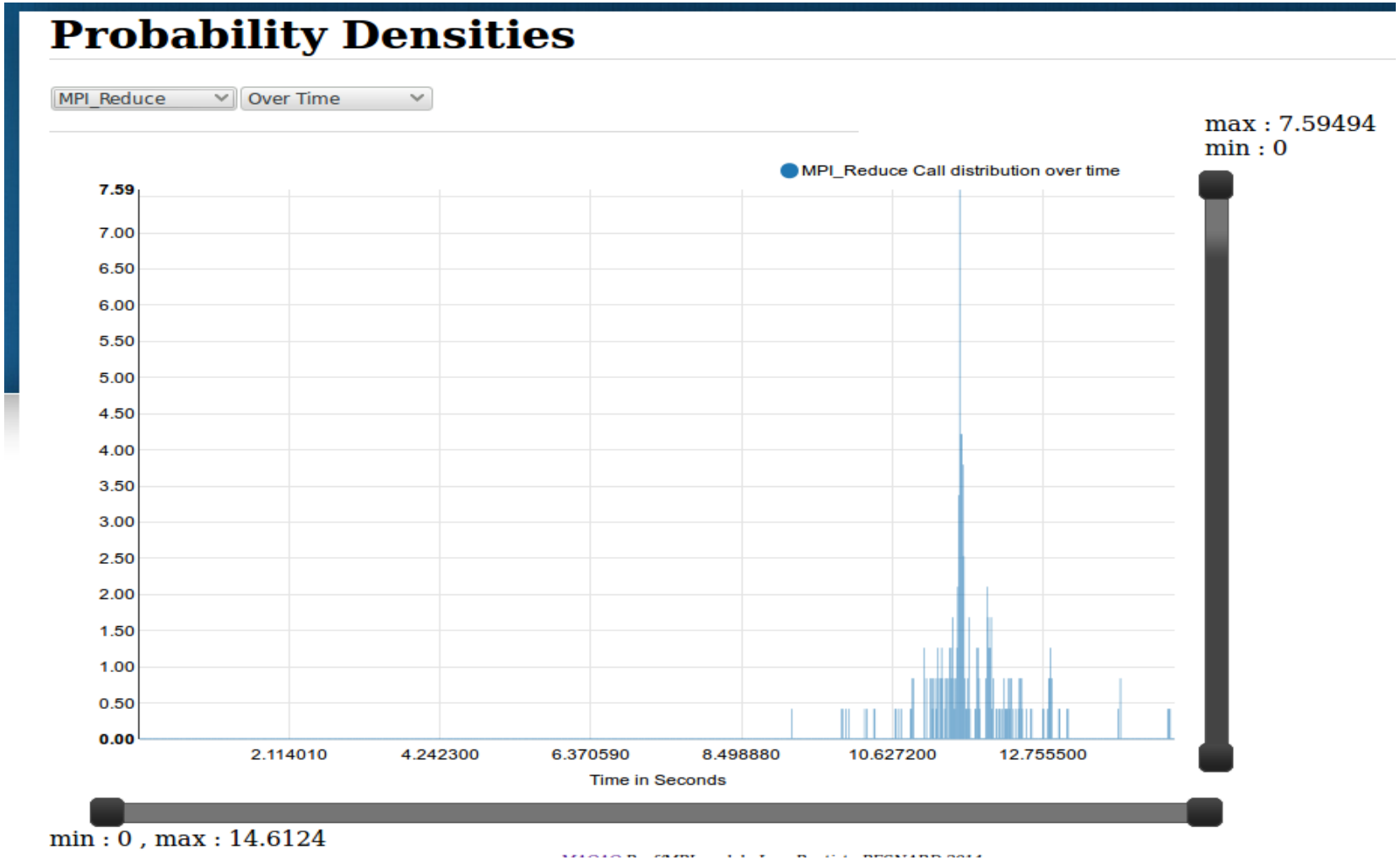
MPI Profile

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%

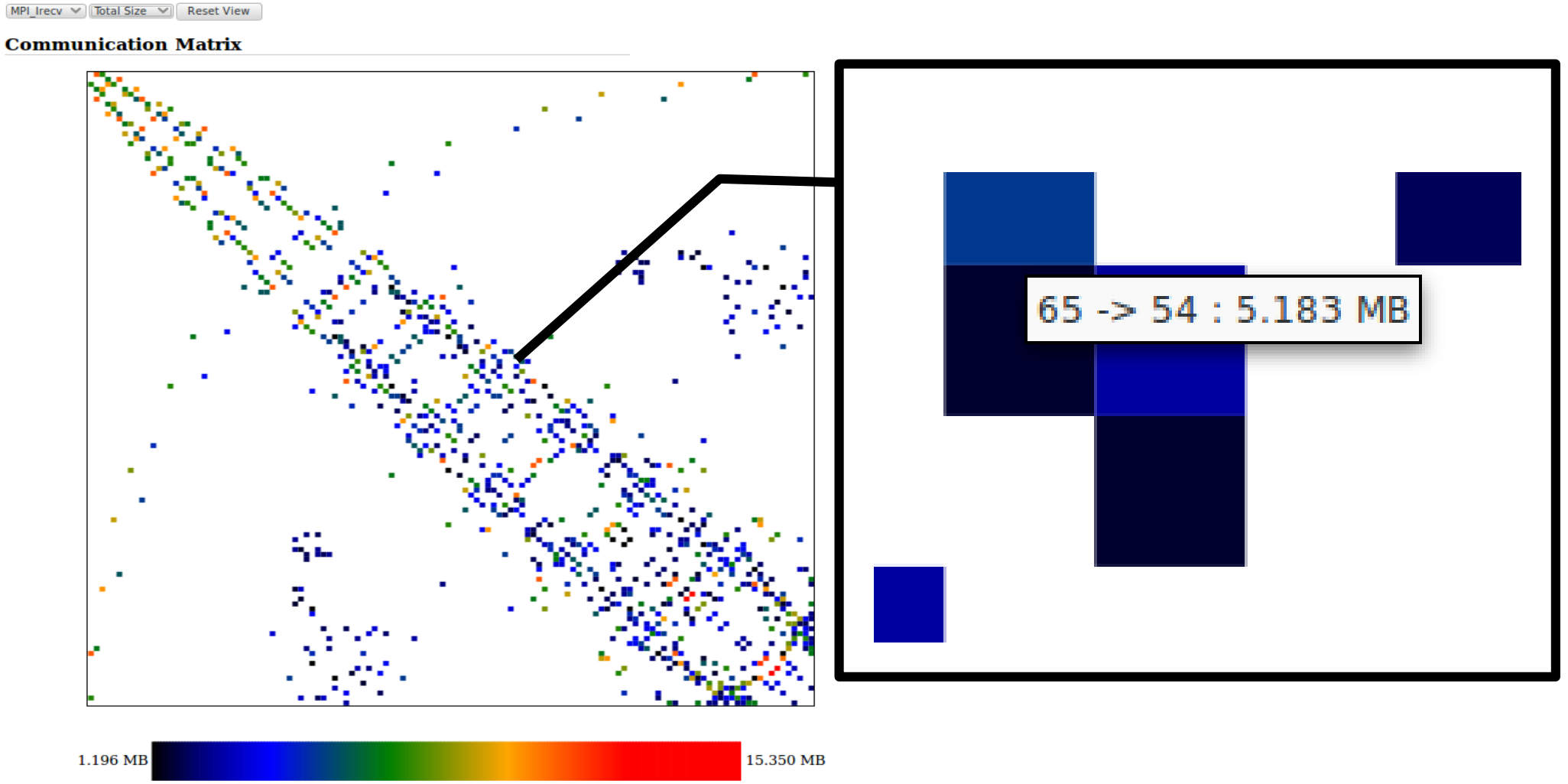
MAQAO LProf/MPI: MPI characterization
Function scattering over time



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

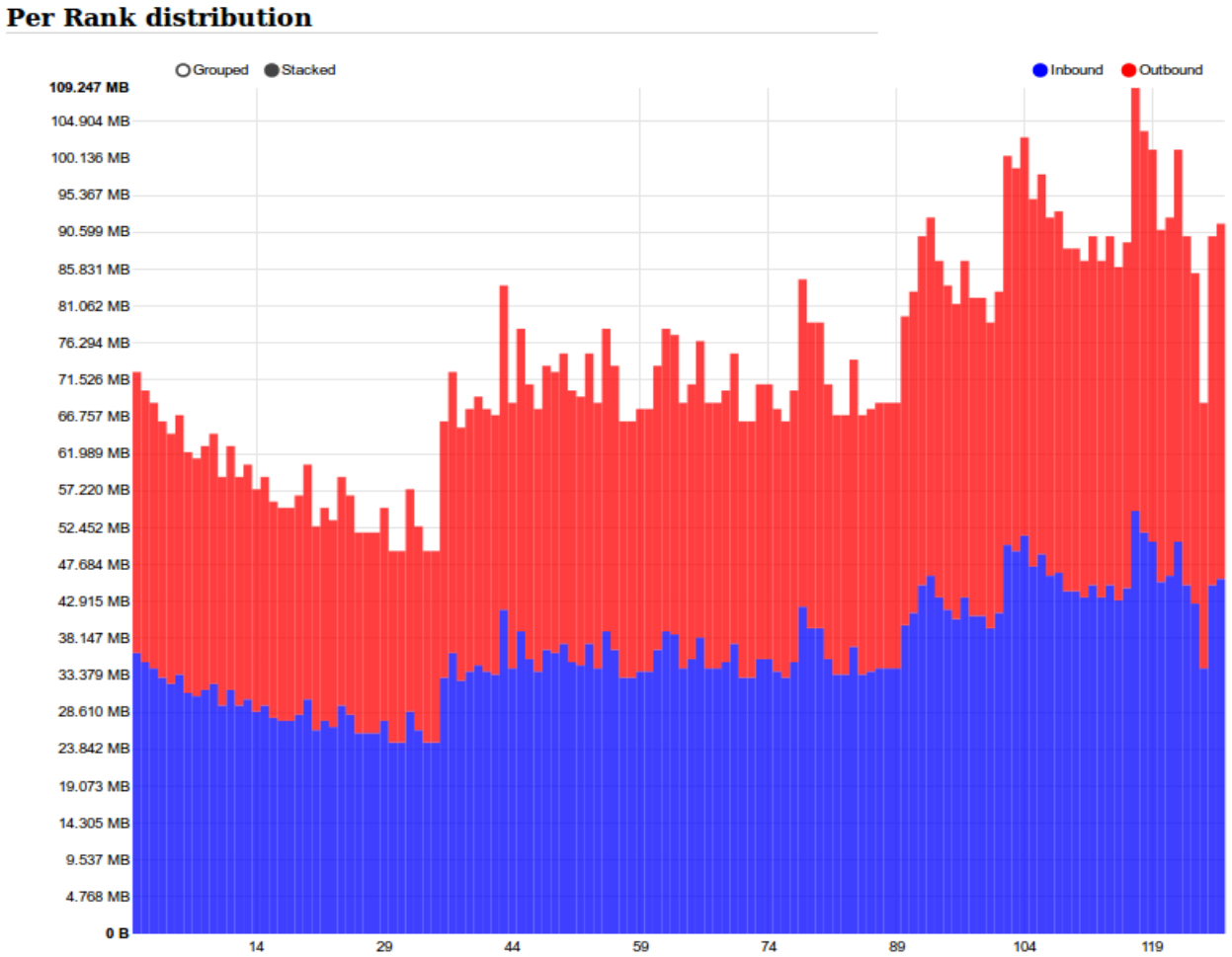


MAQAO LProf/MPI: MPI characterization
2D communication matrix

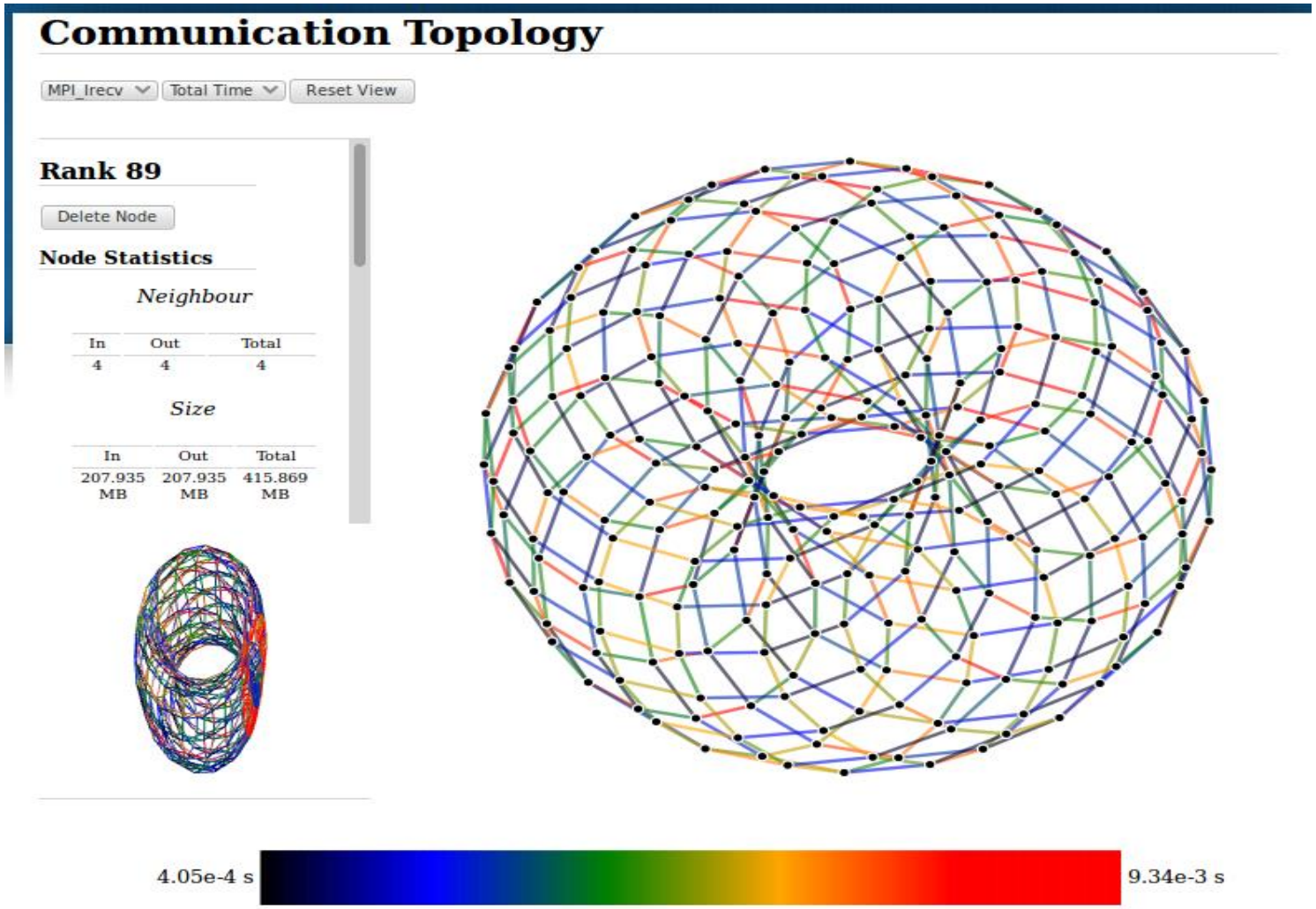


MAQAO LProf/MPI: MPI characterization
Per rank distribution

Checking load balancing



MAQAO LProf/MPI: MPI characterization
3D Topology



MAQAO CQA: Code Quality Analyzer

MAQAO CQA: Code Quality Analyzer
Introduction

Improving performance of the user code

Focusing on loops
- In HPC most of the time is spent in loops

Static analysis of assembly code
- Evaluate the quality of the compiler generated code
- Analysis based on a microarchitecture model
- Returns hints and workarounds to the developer

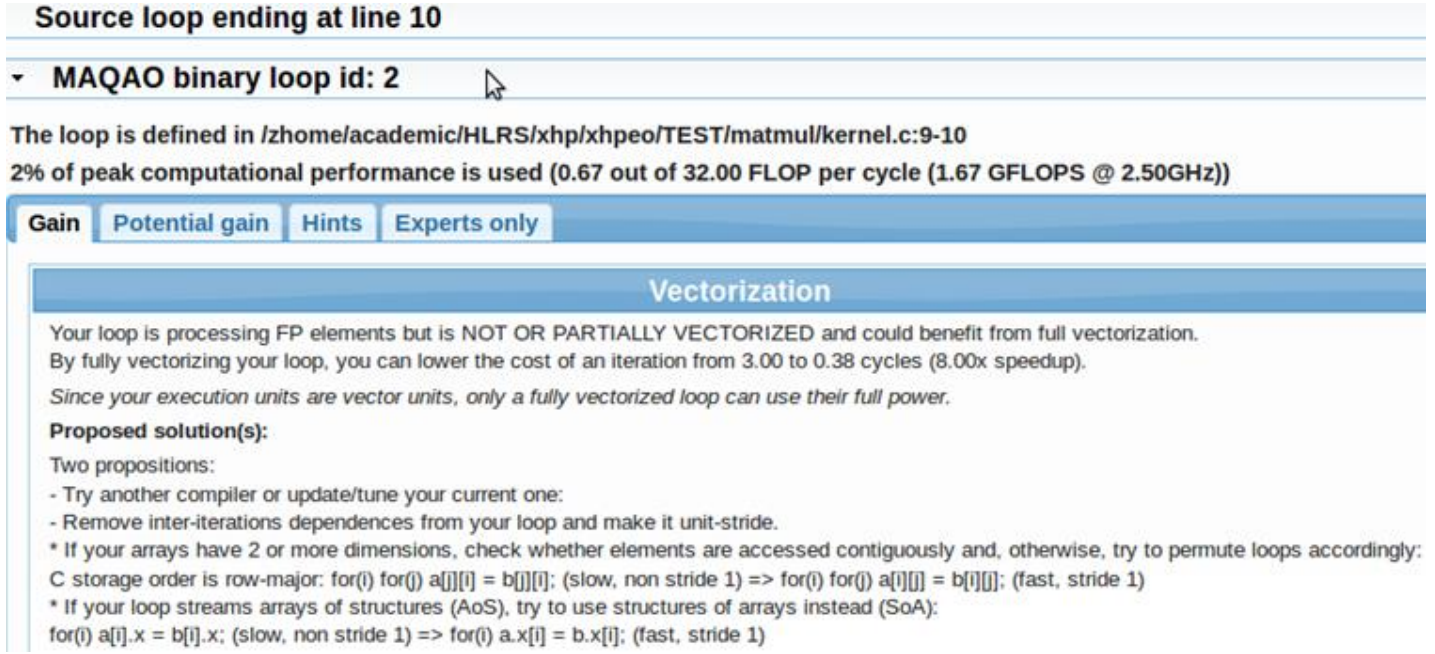
Targets compute bound codes

MAQAO CQA: Code Quality Analyzer
Output

High level reports
- Reference to the source code
- Bottleneck description
- Hints to improve performance
- Reports categorized by confidence level:
  - gain, potential gain

Low level report for performance experts

No runtime cost/overhead

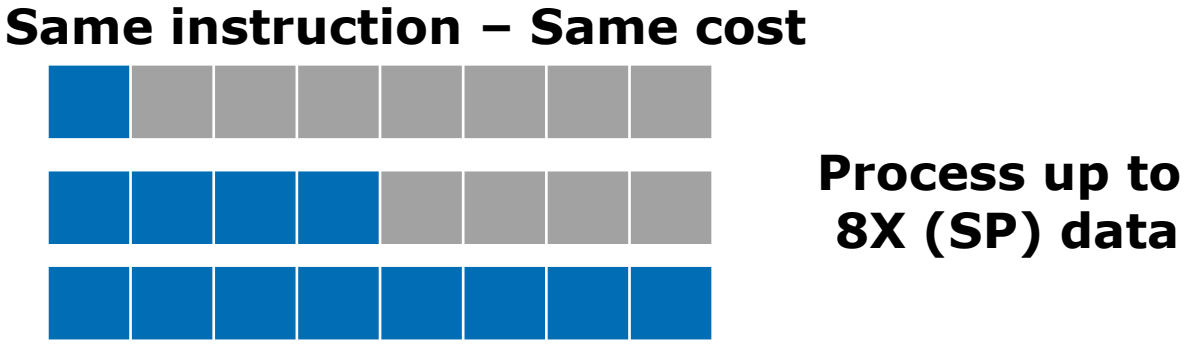


MAQAO CQA: Code Quality Analyzer
Processor Architecture: Core level

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

Concepts:
- Peak performance
- Execution pipeline
- Resources/Functional units

Key performance levers for core level efficiency:
- Vectorization
- Get rid of high latency instructions if possible
- Have the compiler generate an efficient code



MAQAO CQA: Code Quality Analyzer
Compiler and programmer hints

Compiler can be driven using flags and pragmas

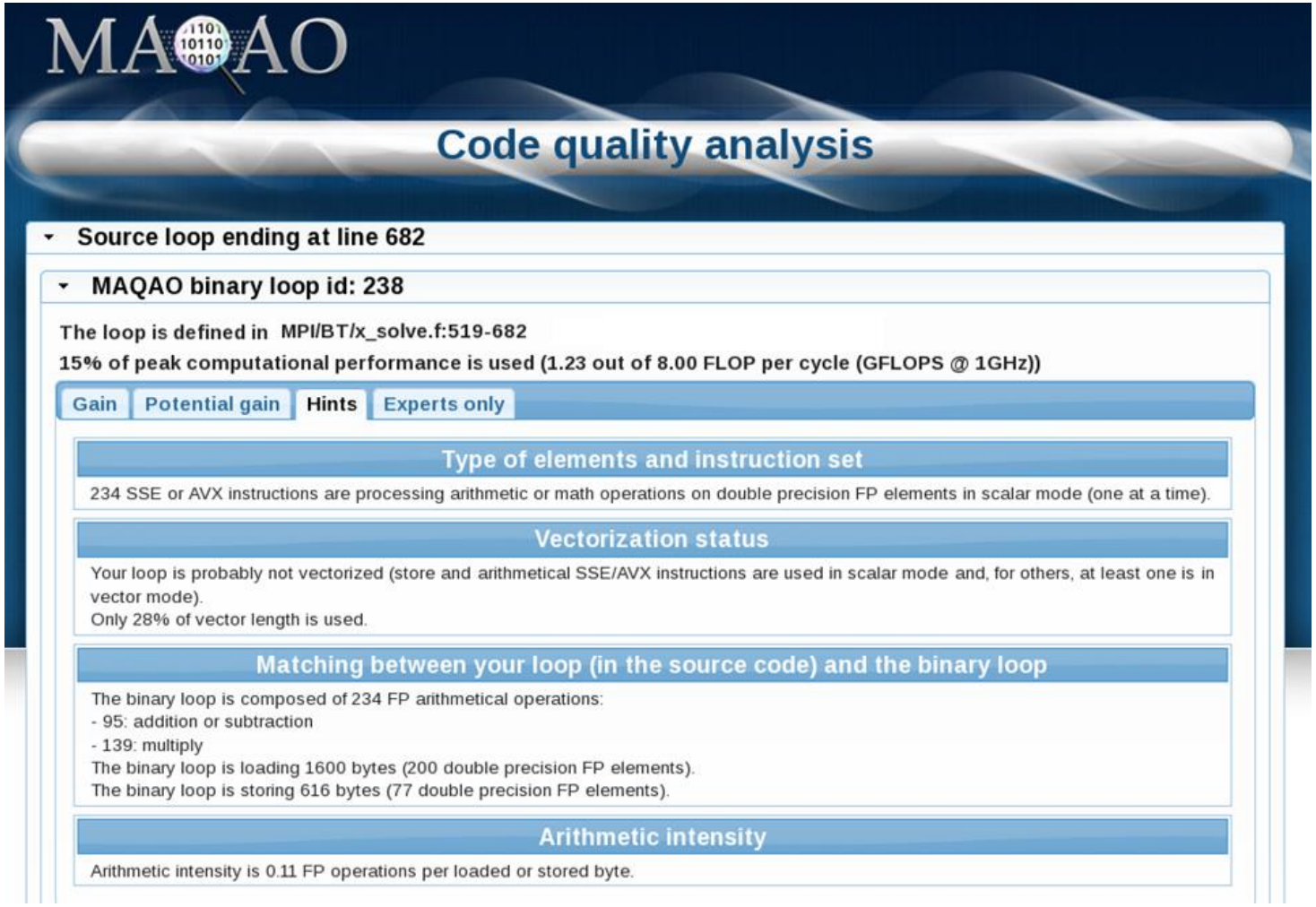
- Architecture specific flags (e.g. -xHost on AVX capable machines)
- Force optimization (unrolling, vectorization, alignment, …)
- Bypass conservative behavior when possible (e.g. 1/X precision)

Implementation changes

- Data access
  - Loop interchange
  - Changing loop strides
- Avoid instructions with high latency

MAQAO CQA: Code Quality Analyzer
GUI sample (1/2)

MAQAO CQA: Code Quality Analyzer
GUI sample (2/2)



Thank you for your attention !

Questions ?