MAQAO
Performance Analysis and Optimization Tool

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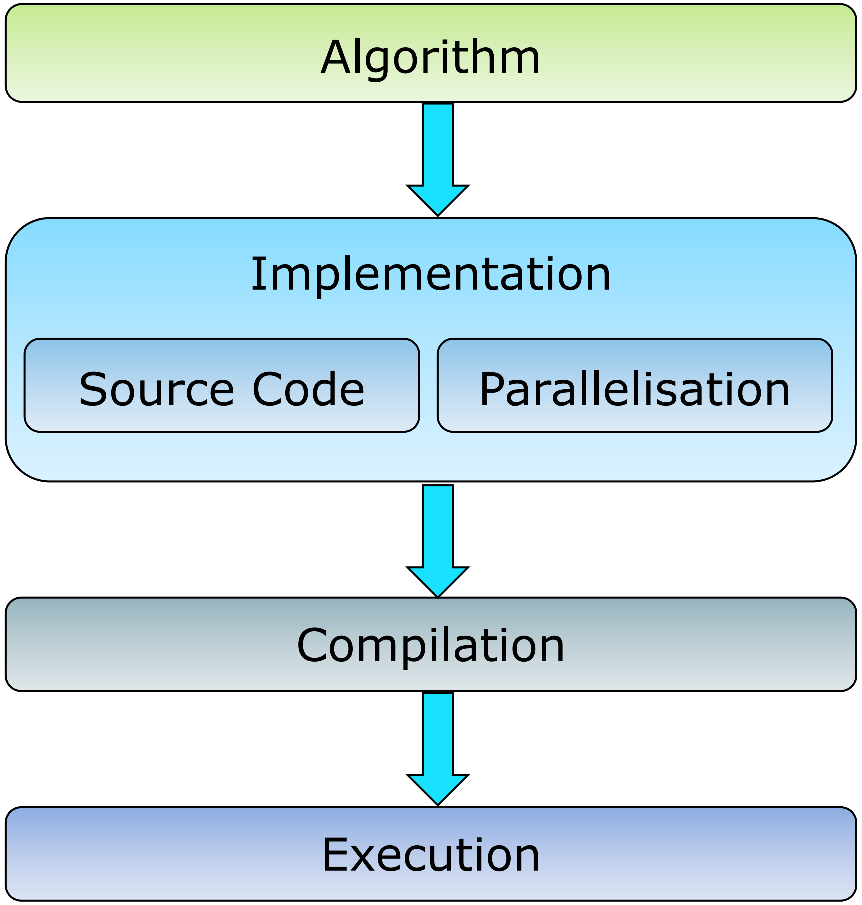
Performance analysis and optimisation

How much of an application can be optimized?
- What would the effort/gain ratio be?

Where is the application spending most execution time and resources?

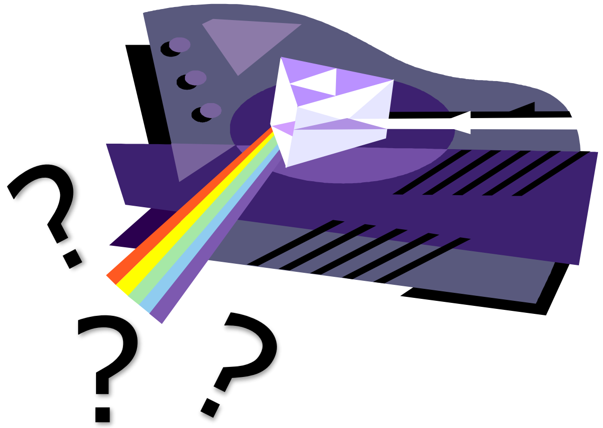
Why is the application spending time there?
- Algorithm, implementation, runtime or hardware?
- Data access or computation?

How to improve the application?
- At which step(s) of the workflow or dev process?
- What additional information is needed?



A multifaceted problem

Pinpointing the performance bottlenecks



Identifying the dominant category of issues

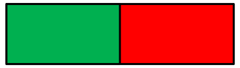
- Algorithms, implementation, parallelism, …

Making the **best use** of the machine features

- Complex multicore and manycore CPUs
- Complex memory organization

➔ **Need for dedicated and complementary tools**

Finding the **most rewarding** issues to be fixed

- **40%** total time, expected **10%** speedup
  - ➔ TOTAL IMPACT: **4%** speedup 
- **20%** total time, expected **50%** speedup
  - ➔ TOTAL IMPACT: **10%** speedup 

Motivating example

Code of a loop representing ~10% walltime

6) Variable number of iterations

2) Non-unit stride accesses

```
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
```

1) High number of statements

4) DIV/SQRT

3) Indirect accesses

5) Reductions

2) 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) Variable number of iterations

MAQAO: Modular Assembly Quality Analyzer and Optimizer

Objectives:

- Characterizing performance of HPC applications
- Focusing on performance at the **core level**
- **Guiding users** through the optimization process
- Estimating return on investment (**R.O.I.**)

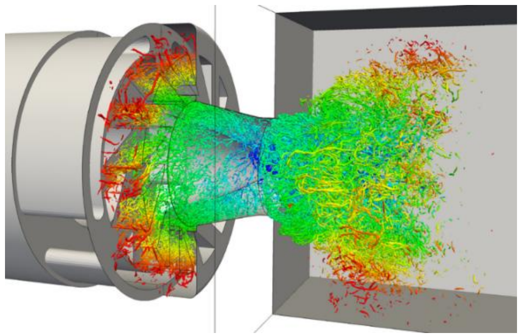
Characteristics:

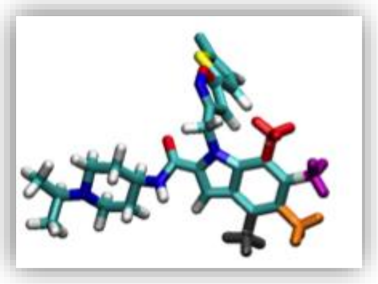
- **Modular tool** offering complementary views
- Support for **Intel x86-64** and **Xeon Phi**
  - ARM on-going development
- LGPL3 Open Source software
- Developed at UVSQ since 2004
- Binary release available as a **static executable**

Success stories

MAQAO is used for optimizing industrial and academic HPC applications:

- QMC=CHEM (IRSAMC)
  - Quantum chemistry
  - Speedup: **> 3x**
    - Optimization: moved invocations of functions with identical parameters out of the loop body
- Yales2 (CORIA)
  - Computational fluid dynamics
  - Speedup: **up to 2.8x**
    - Optimization: removing double structure indirections
- Polaris (CEA)
  - Molecular dynamics
  - Speedup: **1.5x – 1.7x**
    - Optimization: enforcing loop vectorization through compiler directives
- AVBP (CERFACS)
  - Computational fluid dynamics
  - Speedup: **1.08x – 1.17x**
    - Replaced divisions by reciprocal multiplications
    - Complete unrolling of loops with a small number of iterations





Partnerships

MAQAO is funded by UVSQ, Intel and CEA (French department of energy) through Exascale Computing Research (ECR) and the French Ministry of Industry’s various FUI/ITEA projects (H4H, COLOC, PerfCloud, ELCI, etc...)

Provides core binary analysis and instrumentation capabilities and features for other tools:

- TAU performance tools with MADRAS patcher through MIL (MAQAO Instrumentation Language)
- ATOS bullxprof with MADRAS through MIL
- Intel Advisor
- INRIA Bordeaux HWLOC

PeXL ISV also contributes to MAQAO:

- Commercial performance optimization expertise
- Training and software development
- www.pexl.eu

MAQAO team and collaborators

MAQAO Team
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- Romain Pillot, Eng
- Youenn Lebras, Ph.D.

Analysis at binary level

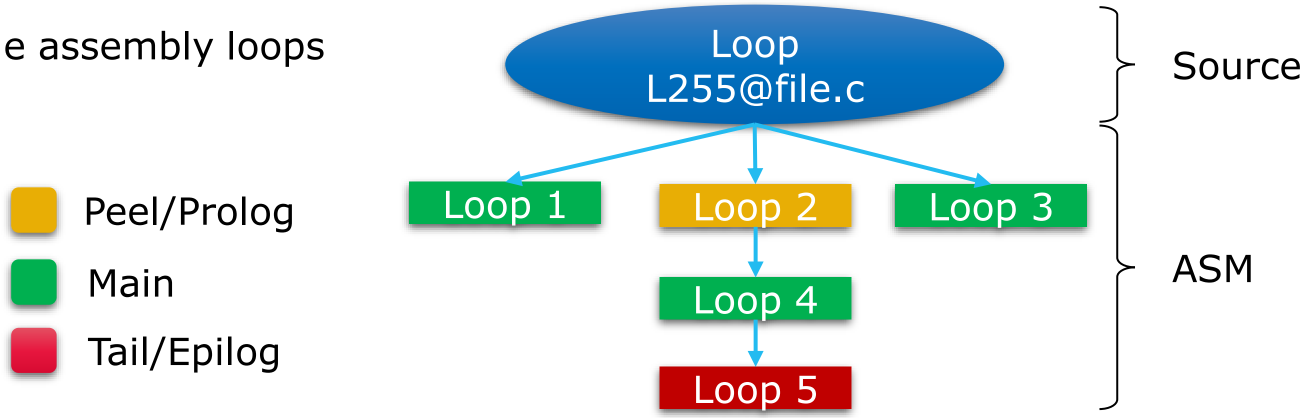
Advantages of binary analysis:

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

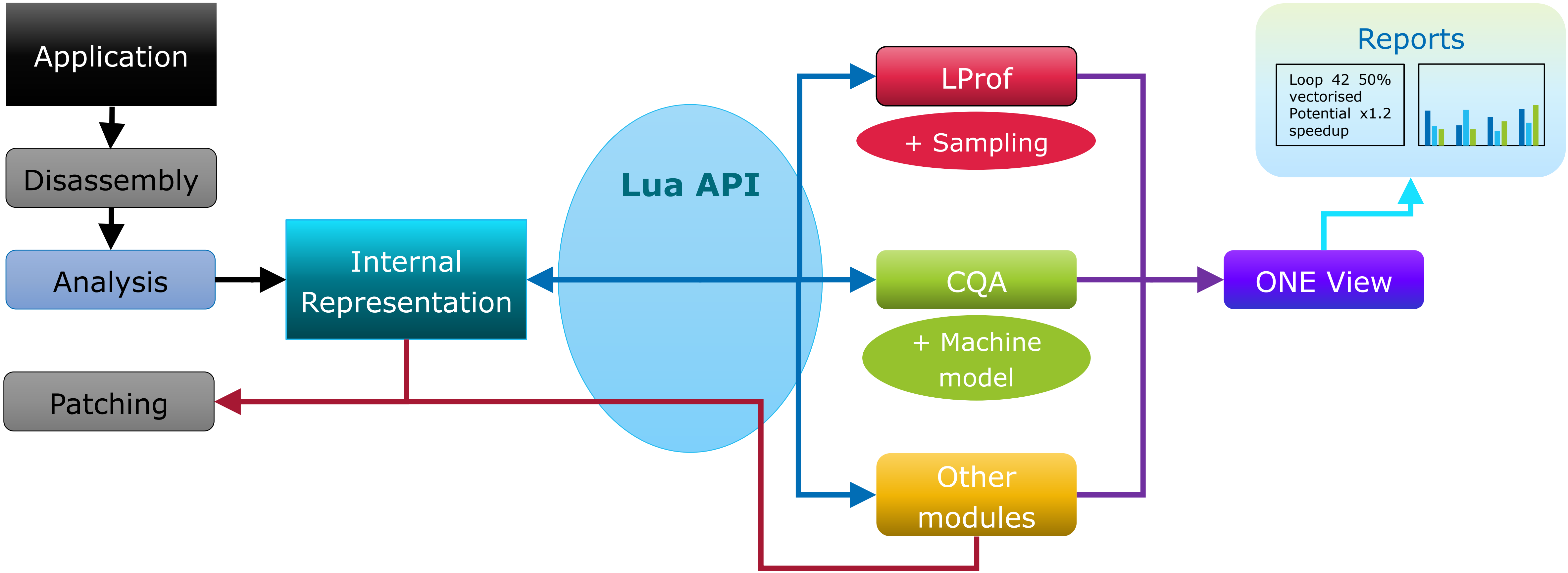
Evaluate the "real" executed code: **What You Analyse Is What You Run**

Main steps:

- Construct high level structures (CFG, DDG, SSA, …)
- Relate the analyses to source code
  - A single source loop can be compiled as multiple assembly loops
  - Affecting unique identifiers to loops

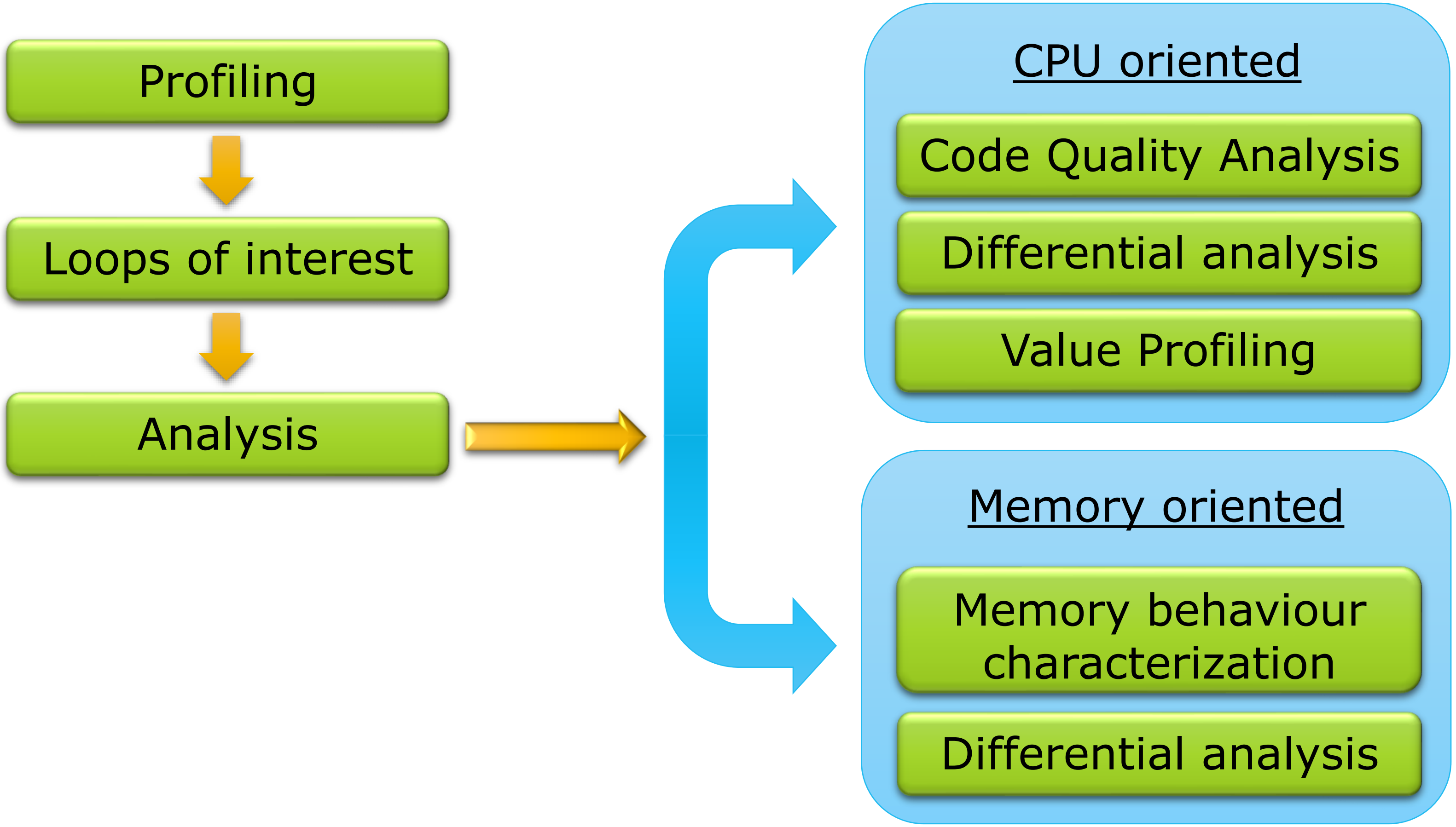


MAQAO Main structure



MAQAO Methodology

Decision tree



MAQAO LProf: Lightweight Profiler

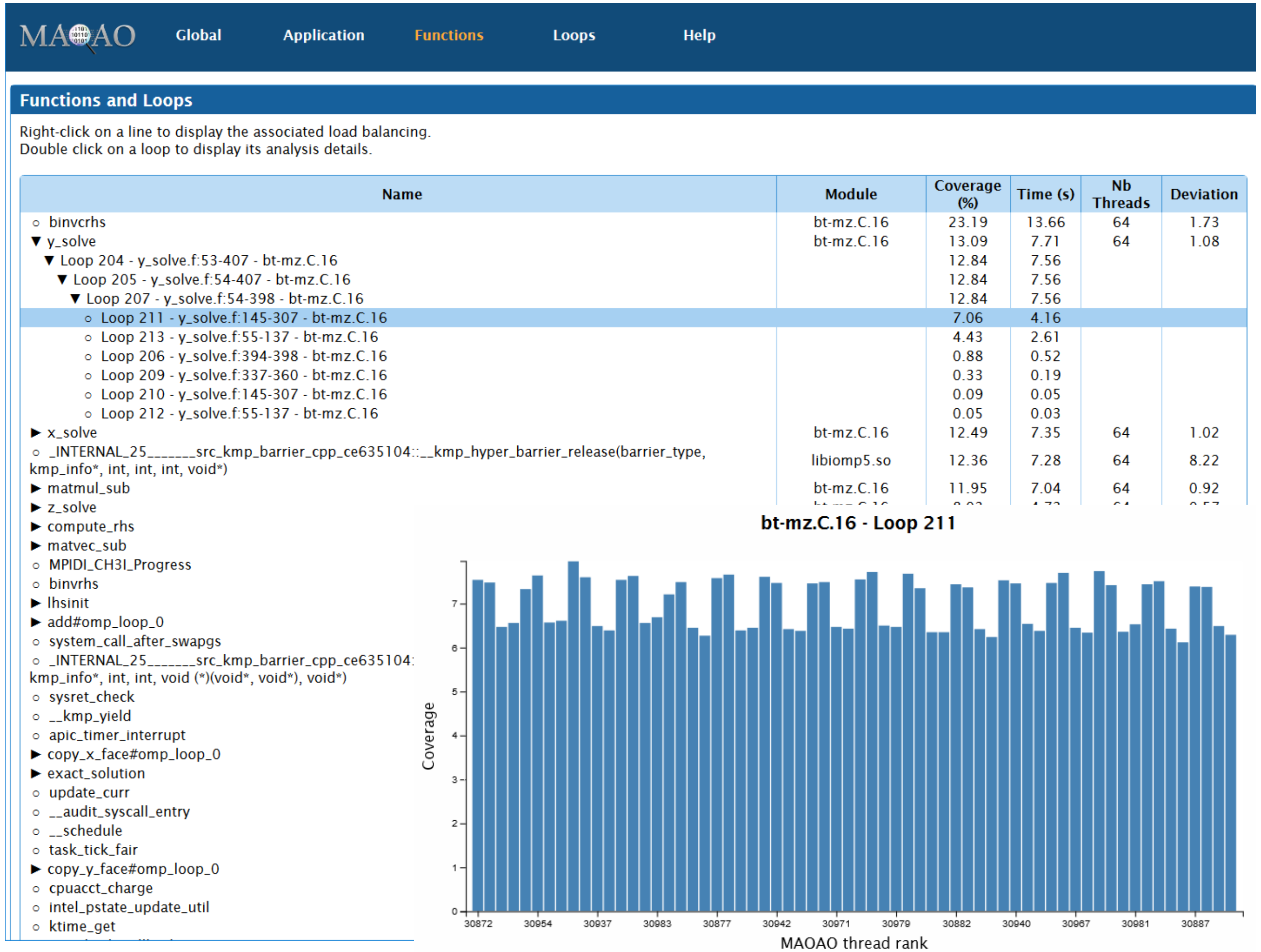
Goal: Lightweight localization of application hotspots

Features:

- **Sampling** based
- Access to hardware counters
- Analysis at function and loop granularity

Strengths:

- **Non intrusive**: No recompilation necessary
- **Low overhead**
- Agnostic with regard to parallel runtime

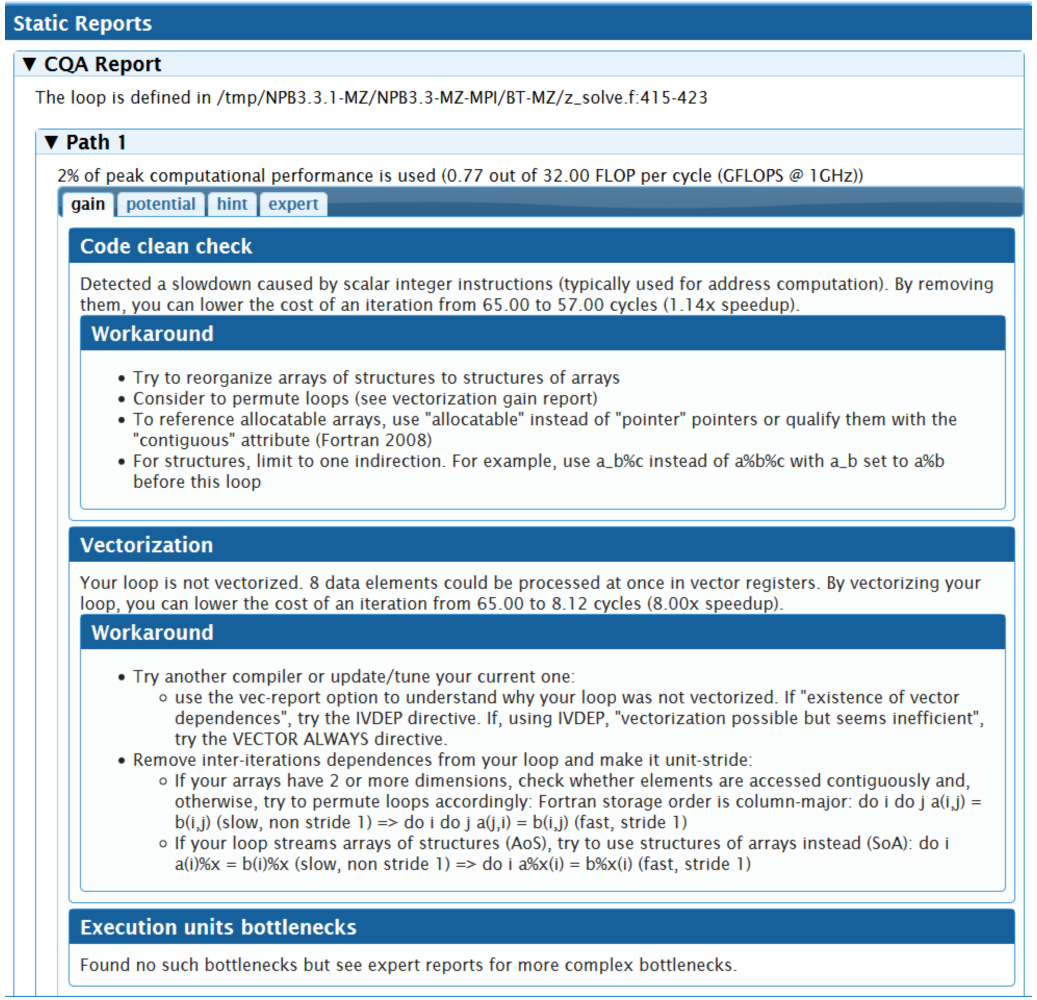


MAQAO CQA: Code Quality Analyzer

Goal: **Assist developers** in improving code performance

Features:

- Static analysis: **no execution** of the application
- Allows **cross-analysis** of/on multiple architectures
- Compiler generated code **quality evaluation**
- Proposes **hints and workarounds** to improve quality/performance
- **Loops centric**
  - In HPC, loops cover most of the processing time
- Targets **compute-bound** codes



MAQAO CQA: Main Concepts

Applications exploit at best 5 to 10% of the peak performance.

Main elements of analysis:

- Peak performance
- Execution pipeline
- Resources/Functional units

Same instruction – Same cost

Process up to 8X data

Key performance levers for core level efficiency:

- Vectorization
- Avoiding high latency instructions if possible (DIV/SQRT)
- Guiding the compiler code optimization
- Reorganizing memory and data structures layout

MAQAO CQA: Guiding the compiler and hints

Compilers can be driven using flags, pragmas, and keywords:

- Ensuring full use of architecture capabilities (e.g. using flag -xHost on AVX capable machines)
- Forcing optimizations (unrolling, vectorization, alignment, …)
- Bypassing conservative behaviour when possible (e.g. 1/X precision)

Hints for implementation changes:

- Improve data access patterns
  - Memory alignment
  - Loop interchange
  - Changing loop strides
  - Reshaping arrays of structures
- Avoid instructions with high latency (SQRT, DIV, GATHER, SCATTER, …)

MAQAO ONE View: Performance View Aggregator

Automating the whole analysis process

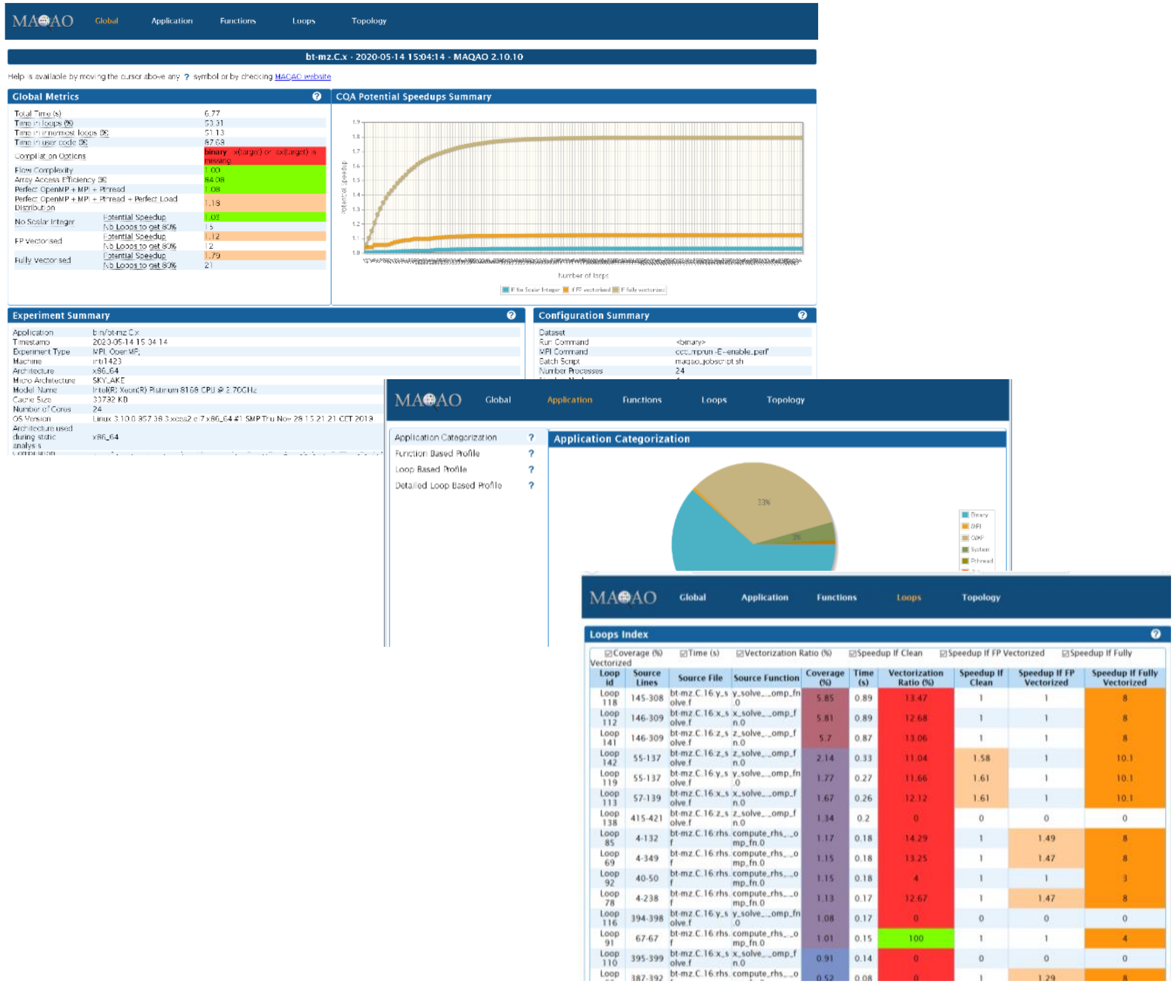
- Invoke multiple MAQAO modules
- Generate **aggregated performance views**
- Generate a report in HTML format

Main steps:

- Invokes LProf to **identify hotspots**
- Invokes CQA on **hotspots**

Available results:

- **Speedup** predictions
- Global **code quality** metrics
- **Hints** for improving performance
- Parallel **efficiency** analysis



Analysing an application with MAQAO

ONE View execution

- Provide all parameters necessary for executing the application
  - Parameters can be passed on the command line or as a configuration file
  - Parameters include binary name, MPI commands, dataset directory, …

```
$ maqao oneview --create-report=one --binary=bt-mz.C.16 --mpi_command="mpirun -n 16"
```

```
$ maqao oneview --create-report=one --config=my_config.lua"
```

- Analyses can be tweaked if necessary
  - Report level **one** corresponds to lightweight profiling (**LProf**) and code quality analysis (**CQA**)
- ONE View can reuse an existing experiment directory to perform further analyses
- Results available in HTML format by default
  - XLS spreadsheets and textual output generation are also available

Online help is available:

```
$ maqao oneview --help
```

Analysing an application with MAQAO

MAQAO modules can be invoked separately for advanced analyses

- LProf
  - Profiling

```
$ maqao lprof xp=exp_dir --mpi-command="mpirun -n 16" -- ./bt-mz.C.16
```

  - Display functions profile

```
$ maqao lprof xp=exp_dir -df
```

  - Displaying the results from a ONE View run

```
$ maqao lprof xp=oneview_xp_dir/lprof_npsu -df
```

- CQA

```
$ maqao cqa loop=42 bt-mz.C.16
```

Online help is available:

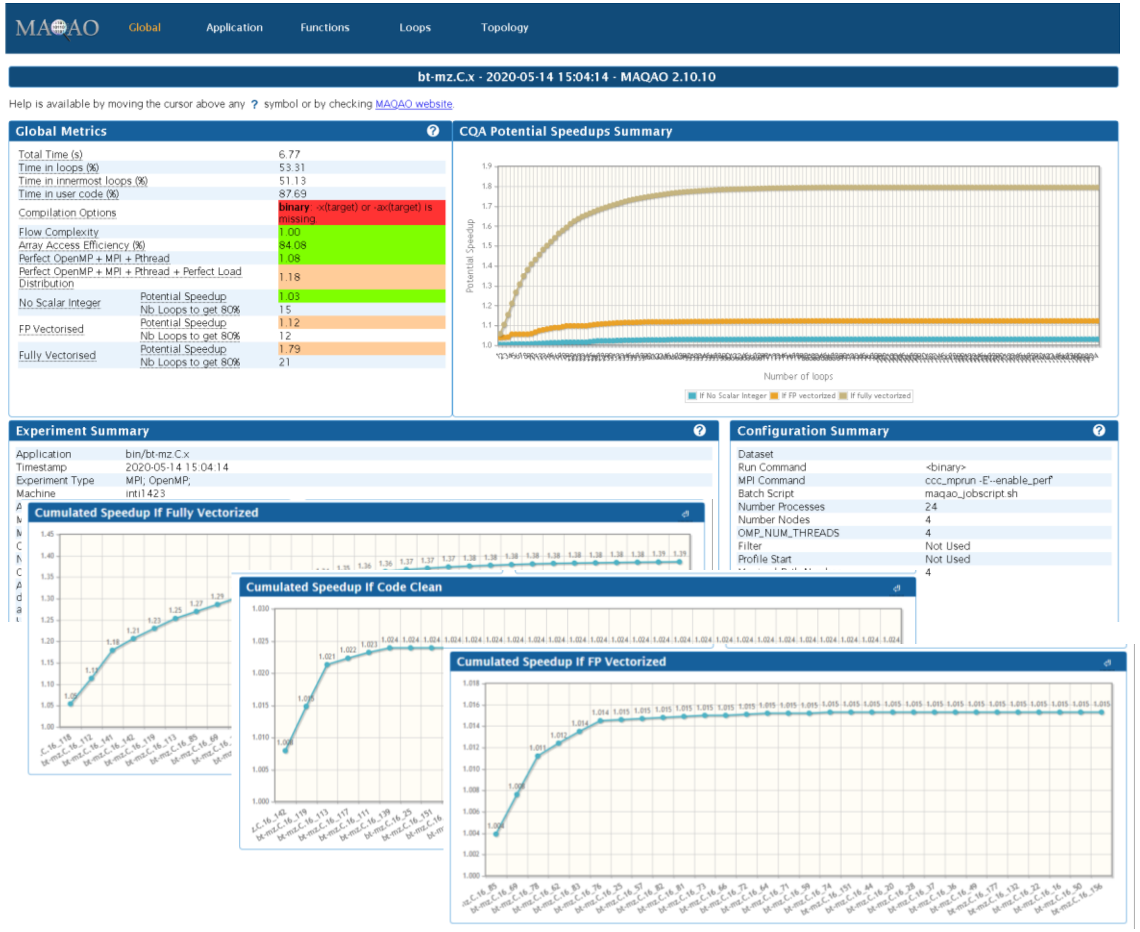
```
$ maqao lprof --help
```

```
$ maqao cqa --help
```

Global summary

Experiment summary
- Machine characteristics and configuration

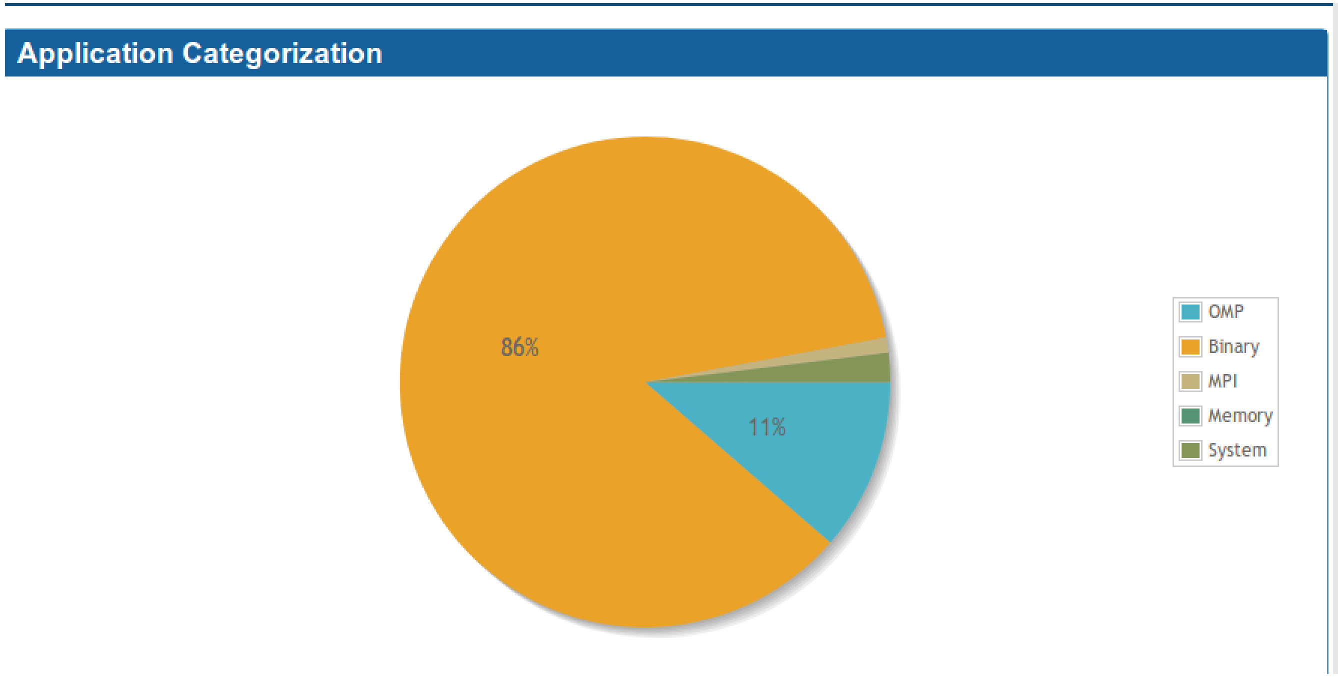
Global metrics
- General quality metrics derived from MAQAO analyses
- Global speedup predictions
  - Speedup prediction depending on the number of vectorised loops
  - Ordered speedups to identify the loops to optimise first



Time Categorisation

Identifying at a glance where time is spent

- Application
  - Main executable
- Parallelization
  - Threads
  - OpenMP
  - MPI
- System libraries
  - I/O operations
  - String operations
  - Memory management functions
- External libraries
  - Specialised libraries such as libm / libmkl
  - Application code in external libraries



Functions Profiling

Identifying hotspots

- Exclusive coverage
- Load balancing across threads
- Loops nests by functions

▼ matmul_sub
- ○ Loop 230 - solve_subs.f:71-175 - bt-mz.C.16
- ○ Loop 231 - solve_subs.f:71-175 - bt-mz.C.16 — Single

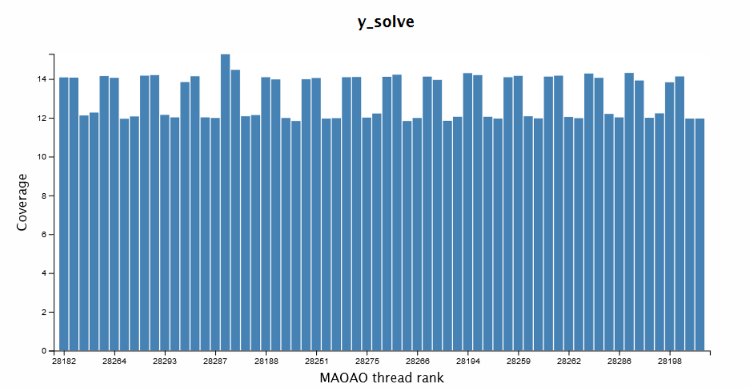
▼ z_solve
- ▼ Loop 232 - z_solve.f:53-423 - bt-mz.C.16 — Outermost
  - ▼ Loop 233 - z_solve.f:54-423 - bt-mz.C.16 — Inbetween
    - ▼ Loop 236 - z_solve.f:54-423 - bt-mz.C.16 — Inbetween
      - ○ Loop 239 - z_solve.f:146-308 - bt-mz.C.16 — Innermost
      - ○ Loop 235 - z_solve.f:55-137 - bt-mz.C.16
      - ○ Loop 234 - z_solve.f:415-423 - bt-mz.C.16

MAQAO Global Application Functions Loops Topology

Functions and Loops

▶ Filters

Name	Module	Coverage (%)	Time (s)	Nb Threads	Deviation (coverage)
○ gomp_team_barrier_wait_end	libgomp.so.1.0.0	21.34	3.26	64	4.47
○ binvcrhs	bt-mz.C.16	16.06	2.45	64	1.10
▶ z_solve._omp_fn.0	bt-mz.C.16	9.84	1.5	64	0.52
○ matmul_sub	bt-mz.C.16	9.52	1.45	64	0.68
▼ y_solve._omp_fn.0	bt-mz.C.16	9.09	1.39	64	0.68
▼ Loop 114 - y_solve.f:4-398 - bt-mz.C.16		8.82	1.35		
▼ Loop 115 - y_solve.f:4-398 - bt-mz.C.16		8.82	1.35		
○ Loop 118 - y_solve.f:145-308 - bt-mz.C.16		5.85	0.89		
○ Loop 119 - y_solve.f:55-137 - bt-mz.C.16		1.77	0.27		
○ Loop 116 - y_solve.f:394-398 - bt-mz.C.16		1.08	0.17		
○ Loop 117 - y_solve.f:337-360 - bt-mz.C.16		0.12	0.02		
▶ x_solve._omp_fn.0	bt-mz.C.16	8.68	1.32	64	0.64
○ gomp_barrier_wait_end	libgomp.so.1.0.0	8.26	1.26	64	4.91
▶ compute_rhs._omp_fn.0	bt-mz.C.16	7.57	1.16	64	0.46
○ mca_btl_vader_component_progress	mca_btl_vader.so	3.62	0.55	16	1.76
○ matvec_sub	bt-mz.C.16	2.73	0.42	64	0.20
○ lhsinit	bt-mz.C.16	0.54	0.08	64	0.06
○ opal_progress					0.18
▶ copy_x_face._omp_fn.2					0.06
▶ add._omp_fn.0					0.05
○ binvrhs					0.04
○ ompi_coll_libnbc_progress					0.13
▶ copy_y_face._omp_fn.0					0.05
○ opal_timer_linux_get_cycles_sys_timer					0.09
○ exact_solution					0.03
▶ copy_x_face._omp_fn.3					0.02
▶ copy_y_face._omp_fn.1					0.02
○ gomp_team_barrier_wait_final					0.02
○ exact_rhs._omp_fn.0					0.02
○ opal_progress@plt					0.03
▶ initialize._omp_fn.0					0.01
○ ompi_request_default_wait_all					0.03
○ gomp_thread_start					0.01
○ Unknown kernel region					0.01



Loops Profiling Summary

Identifying loop hotspots

- Vectorisation information
- Potential speedup by optimisation
  - No scalar integer: Removing address computations
  - FP Vectorised: Vectorising floating-point computations
  - Fully Vectorised: Vectorising floating-point computations and memory accesses
  - Perfect Load Balancing: Optimal balance across all threads

MAQAO Global Application Functions Loops Topology

Show Full Profile | Open Expert Summary

Loops Index

73 loops have been discarded from the report because their coverage is lower than the threshold set by *object_coverage_threshold* (0.01%). It represents about 0% of the application. To include them, change the value of *object_coverage_threshold* in the experiment directory configuration file, then rerun the command with the additionnal parameter *--force-static-analysis*

▶ **Filters**

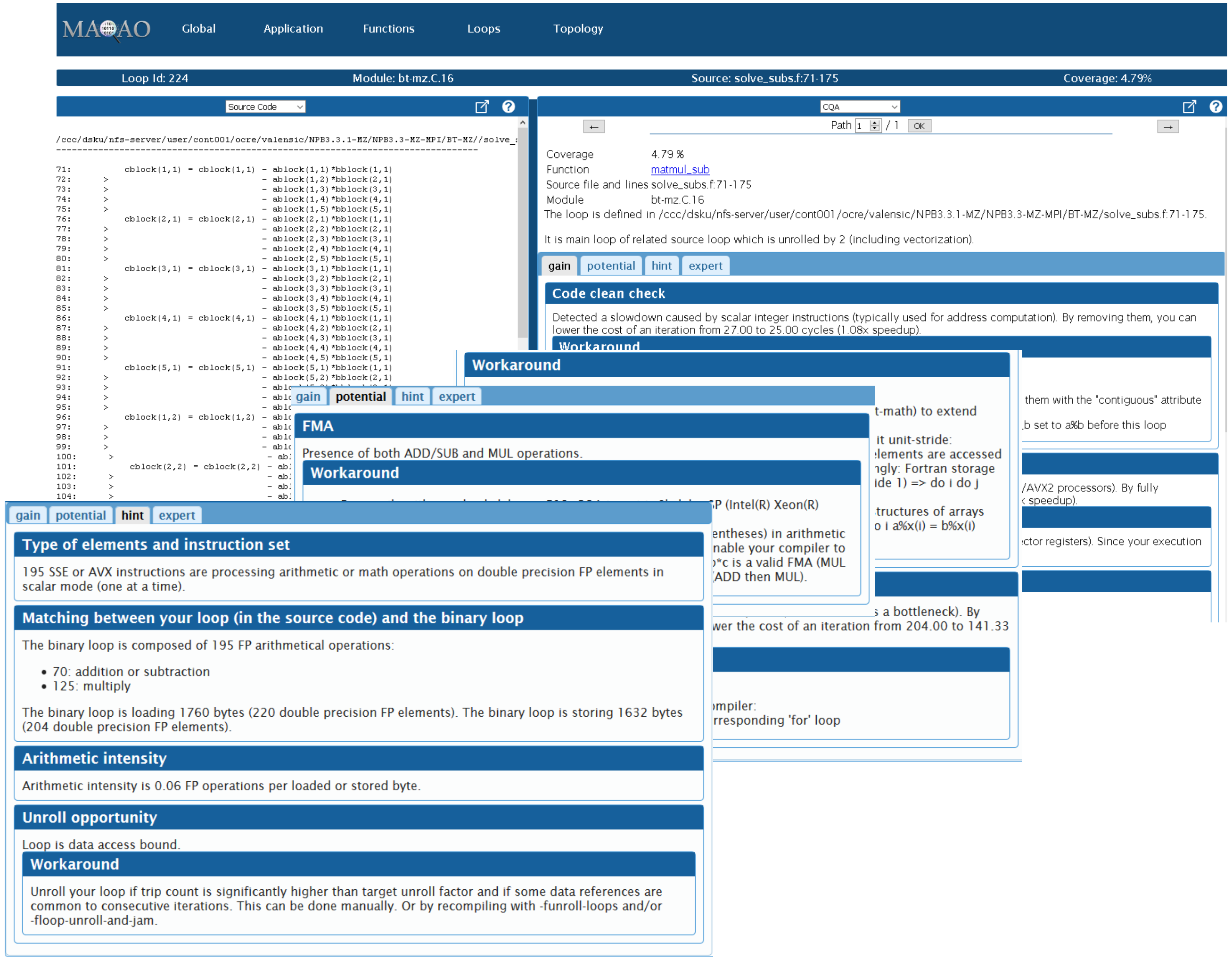
☑Coverage (%) ☑Level ☑Time (s) ☑Vectorization Ratio (%) ☑Speedup If No Scalar Integer ☑Speedup If FP Vectorized ☑Speedup If Fully Vectorized ☑Speedup If Perfect Load Balancing Select none

Loop id	Source Location	Source Function	Coverage (%)	Level	Time (s)	Vectorization Ratio (%)	Speedup If No Scalar Integer	Speedup If FP Vectorized	Speedup If Fully Vectorized	Speedup If Perfect Load Balancing
179	bt-mz_C.8 - x_solve.f:146-309	x_solve_._omp_fn.0	7.67	Innermost	1.29	5.02	1.04	1	2.06	1.22
207	bt-mz_C.8 - z_solve.f:146-309	z_solve_._omp_fn.0	7.67	Innermost	1.29	5.31	1.02	1	2.06	1.15
185	bt-mz_C.8 - y_solve.f:145-308	y_solve_._omp_fn.0	7.35	Innermost	1.24	5.17	1.03	1	2.06	1.22
208	bt-mz_C.8 - z_solve.f:55-137	z_solve_._omp_fn.0	3.48	Innermost	0.59	7.09	1	1.13	2.26	1.17
180	bt-mz_C.8 - x_solve.f:57-139	x_solve_._omp_fn.0	3.09	Innermost	0.52	7.04	1	1.11	2.23	1.25
186	bt-mz_C.8 - y_solve.f:55-137	y_solve_._omp_fn.0	3.06	Innermost	0.52	7.09	1	1.11	2.23	1.21
156	bt-mz_C.8 - rhs.f:40-50	compute_rhs_._omp_fn.0	2.41	Innermost	0.41	0	1	2	2	1.15
133	bt-mz_C.8 - rhs.f:4-349	compute_rhs_._omp_fn.0	1.84	Innermost	0.31	0	1	1.65	3.41	1.29
150	bt-mz_C.8 - rhs.f:4-132	compute_rhs_._omp_fn.0	1.77	Innermost	0.3	0	1	1.71	3.68	1.27
142	bt-mz_C.8 - rhs.f:4-238	compute_rhs_._omp_fn.0	1.76	Innermost	0.3	0	1	1.65	3.41	1.27
204	bt-mz_C.8 - z_solve.f:415-421	z_solve_._omp_fn.0	1.7	Innermost	0.29	0	1	1	2.83	1.17

Loop Analysis Reports

High level reports

- Reference to the source code
- Bottleneck description
- Hints for improving performance
- Reports categorized by probability that applying hints will yield predicted gain
  - Gain: Good probability
  - Potential gain: Average probability
  - Hints: Lower probability



Loop Analysis Reports – Expert View

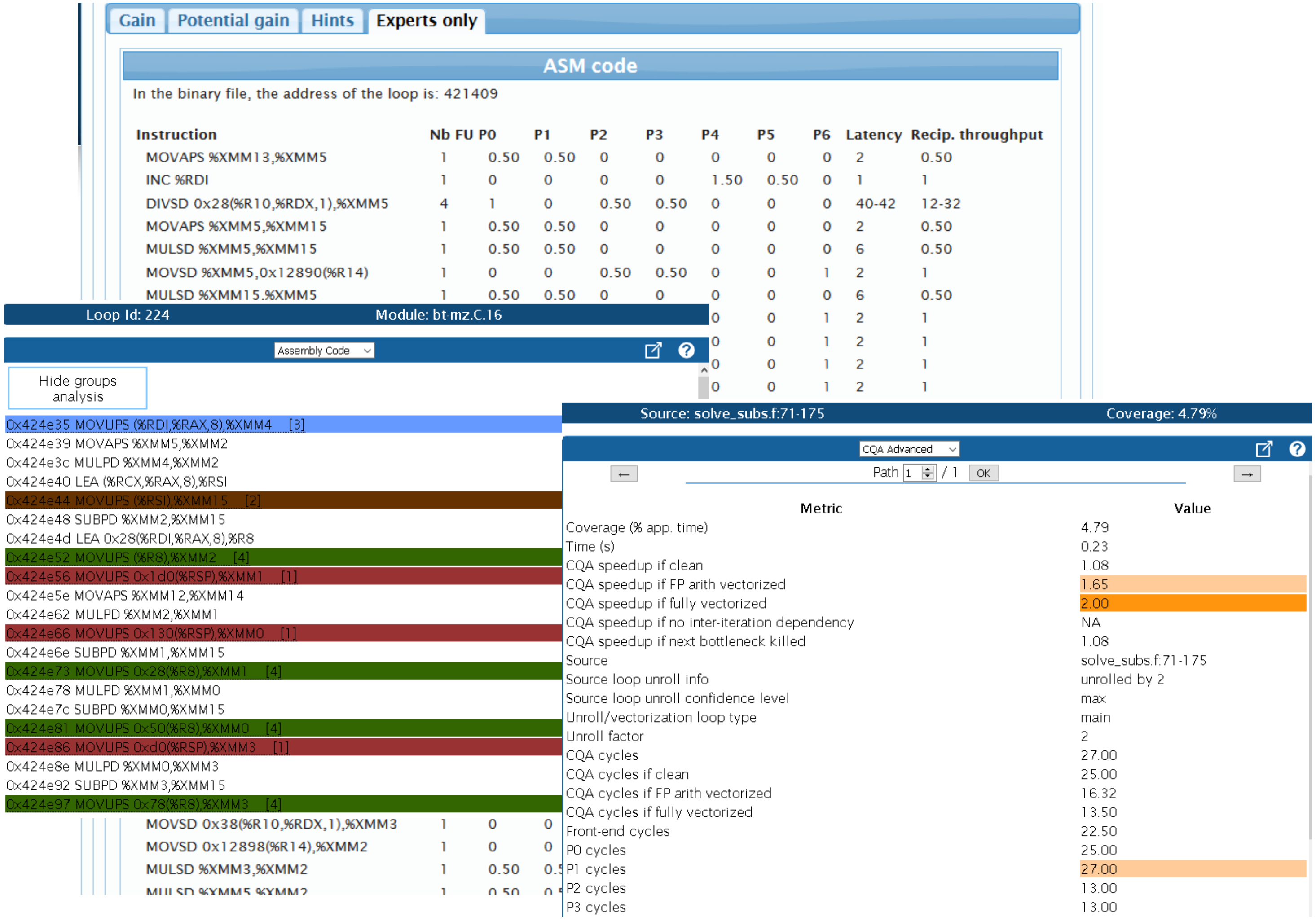
Low level reports for performance experts

- Assembly-level
- Instructions cycles costs
- Instructions dispatch predictions
- Memory access analysis

Assembly code

- Highlights groups of instructions accessing the same memory addresses

CQA internal metrics



Application to Motivating Example

Issues identified by CQA

6) Variable number of iterations

2) Non-unit stride accesses

1) High number of statements

7) Vector vs scalar

```
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
```

4) DIV/SQRT

3) Indirect accesses

5) Reductions

2) Non-unit stride accesses

CQA can detect and provide hints to resolve most of the identified issues:

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

Application to Motivating Example

Gain | Potential gain | Hints | Experts only

Vectorization

Your loop is partially vectorized.
Only 28% of vector register length is used (average across all SSE/AVX instructions).
By fully vectorizing your loop, you can lower the cost of an iteration from 57.00 to 21.50 cycles (2.65x speedup).
51% of SSE/AVX instructions are used in vector version (process two or more data elements in vector registers):

- *24% of SSE/AVX loads are used in vector version.*
- *0% of SSE/AVX stores are used in vector version.*

Since your execution units are vector units, only a fully vectorized loop can use their full power.

Proposed solution(s):

- Try another compiler or update/tune your current one:
  - use the vec-report option to understand why your loop was not vectorized. If "existence of vector dependences", try the IVDEP directive. If, using IVDEP, "vectorization possible but seems inefficient", try the VECTOR ALWAYS directive.
- Remove inter-iterations dependences from your loop and make it unit-stride:
  - If your arrays have 2 or more dimensions, check whether elements are accessed contiguously and, otherwise, try to permute loops accordingly:
    Fortran storage order is column-major: do i do j a(i,j) = b(i,j) (slow, non stride 1) => do i do j a(j,i) = b(i,j) (fast, stride 1)
  - If your loop streams arrays of structures (AoS), try to use structures of arrays instead (SoA):
    do i a(i)%x = b(i)%x (slow, non stride 1) => do i a%x(i) = b%x(i) (fast, stride 1)

Execution units bottlenecks

Performance is limited by:

- execution of divide and square root operations (the divide/square root unit is a bottleneck)
- execution of INT/FP operations on vector registers (the VPU is a bottleneck)

By removing all these bottlenecks, you can lower the cost of an iteration from 57.00 to 48.00 cycles (1.19x speedup).

Proposed solution(s):

- Reduce the number of division or square root instructions.
  If denominator is constant over iterations, use reciprocal (replace x/y with x*(1/y)). Check precision impact. This will be done by your compiler with no-prec-div or Ofast.
  Check whether you really need double precision. If not, switch to single precision to speedup execution.
- Reduce arithmetical operations on array elements

Gain | Potential gain | Hints | Experts only

FMA

Detected 48 FMA (fused multiply-add) operations.
Presence of both ADD/SUB and MUL operations.
Proposed solution(s):
Try to change order in which elements are evaluated (using parentheses) in arithmetic expressions containing both ADD/SUB and MUL operations to enable your compiler to generate FMA instructions wherever possible.
For instance a + b*c is a valid FMA (MUL th
However (a+b)* c cannot be translated into

Gain | Potential gain | Hints | Experts only

Slow data structures access

Detected data structures (typically arrays) that cannot be efficiently read/written

- *Constant non-unit stride: 1 occurrence(s)*
- *Irregular (variable stride) or indirect: 1 occurrence(s)*

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

MAQAO ONE View Thread/Process View

Software Topology

- List of nodes
- Processes by node
- Thread by process

View by thread

- Function profile at the thread or process level

MAQAO Global Application Functions Loops Topology

Software Topology

ID	Processes	Threads	Time(s)
▼ Node c251-109.wrangler.tacc.utexas.edu	8	32	5.34
▼ Process 145897		4	5.34
○ Thread 145897			5.34
○ Thread 145933			5.32
○ Thread 145952			5.32
○ Thread 145969			5.3
▶ Process 145899		4	5.34
▶ Process 145901		4	5.34
▶ Process 145903		4	5.34
▶ Process 145898		4	5.34
▶ Process 145900		4	5.34
▶ Process 145895		4	5.34
▶ Process 145896		4	5.34
▶ Node c251-110.wrangler.tacc.utexas.edu	8	32	5.36
○ AVERAGE			5.36

MAQAO Global

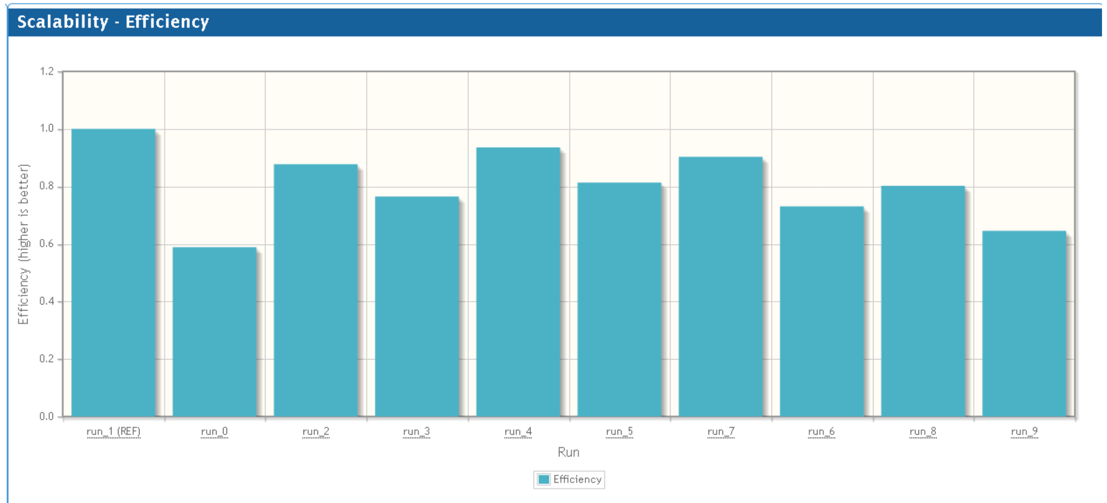
Profiling node c251-109.wrangler.tacc.utexas.edu - process 145897 - thread 145897

Name	Module	Coverage (%)	Time (s)
○ binvcrhs	bt-mz_B.16	24.34	1.3
○ _INTERNAL_25_______src_kmp_barrier_cpp_fa608613::__kmp_hyper_barrier_gather(barrier_type, kmp_info*, int, int, void (*)(void*, void*), void*)	libiomp5.so	17.6	0.94
▶ matmul_sub	bt-mz_B.16	12.73	0.68
▶ y_solve	bt-mz_B.16	7.87	0.42
▶ compute_rhs	bt-mz_B.16	7.49	0.4
▶ x_solve	bt-mz_B.16	7.12	0.38
▶ z_solve	bt-mz_B.16	6.74	0.36

MAQAO ONE View Scalability Reports

Goal: Provide a view of the application scalability

- Profiles with different numbers of threads/processes
- Displays efficiency metrics for application



▼ Detailed Efficiency

Run	Number of observed threads	Efficiency (ideal is 1)
run_1 (REF)	2	1
run_0	96	0.59
run_2	3	0.88
run_3	5	0.77
run_4	8	0.94
run_5	9	0.81
run_7	9	0.9
run_6	16	0.73
run_8	16	0.8
run_9	32	0.65

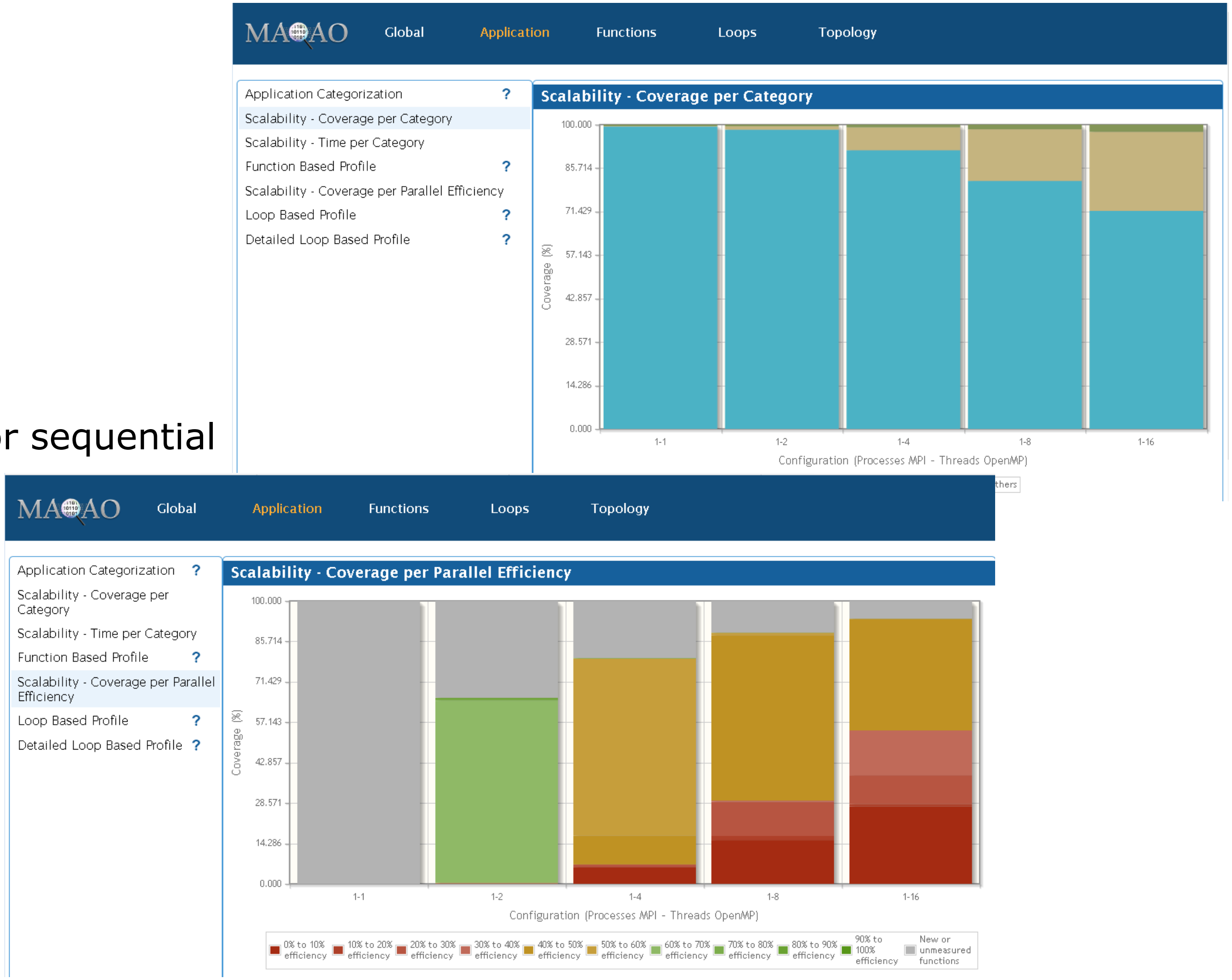
MAQAO ONE View Scalability Reports – Application View

Coverage per category

- Comparison of categories for each run

Coverage per parallel efficiency

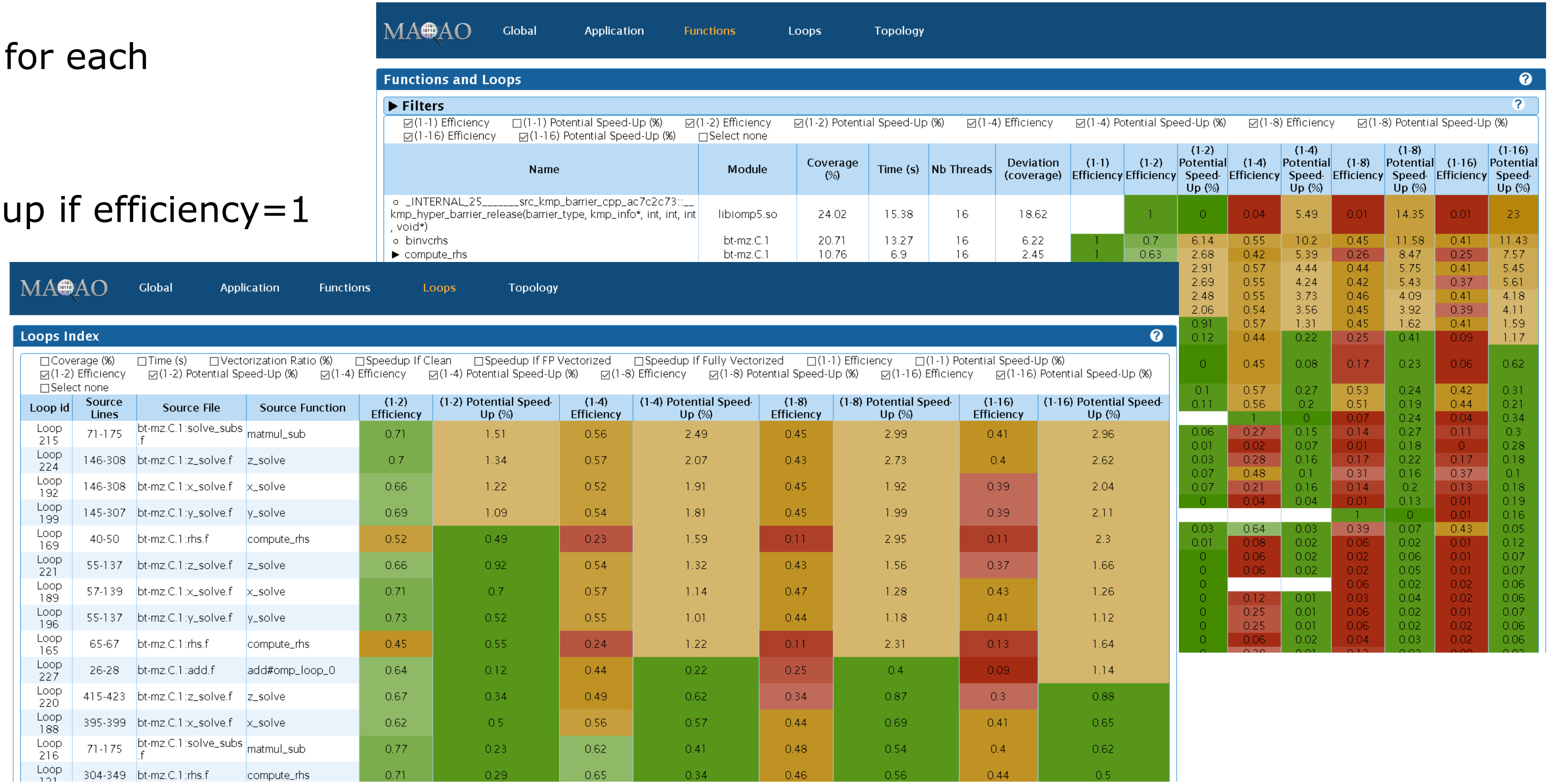
- $Efficiency = \frac{T_{sequential}}{T_{parallel} * N_{threads}}$
  - Distinguishing functions only represented in parallel or sequential
- Displays efficiency by coverage



MAQAO ONE View Scalability Reports – Functions and Loops Views

Displays metrics for each function/loop

- Efficiency
- Potential speedup if efficiency=1



Loop id	Source Lines	Source File	Source Function	(1-2) Efficiency	(1-2) Potential Speed-Up (%)	(1-4) Efficiency	(1-4) Potential Speed-Up (%)	(1-8) Efficiency	(1-8) Potential Speed-Up (%)	(1-16) Efficiency	(1-16) Potential Speed-Up (%)
Loop 215	71-175	bt-mz.C.1:solve_subs.f	matmul_sub	0.71	1.51	0.56	2.49	0.45	2.99	0.41	2.96
Loop 224	146-308	bt-mz.C.1:z_solve.f	z_solve	0.7	1.34	0.57	2.07	0.43	2.73	0.4	2.62
Loop 192	146-308	bt-mz.C.1:x_solve.f	x_solve	0.66	1.22	0.52	1.91	0.45	1.92	0.39	2.04
Loop 199	145-307	bt-mz.C.1:y_solve.f	y_solve	0.69	1.09	0.54	1.81	0.45	1.99	0.39	2.11
Loop 169	40-50	bt-mz.C.1:rhs.f	compute_rhs	0.52	0.49	0.23	1.59	0.11	2.95	0.11	2.3
Loop 221	55-137	bt-mz.C.1:z_solve.f	z_solve	0.66	0.92	0.54	1.32	0.43	1.56	0.37	1.66
Loop 189	57-139	bt-mz.C.1:x_solve.f	x_solve	0.71	0.7	0.57	1.14	0.47	1.28	0.43	1.26
Loop 196	55-137	bt-mz.C.1:y_solve.f	y_solve	0.73	0.52	0.55	1.01	0.44	1.18	0.41	1.12
Loop 165	65-67	bt-mz.C.1:rhs.f	compute_rhs	0.45	0.55	0.24	1.22	0.11	2.31	0.13	1.64
Loop 227	26-28	bt-mz.C.1:add.f	add#omp_loop_0	0.64	0.12	0.44	0.22	0.25	0.4	0.09	1.14
Loop 220	415-423	bt-mz.C.1:z_solve.f	z_solve	0.67	0.34	0.49	0.62	0.34	0.87	0.3	0.88
Loop 188	395-399	bt-mz.C.1:x_solve.f	x_solve	0.62	0.5	0.56	0.57	0.44	0.69	0.41	0.65
Loop 216	71-175	bt-mz.C.1:solve_subs.f	matmul_sub	0.77	0.23	0.62	0.41	0.48	0.54	0.4	0.62
Loop [illegible]	304-349	bt-mz.C.1:rhs.f	compute_rhs	0.71	0.29	0.65	0.34	0.46	0.56	0.44	0.5

More on MAQAO

MAQAO website: www.maqao.org

- Documentation: www.maqao.org/documentation.html
  - Tutorials for ONE View, LProf and CQA
  - Lua API documentation
- Latest release: http://www.maqao.org/downloads.html
  - Binary releases (2-3 per year)
  - Source code
- Publications around MAQAO: http://www.maqao.org/publications.html

Thank you for your attention !

Questions ?