Tutorial Exercise NPB-MPI/BT

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Performance analysis steps

0. Reference preparation for validation
1. Program instrumentation: `skin`
2. Summary measurement collection & analysis: `scan [-s]`
3. Summary analysis report examination: `square`
4. Summary experiment scoring: `square -s`
5. Event trace collection & analysis: `scan -t`
6. Event trace analysis report examination: `square`

- Configuration & customization
  - Instrumentation, Measurement, Analysis, Presentation

NPB-BT

- Intermediate-level tutorial example
- Available in MPI, OpenMP, hybrid OpenMP/MPI variants
  - also MPI File I/O variants (collective & individual)
- Summary measurement collection & analysis
  - Automatic instrumentation
    - OpenMP, MPI & application functions
  - Summary analysis report examination
  - PAPI hardware counter metrics
- Trace measurement collection & analysis
  - Filter determination, specification & configuration
  - Automatic trace analysis report patterns
- Manual instrumentation
- Measurement configuration
- Analysis report algebra

Load the Scalasca module

- Load the module

```
% module load UNITE
UNITE loaded
% module load scalasca
scalasca/1.3 loaded
```

- ... and run `scalasca` for brief usage information

```
% scalasca
Scalasca 1.3
Toolset for scalable performance analysis of large-scale applications
usage: scalasca [-v][-n] {action}
    1. prepare application objects and executable for measurement:
       scalasca -instrument <compile-or-link-command>       # skin
    2. run application under control of measurement system:
       scalasca -analyze <application-launch-command>       # scan
    3. interactively explore measurement analysis report:
       scalasca -examine <experiment-archive|report>        # square

   -v: enable verbose commentary
   -n: show actions without taking them
   -h: show quick reference guide (only)
```

NPB instrumentation

- Prefix compile/link commands in Makefile definitions (config/make.def) with the Scalasca instrumenter

```
MPIF77 = scalasca -instrument mpif77
FLINK = $(MPIF77)
FFLAGS = -O

mpi-bt: $(OBJECTS)
        $(FLINK) $(FFLAGS) -o mpi-bt $(OBJECTS)
.f.o:
        $(MPIF77) $(FFLAGS) -c $<
```

- or use PREP macro as customizable preparation preposition

```
MPIF77 = $(PREP) mpif77
```

  - By default, PREP macro is not set and no instrumentation is performed for a regular “production” build
  - Specifying a PREP value in the Makefile or on the make command line uses it as a preposition, e.g., for instrumentation
    - % make PREP=“scalasca -instrument” ...

```
scalasca -instrument  mpif77 -O -c bt.f
```

NPB-MPI-BT instrumented build

- Return to root directory and clean-up

```
% make clean
```

- Re-build specifying Scalasca instrumenter as PREP

```
% make bt NPROCS=16 CLASS=W PREP=”scalasca -instrument”
cd BT; make NPROCS=16 CLASS=W SUBTYPE= VERSION=
gmake: Entering directory 'BT'
cd ../sys; cc  -o setparams setparams.c
../sys/setparams bt 16 W
scalasca -instrument mpif77 -c  -O bt.f
...
scalasca -instrument mpif77 -c  -O setup_mpi.f
cd ../common;  scalasca -instrument mpif77 -c  -O print_results.f
cd ../common;  scalasca -instrument mpif77 -c  -O timers.f
scalasca -instrument mpif77 -c  -O btio.f
scalasca -instrument mpif77 -O -o ../bin.scalasca/bt_W.16 \
bt.o make_set.o initialize.o exact_solution.o exact_rhs.o \
set_constants.o adi.o define.o copy_faces.o rhs.o solve_subs.o \
x_solve.o y_solve.o z_solve.o add.o error.o verify.o setup_mpi.o \
../common/print_results.o ../common/timers.o btio.o
INFO: Instrumented executable for MPI measurement
gmake: Leaving directory 'BT'
```

NPB-BT summary measurement

- Run the application using the Scalasca measurement collection & analysis nexus prefixed to launch command

```
% cd bin.scalasca; scalasca -analyze  mpiexec -np 16 ./bt_W.16
S=C=A=N: Scalasca 1.1 runtime summarization
S=C=A=N: ./epik_bt_W_16_sum experiment archive
S=C=A=N: Sun Mar 29 16:36:31 2009: Collect start
mpiexec -np 16 ./bt_W.16
[00000]EPIK: Created new measurement archive ./epik_bt_W_16_sum
[00000]EPIK: Activated ./epik_bt_W_16_sum [NO TRACE] (0.006s)

        [... Application output ...]

[00000]EPIK: Closing experiment ./epik_bt_W_16_sum
[00000]EPIK: 102 unique paths (102 max paths, 4 max frames, 0 unknown)
[00000]EPIK: Unifying... done (0.023s)
[00000]EPIK: Collating... done (0.049s)
[00000]EPIK: Closed experiment ./epik_bt_W_16_sum (0.073s)
S=C=A=N: Sun Mar 29 16:36:45 2009: Collect done (status=0) 14s
S=C=A=N: ./epik_bt_W_16_sum complete.
```

- Produces experiment directory ./epik_bt_W_16_sum

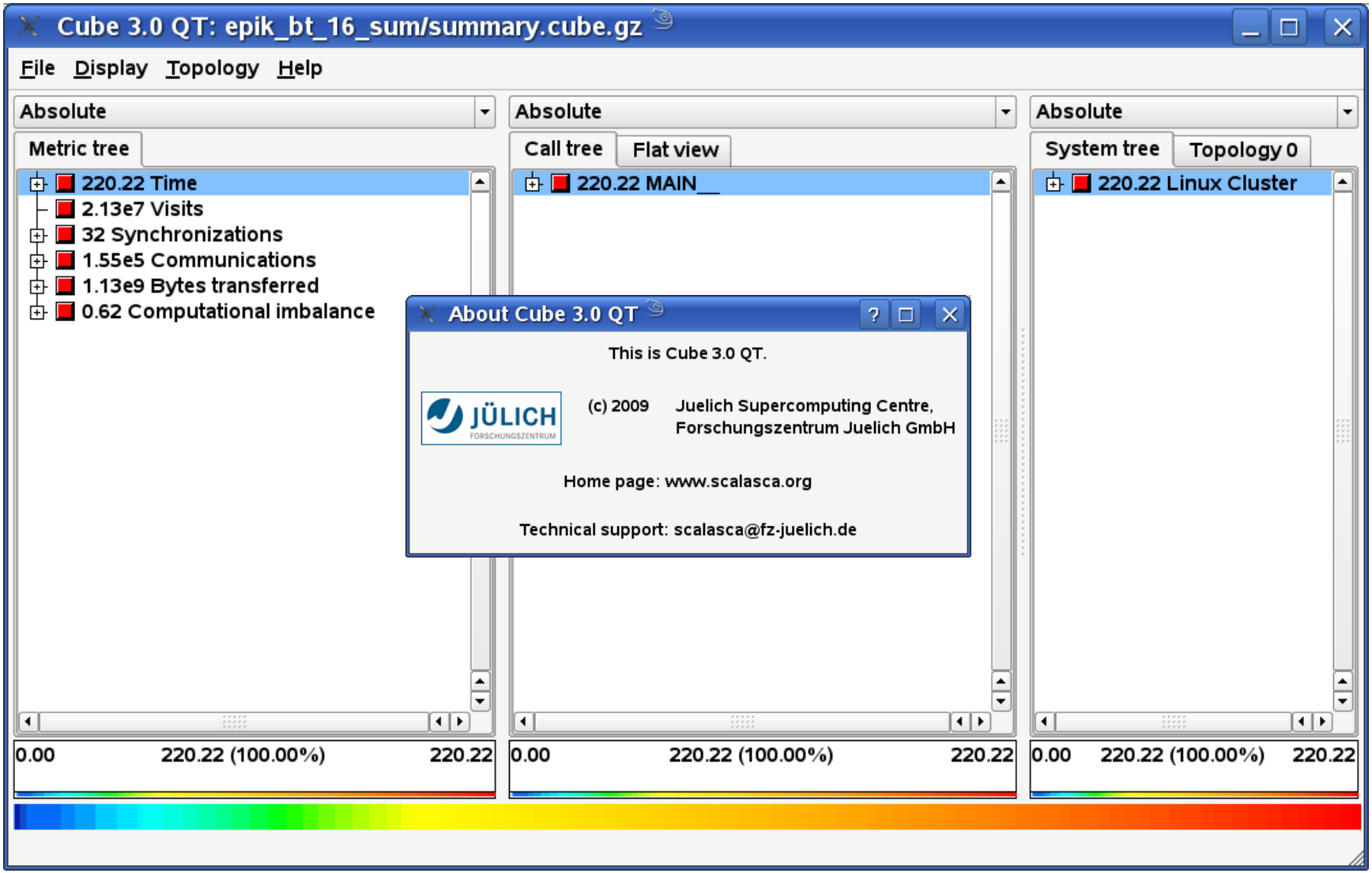
NPB-BT summary analysis report examination

- Interactive exploration with Scalasca GUI

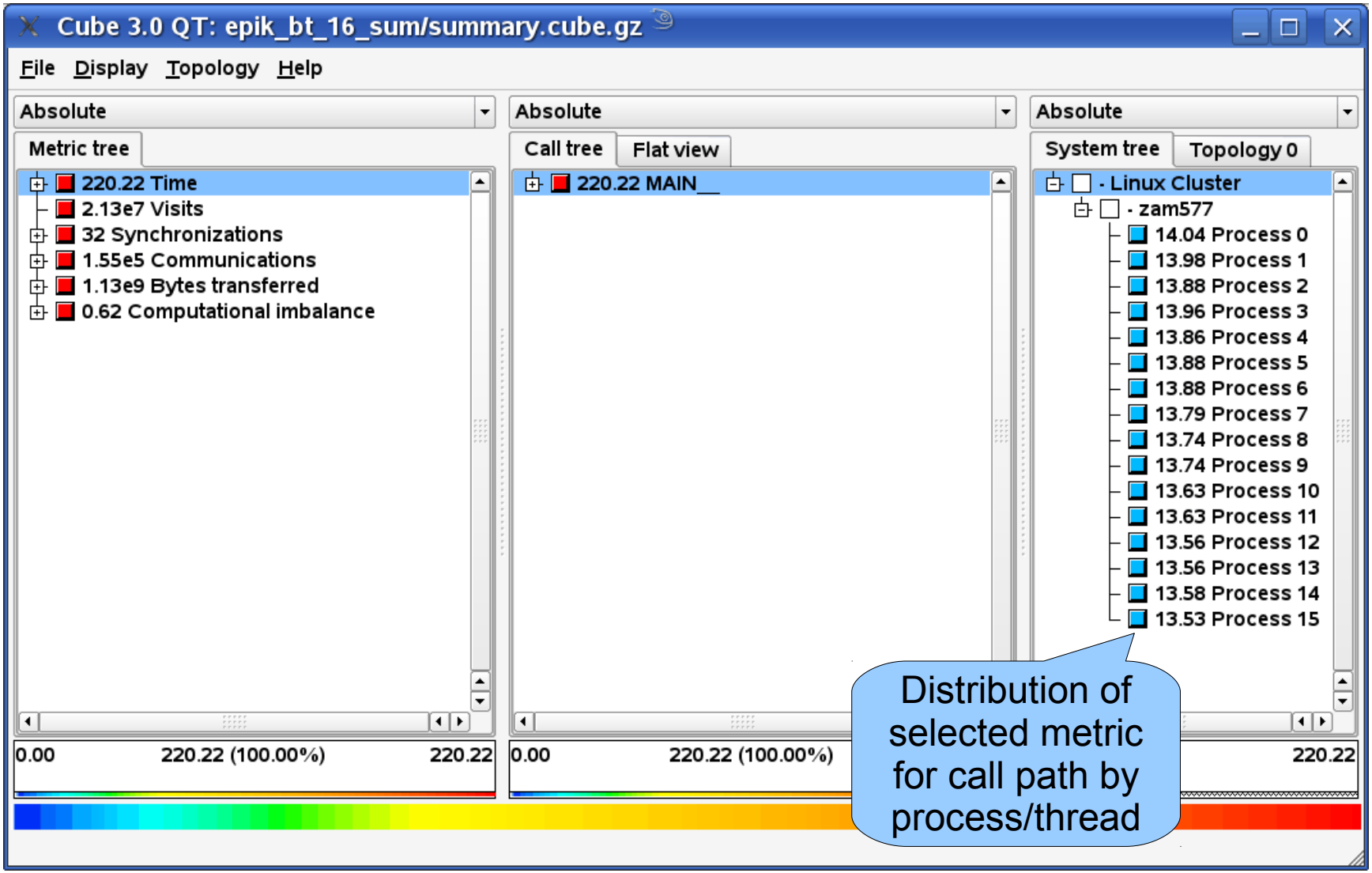
```
% scalasca -examine  epik_bt_W_16_sum
INFO: Post-processing runtime summarization result...
INFO: Displaying ./epik_bt_W_16_sum/summary.cube...

                  [GUI showing summary analysis report]
```

- The measurement archive directory ultimately contains
  - a copy of the execution output (epik.log)
  - a record of the measurement configuration (epik.conf)
  - the basic analysis report that was collated after measurement (epitome.cube)
  - the complete analysis report produced during post-processing (summary.cube.gz)

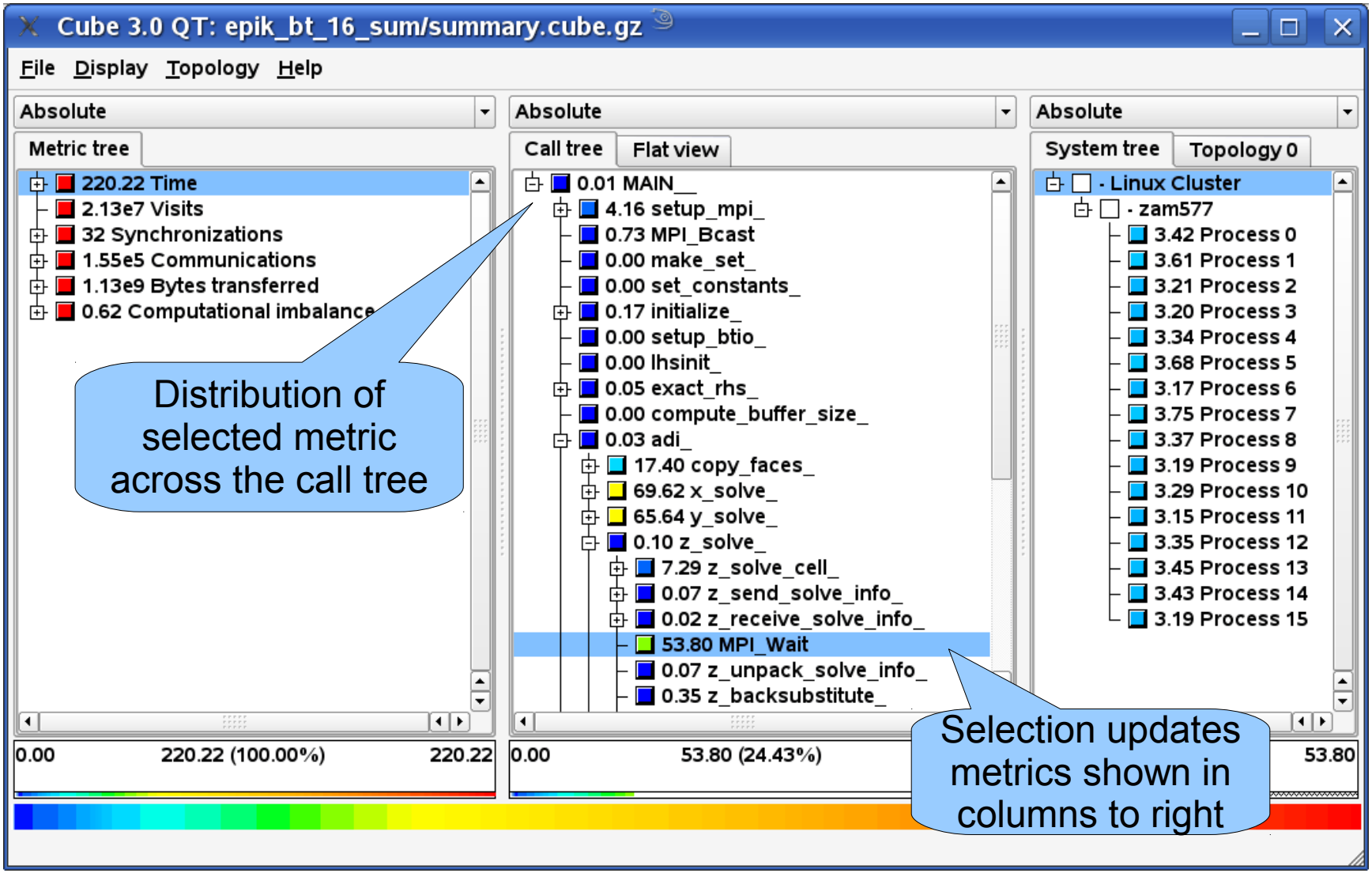
Analysis report exploration (opening view)



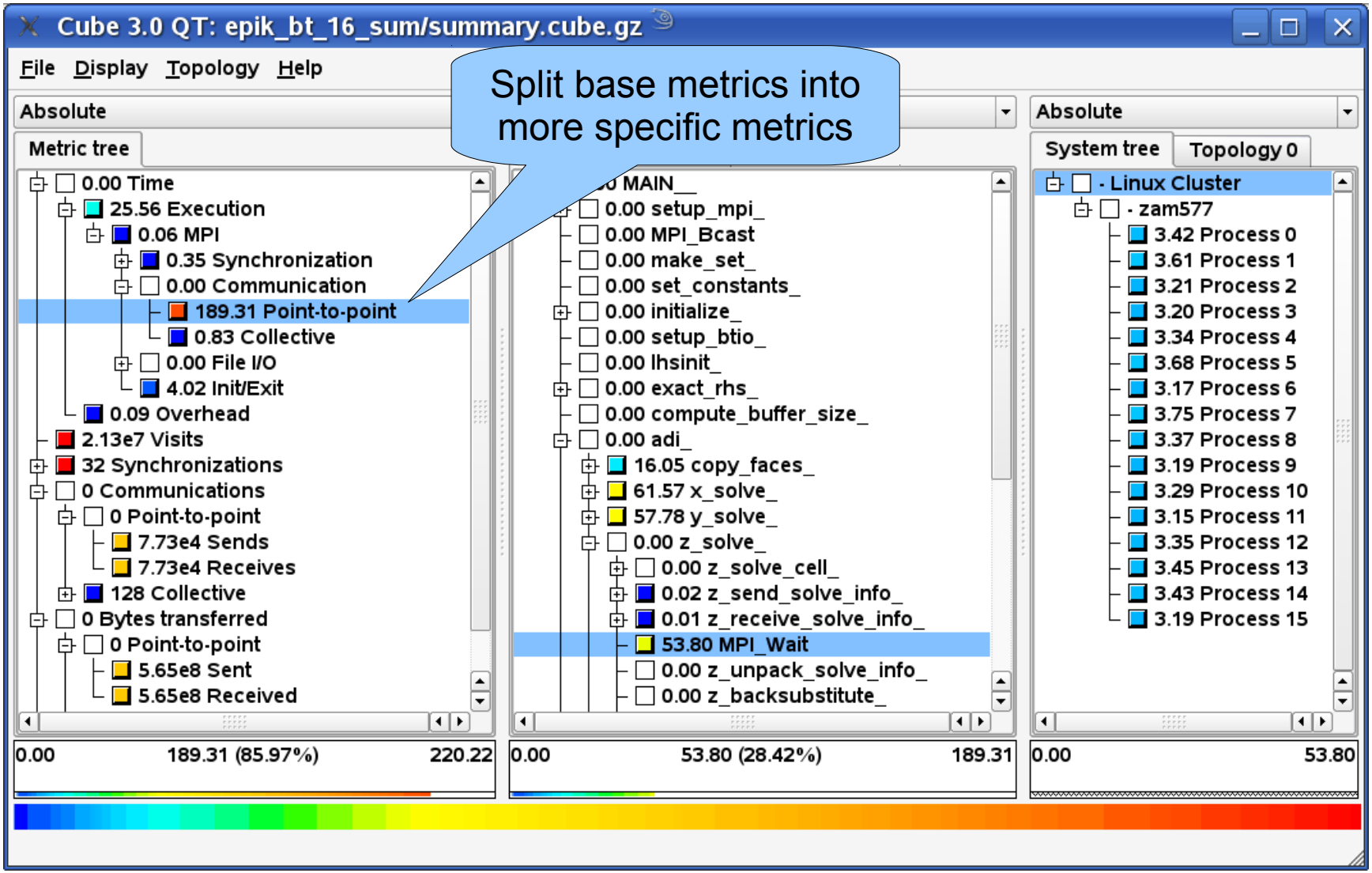
Analysis report exploration (system tree)



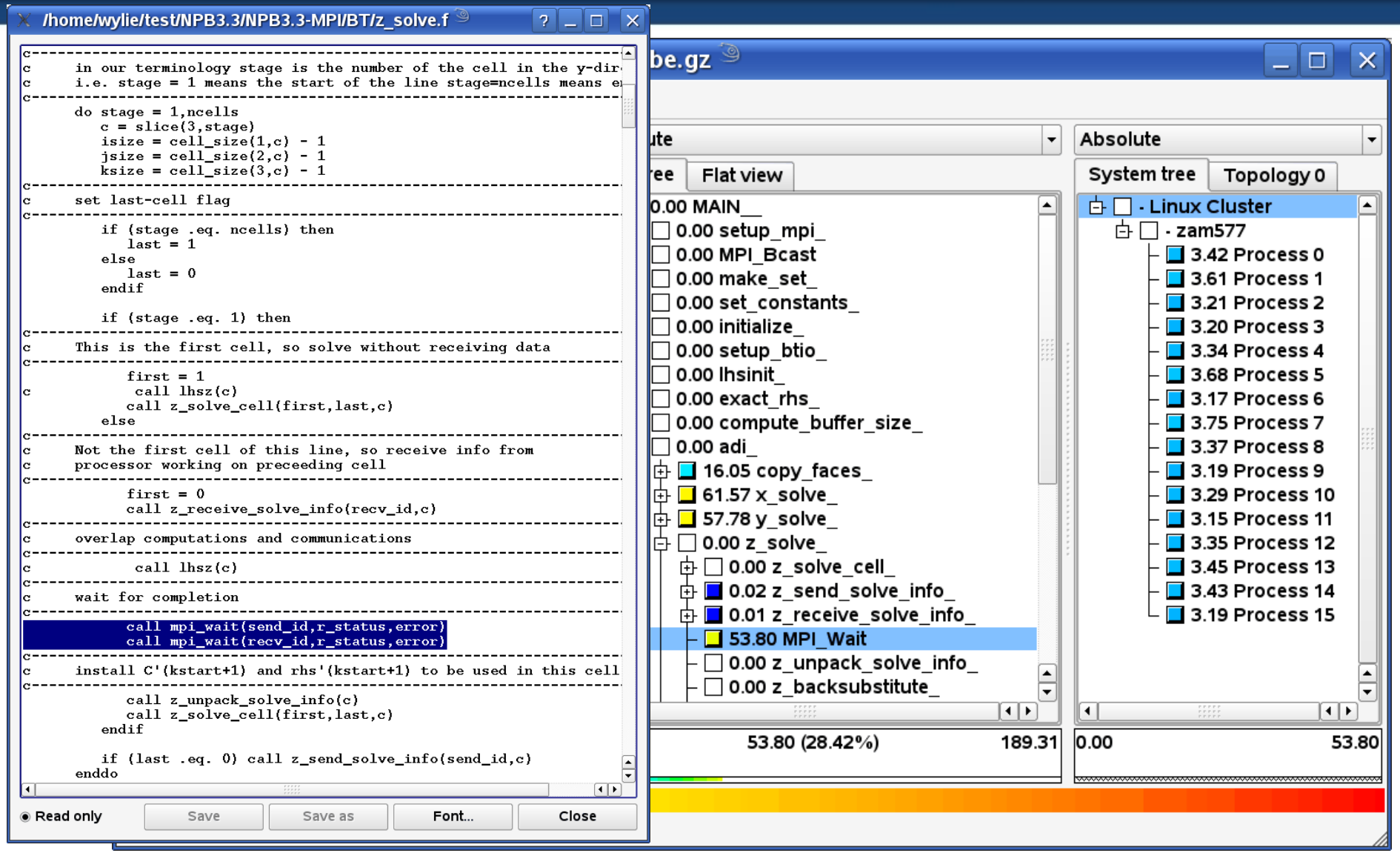
Analysis report exploration (call tree)



Analysis report exploration (metric tree)



Analysis report exploration (source browser)



Congratulations!?

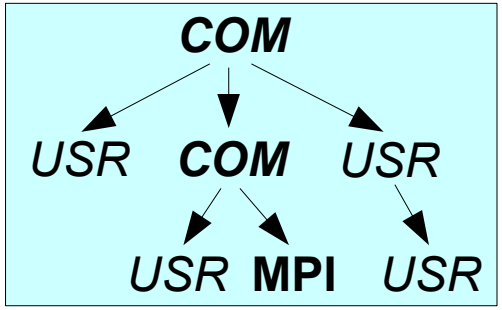
- If you made it this far, you successfully used Scalasca to
  - *instrument* the application
  - *analyze* its execution with a summary measurement, and
  - *examine* it with the interactive analysis report explorer GUI
- ... revealing the call-path profile annotated with
  - Time metrics (including MPI time, P2P & Collective times)
  - Visit counts
  - MPI message statistics (sends/receives, bytes sent/received)
  - Computational imbalance
- ... but how ***good*** was the measurement?
  - The measured execution produced the desired valid result
  - however, the execution took rather longer than expected!
    - even when ignoring measurement start-up/completion, therefore
    - it was probably dilated by instrumentation/measurement overhead

NPB-BT summary analysis report scoring

- Report scoring as textual output

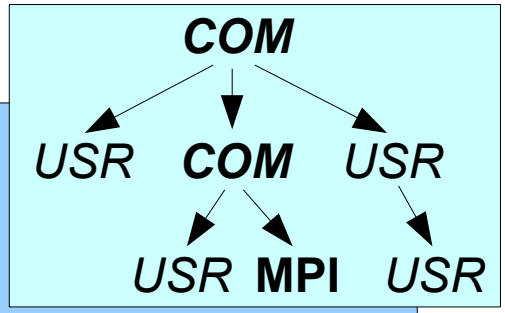
```
% scalasca -examine -s  epik_bt_W_16_sum
cube3_score -r ./epik_bt_W_16_sum/summary.cube
Reading ./epik_bt_W_16_sum/summary.cube... done.
Estimated aggregate size of event trace (total_tbc): 513,823,960 bytes
Estimated size of largest process trace (max_tbc):    32,528,680 bytes
(When tracing set ELG_BUFFER_SIZE to avoid intermediate flushes or
 reduce requirements using filter file listing names of USR regions.)

INFO: Score report written to ./epik_bt_16_sum/epik.score
```

- Region/callpath classification
  - MPI (pure MPI library functions)
  - OMP (pure OpenMP functions/regions)
  - USR (user-level source local computation)
  - COM (“combined” USR + OpenMP/MPI)
  - ANY/ALL (aggregate of all region types)



NPB-BT summary analysis report breakdown

- Score report breakdown by region




```
% less  epik_bt_W_16_sum/epik.score

flt  type    max_tbc      time        % region
      ANY   32528680    220.22   100.00 (summary) ALL
      MPI     642712    194.57    88.35 (summary) MPI
      COM     197928      1.03     0.47 (summary) COM
      USR   31688040     24.62    11.18 (summary) USR

      USR   10231704      4.44     2.02 binvcrhs_
      USR   10231704      3.06     1.39 matvec_sub_
      USR   10231704      3.53     1.60 matmul_sub_
      USR     492048      0.16     0.07 binvrhs_
      USR     360576      0.12     0.05 exact_solution_
      MPI     241500      0.27     0.12 MPI_Isend
      MPI     222180      0.12     0.06 MPI_Irecv
      MPI     173664    173.02    78.57 MPI_Wait
      USR      57888      0.06     0.03 lhsabinit_
      USR      19296      3.53     1.60 y_solve_cell_
      USR      19296      3.45     1.56 x_solve_cell_
      USR      19296      3.54     1.61 z_solve_cell_
      USR      19296      0.35     0.16 z_backsubstitute_
...
```

NPB-BT summary analysis score

- Summary measurement analysis score reveals
  - Total size of event trace would be over 500MB
  - Maximum trace buffer size would be over 30MB per process
    - smaller buffer would require flushes to disk during measurement resulting in substantial perturbation
  - 97% of the trace requirements are for USR regions
    - purely computational routines never found on COM call-paths common to communication routines
  - These USR regions contribute around 10% of total time
    - however, much of that is very likely to be measurement overhead for a few frequently-executed small routines
- Advisable to tune measurement configuration
  - Specify an adequate trace buffer size
  - Specify a filter file listing (USR) regions not to be measured

NPB-BT summary analysis report filtering

- Report scoring with prospective filter listing USR regions

```
% scalasca -examine -s -f npb.filt  epik_bt_W_16_sum
cube3_score -r -f npb.filt ./epik_bt_W_16_sum/summary.cube
Applying filter "./npb.filt":
Estimated aggregate size of event trace (total_tbc):  16,852,888 bytes
Estimated size of largest process trace (max_tbc):     1,053,304 bytes

INFO: Score report written to ./epik_bt_W_16_sum/epik.score_bt.filt

% less epik_bt_W_16_sum/epik.score_bt.filt
flt  type    max_tbc     time       % region
 +    FLT   31475376    11.37    5.16 (summary) FLT
 *    ANY    1053328   208.85   94.84 (summary) ALL-FLT
 -    MPI     642712   194.57   88.35 (summary) MPI-FLT
 *    COM     197928     1.03    0.47 (summary) COM-FLT
 *    USR     212688    13.25    6.02 (summary) USR-FLT

 +    USR   10231704     4.44    2.02 binvcrhs_
 +    USR   10231704     3.06    1.39 matvec_sub_
 +    USR   10231704     3.53    1.60 matmul_sub_
 +    USR     492048     0.16    0.07 binvrhs_
 +    USR     360576     0.12    0.05 exact_solution_
 -    MPI     241500     0.27    0.12 MPI_Isend
 -    MPI     222180     0.12    0.06 MPI_Irecv
...
```

Filtered routines marked with '+'

```
% cat npb.filt
# filter for bt
binvcrhs_
matvec_sub_
matmul_sub_
binvrhs_
exact_solution_
timer_*
```

NPB-BT filtered summary measurement

- Rename former measurement archive directory, set new filter configuration and re-run the measurement

```
% mv epik_bt_W_16_sum epik_bt_W_16_sum.nofilt
% export EPK_FILTER=npb.filt
% scalasca -analyze  mpiexec -np 16 ./bt_W.16
S=C=A=N: Scalasca 1.1 runtime summarization
S=C=A=N: ./epik_bt_W_16_sum experiment archive
S=C=A=N: Sun Mar 29 16:58:34 2009: Collect start
mpiexec -np 16 ./bt_W.16
[00000]EPIK: Created new measurement archive ./epik_bt_W_16_sum
[00000]EPIK: EPK_FILTER “npb.filt” filtered 9 of 96 functions
[00000]EPIK: Activated ./epik_bt_W_16_sum [NO TRACE] (0.071s)

         [... Application output ...]

[00000]EPIK: Closing experiment ./epik_bt_W_16_sum
[00000]EPIK: 84 unique paths (84 max paths, 4 max frames, 0 unknowns)
[00000]EPIK: Unifying... done (0.014s)
[00000]EPIK: Collating... done (0.059s)
[00000]EPIK: Closed experiment ./epik_bt_W_16_sum (0.075s)
S=C=A=N: Sun Mar 29 16:58:41 2009: Collect done (status=0) 7s
S=C=A=N: ./epik_bt_W_16_sum complete.
```

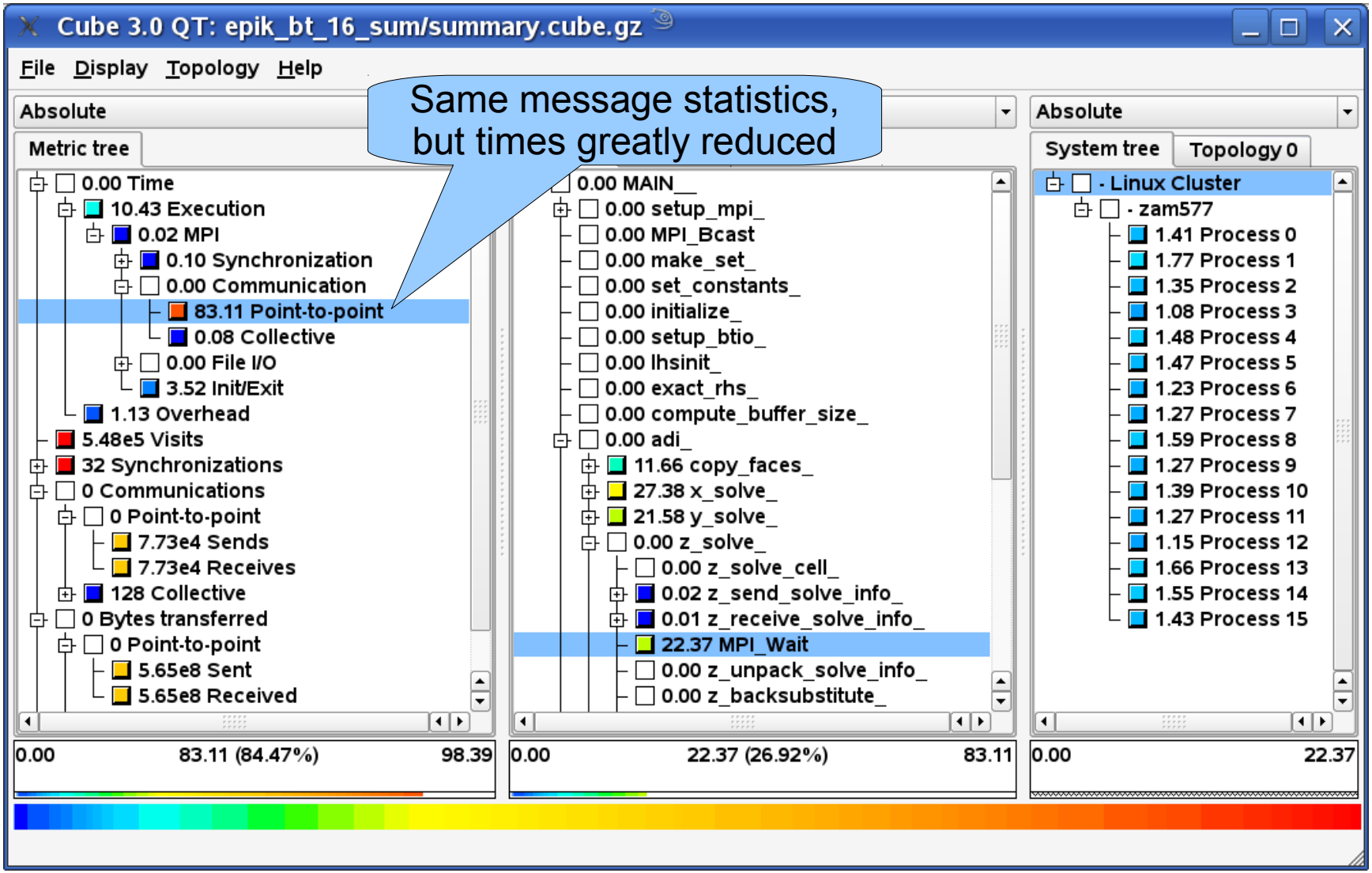
NPB-BT filtered summary analysis report score

- Scoring of new analysis report as textual output

```
% scalasca -examine -s  epik_bt_W_16_sum
INFO: Post-processing runtime summarization result...
cube3_score ./epik_bt_W_16_sum/summary.cube
Estimated aggregate size of event trace (total_tbc):  16,852,888 bytes
Estimated size of largest process trace (max_tbc):     1,053,328 bytes
(When tracing set ELG_BUFFER_SIZE to avoid intermediate flushes or
 reduce requirements using filter file listing names of USR regions.)

INFO: Score report written to ./epik_bt_W_16_sum/epik.score

flt  type       max_tbc         time       % region
      ANY       1053328        98.39  100.00 (summary) ALL
      MPI        642712        86.83   88.25 (summary) MPI
      COM        197928         1.68    1.71 (summary) COM
      USR        212688         9.88   10.04 (summary) USR
```

- Significant reduction in runtime (measurement overhead)
  - Not only reduced time for USR regions, but MPI reduced too!
- Further measurement tuning (filtering) may be appropriate
  - e.g., "`timer_*`" filters `timer_start_`, `timer_read_`, etc.

Summary analysis report exploration (filtered)



NPB-BT trace measurement collection ...

- Re-run the application using Scalasca nexus with “-t” flag

```
% scalasca -analyze -t  mpiexec -np 16 ./bt_W.16
S=C=A=N: Scalasca trace collection and analysis
S=C=A=N: ./epik_bt_W_16_trace experiment archive
S=C=A=N: Sun Apr  5 18:50:57 2009: Collect start
mpiexec -np 16 ./bt_W.16
[00000]EPIK: Created new measurement archive ./epik_bt_W_16_trace
[00000]EPIK: EPK_FILTER "npb.filt" filtered 9 of 96 functions
[00000]EPIK: Activated ./epik_bt_W_16_trace [10000000 bytes] (0.051s)

          [... Application output ...]

[00000]EPIK: Closing experiment ./epik_bt_W_16_trace [0.016GB] (max 1053310)
[00000]EPIK: Flushed 1053330 bytes to file ./epik_bt_W_16_trace/ELG/00000
[00000]EPIK: 84 unique paths (84 max paths, 4 max frames, 0 unknowns)
[00000]EPIK: Unifying... done (0.021s)
[00013]EPIK: Flushed 1053306 bytes to file ./epik_bt_W_16_trace/ELG/00013
...
[00001]EPIK: Flushed 1053306 bytes to file ./epik_bt_W_16_trace/ELG/00001
[00000]EPIK: 1flush=0.001GB@2.582MB/s, Pflush=0.015GB@35.458MB/s
[00000]EPIK: Closed experiment ./epik_bt_W_16_trace (0.178s)
S=C=A=N: Sun Apr  5 18:51:05 2009: Collect done (status=0) 8s
[.. continued ...]
```

- Separate trace file per MPI rank written straight into new experiment directory ./epik_bt_W_16_trace

NPB-BT trace measurement … analysis

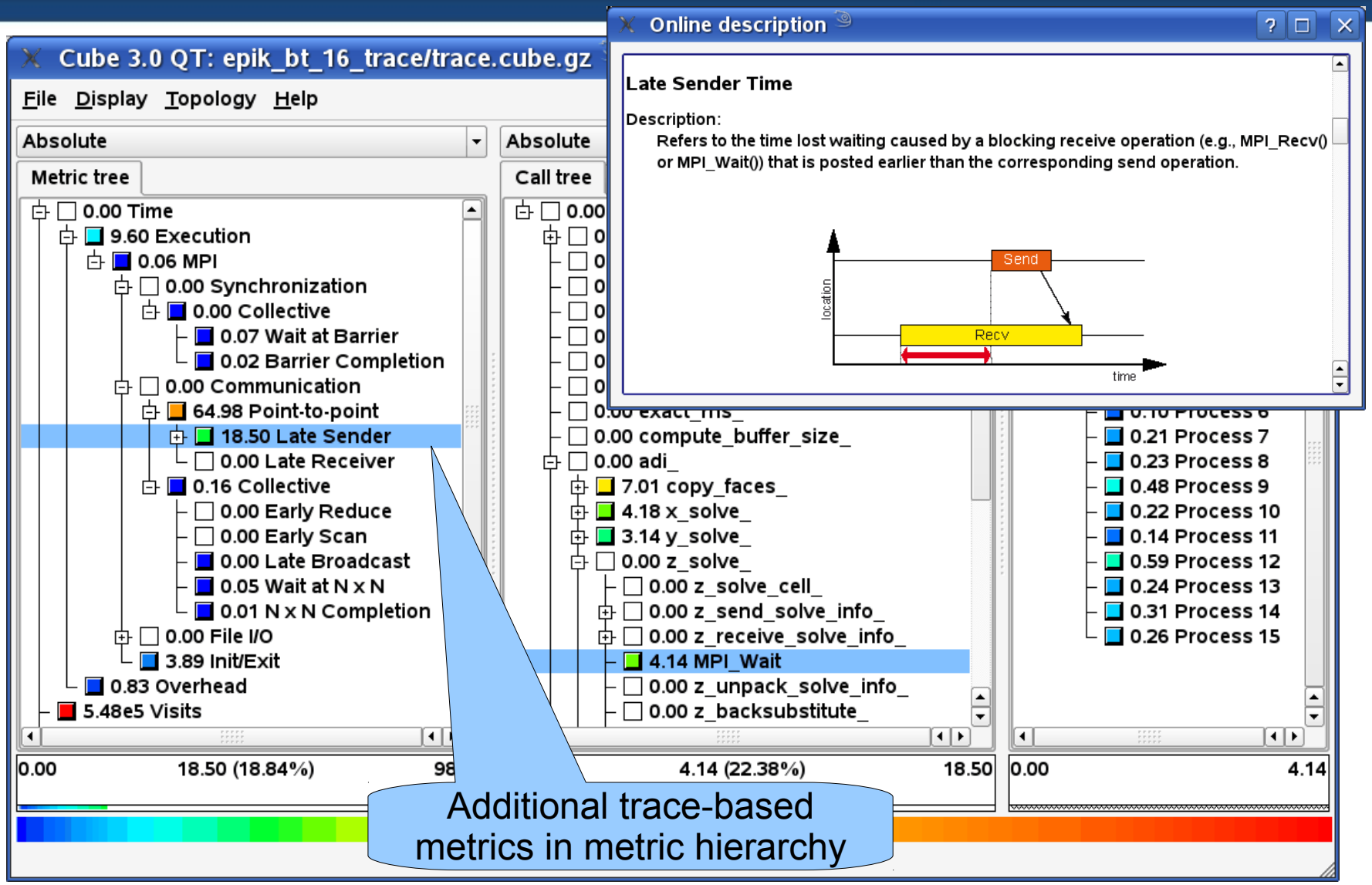
- Continues with automatic (parallel) analysis of trace files

```
S=C=A=N: Sun Apr  5 18:51:05 2009: Analyze start
mpiexec -np 16 scout.mpi ./epik_bt_W_16_trace
SCOUT   Copyright (c) 1998-2009 Forschungszentrum Juelich GmbH

Analyzing experiment archive ./epik_bt_W_16_trace

Reading definitions file  ... done (0.563s).
Reading event trace files ... done (0.495s).
Preprocessing             ... done (0.134s).
Analyzing event traces    ... done (2.186s).
Writing CUBE report       ... done (0.160s).

Total processing time     : 3.737s
Max. memory usage         : 7.000MB

S=C=A=N: Sun Apr  5 18:51:09 2009: Analyze done (status=0) 4s
S=C=A=N: ./epik_bt_W_16_trace complete.
```

- Produces trace analysis report in experiment directory

```
% scalasca -examine epik_bt_W_16_trace
INFO: Post-processing runtime summarization result...
INFO: Post-processing trace analysis report ...
INFO: Displaying ./epik_bt_W_16_sum/trace.cube...

                  [GUI showing trace analysis report]
```

Trace analysis report exploration



Further information

- Consult quick reference guide for further information

```
% scalasca -h
Scalasca 1.3 – quick reference guide
pdfview /UNITE/packages/scalasca/1.3/doc/manuals/QuickReference.pdf

              [PDF viewer showing quick reference guide]
```

- CUBE GUI provides context sensitive help and on-line metric descriptions (including problem diagnosis hints)
- EPIK archive directories contain analysis report(s), measurement collection & analysis logs, etc.
- Instrumentation, measurement, analysis & presentation can all be extensively customized
  - covered in more detailed presentation
- Visit www.scalasca.org or mail scalasca@fz-juelich.de

Scalasca usage recap

0. Reference preparation for validation
1. Program instrumentation: `skin`
2. Summary measurement collection & analysis: `scan [-s]`
3. Summary analysis report examination: `square`
4. Summary experiment scoring: `square -s`
5. Event trace collection & analysis: `scan -t`
6. Event trace analysis report examination: `square`

- General usage/help: `scalasca [-h]`
- Instrumentation, measurement, analysis & presentation can all be extensively customized
  - covered in more detailed presentation
- Visit www.scalasca.org or mail scalasca@fz-juelich.de

skin – Scalasca application instrumenter

- Prepares application objects & executables for measurement
  - ***skin*** = **scalasca -instrument**
  - skin [options] <*compile-or-link-command*>
    - defaults to automatic instrumentation of USR routines by compiler
      - available for most compilers, but not all
      - when not desired, disable with -comp=none
    - for OpenMP, includes source-level pre-processing of directives
    - for MPI, links wrappers to PMPI library routines
  - [-pdt] pre-process sources with PDToolkit (when available)
    - configurable instrumentation of specified routines (or all by default)
  - Manual instrumentation activation
    - offers complementary program structure information for analyses via user-provided annotations (e.g., phases, loops, ...)
    - [-user] enable EPIK user instrumentation API macros
    - [-pomp] enable processing of POMP region pragmas/directives

PDT-based instrumentation

- Automatic source instrumentation using PDToolkit [**-pdt**]
  - only available if configured when Scalasca installed
- By default, instruments all routines in source file
  - source routines are automatically instrumented by compiler, therefore use **-comp=none** to avoid duplicate instrumentation
- Selective instrumentation of specified routines
  - -optTauSelectFile=<filename>
  - TAU-format plain text specification file
    - list names of source files and routines to exclude from instrumentation, using wildcard patterns
      - unsupported TAU instrumentation features are silently ignored
    - refer to TAU/PDToolkit documentation for details
    - refer to Scalasca User Guide for known limitations

EPIK user instrumentation API

- EPIK user instrumentation API
  - #include “epik_user.h”
  - EPIK_USER_REG(epik_solve, “<<Solve>>”)
  - EPIK_USER_START(epik_solve)
  - EPIK_USER_END(epik_solve)
- Can be used to mark initialization, solver & other phases
  - Annotation macros ignored by default
  - Instrumentation enabled with “**-user**” flag to instrumenter
  - Also available for Fortran
    - #include “epik_user.inc” and use C preprocessor
- Appear as additional regions in analyses
  - Distinguishes performance of important phase from rest

scan – Scalasca collection/analysis nexus

- Runs application under control of measurement system to collect and analyze an execution experiment
  - ***scan*** = **scalasca -analyze**
  - scan [options] <*application-launch-command*>
    - e.g., scan [options] [$MPIEXEC [mpiexec-options]] [target [args]]
  - **[-s]** collect summarization experiment [default]
  - **[-t]** collect event traces and then analyze them automatically
  - Additional options
    - [-e title] specify experiment archive (directory) name: epik_*title*
    - [-f filter] specify file listing routines to ignore during measurement
    - [-m metric1:metric2:...] include hardware counter metrics
    - [-n] preview scan and perform checks but don't execute
    - [-q] quiesce (disable most) measurement collection
    - [-a] (re-)analyze a previously collected trace experiment

EPIK measurement configuration

- Via ./EPIK.CONF file

```
EPK_FILTER=smg2000.filt
EPK_MPI_ENABLED=CG:COLL:ENV:IO:P2P:RMA:TOPO
ELG_BUFFER_SIZE=40000000
```

- Via environment variables

```
% export EPK_FILTER=smg2000.filt
% export EPK_MPI_ENABLED=CG:COLL:ENV:IO:P2P:RMA:TOPO
% export ELG_BUFFER_SIZE=40000000
```

- Via command-line flags (partially)

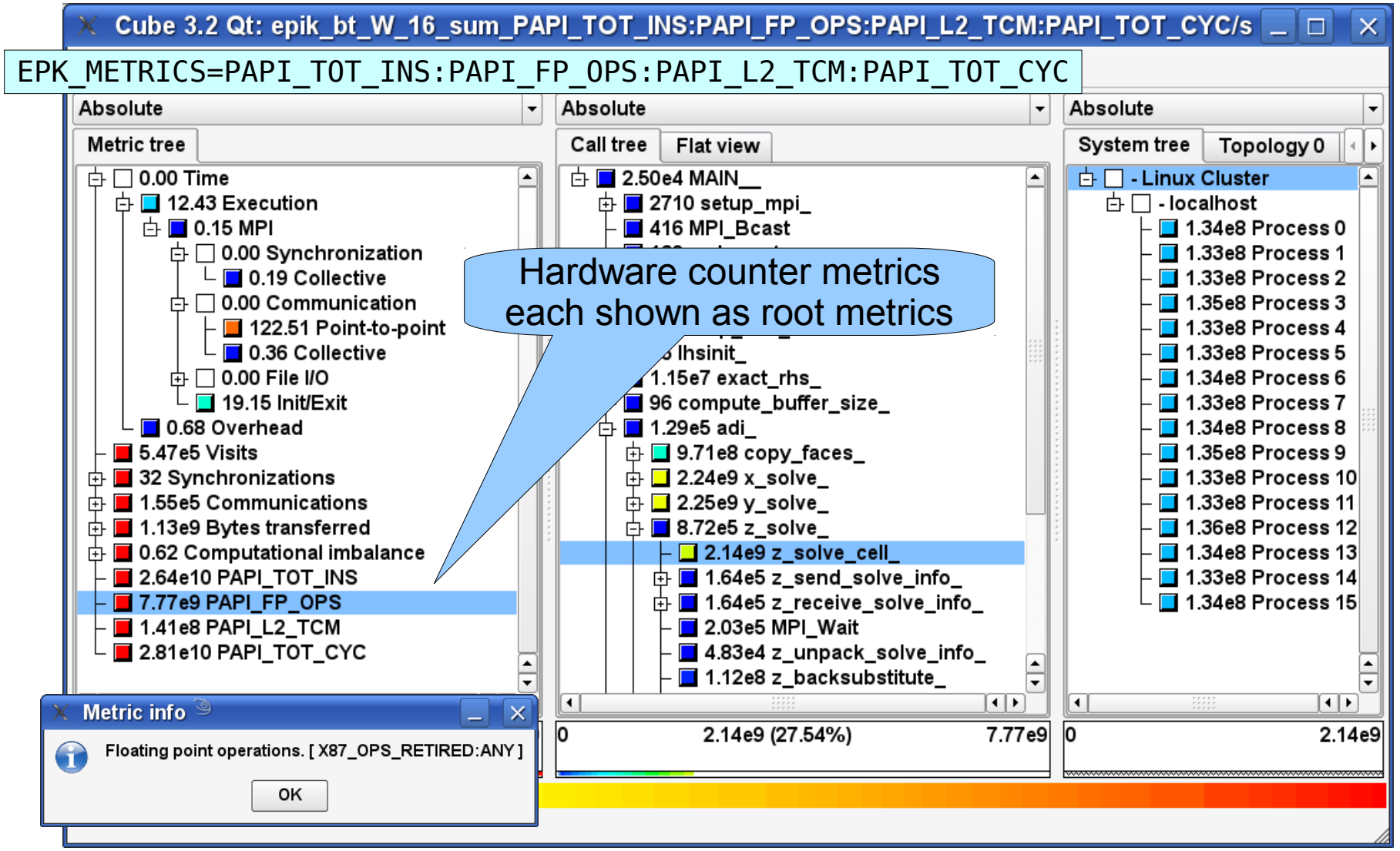
```
% scalasca -analyze -f smg2000.filt ...
```

- To show current/default configuration

```
% epik_conf
```

- Actual Scalasca measurement configuration saved in experiment archive as `epik.conf`

Summary analysis report with HWC metrics



Hints for the Scalasca analysis nexus

- Generally, the SCAN nexus will correctly parse execution command lines, but occasionally you may need to help it
- MPI launcher arguments may need to be explicitly separated from the target application with a double-dash

```
% scalasca -analyze  mpirun -np 16  --  a.exe arg
```

- Unusual MPI launcher options may need to be quoted

```
% scalasca -analyze  mpirun -np 16  "-verbose 2"  a.exe arg
```

  - (On most systems `-verbose` doesn't take an argument)
- Explicitly specify the instrumented target executable name when using imposition commands/scripts

```
% export SCAN_TARGET=a.exe
% scalasca -analyze  imposter.sh i.arg  a.exe arg
% scan -t  mpirun -np 16  imposter.sh i.arg  a.exe arg
```

  - (*dplace, omplace* and *numactl* are common imposters)

square – Scalasca analysis report examiner

- Prepares and presents measurement analysis report(s) for scoring and/or interactive exploration
  - ***square*** = **scalasca -examine**
  - square [options] <*experiment-archive*|*report*>
    - e.g., square epik_*title*
  - Post-processes intermediate measurement analysis reports
  - Launches GUI and presents default analysis report (if multiple reports available)
    - trace analysis given precedence over summary analysis
    - select other reports via File/Open menu
  - [-s] skip display and output textual score report
    - estimate total trace size and maximum rank trace size
    - breakdown of USR vs. MPI/OMP vs. COM region requirements

CUBE algebra utilities

- Extracting a sub-tree from an analysis report

```
% cube3_cut  -r '<<SMG.Solve>>'  epik_smg2000_12_trace/trace.cube
Writing cut.cube... done.
```

- Calculating difference of two analysis reports

```
% cube3_diff  epik_bt_9_trace/trace.cube  epik_bt_16_trace/trace.cube
Writing diff.cube... done.
```

- Combining two or more related analysis reports

```
% cube3_merge  trace/trace.cube  HWC1/summary.cube  HWC2/summary.cube
Writing merge.cube... done.
```

- Additional algebra utilities for calculating mean, etc.
  - Default output of cube3_*utility* is a new report *utility*.cube
- Further utilities for report scoring & statistics
- Run utility with “-h” (or no arguments) for brief usage info

DON'T PANIC!

- Remember the Scalasca User Guide is your friend
- And if you need more advice, mailto:scalasca@fz-juelich.de