

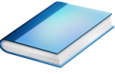
## Score-P instrumentation and measurement infrastructure

Reference material

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# Mastering build systems



- Hooking up the Score-P instrumenter `scorep` into complex build environments like *Autotools* or *CMake* was always challenging
- Score-P provides convenience wrapper scripts to simplify this (since Score-P 2.0)
- *Autotools* and *CMake* need the used compiler already in the *configure step*, but instrumentation should not happen in this step, only in the *build step*

```
% SCOREP_WRAPPER=off \  
> cmake .. \  
> -DCMAKE_C_COMPILER=scorep-icc \  
> -DCMAKE_CXX_COMPILER=scorep-icpc
```

Disable instrumentation in the *configure step*

Specify the wrapper scripts as the compiler to use

- Allows to pass addition options to the Score-P instrumenter and the compiler via environment variables without modifying the *Makefiles*:  
`SCOREP_WRAPPER_INSTRUMENTER_FLAGS`, `SCOREP_WRAPPER_COMPILER_FLAGS`
- Run `scorep-wrapper --help` for a detailed description and the available wrapper scripts of the Score-P installation

# Score-P user instrumentation API

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- Can be used to partition application into coarse grain phases
  - E.g., initialization, solver, & finalization
- Can be used to further subdivide functions
  - E.g., multiple loops inside a function
- Enabled with `--user` flag to Score-P instrumenter
- Available for Fortran / C / C++

# Score-P user instrumentation API (Fortran)



```
#include "scorep/SCOREP_User.inc"

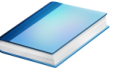
subroutine foo(...)
  ! Declarations
  SCOREP_USER_REGION_DEFINE( solve )

  ! Some code...
  SCOREP_USER_REGION_BEGIN( solve, "<solver>", \
                           SCOREP_USER_REGION_TYPE_LOOP )

  do i=1,100
    [...]
  end do
  SCOREP_USER_REGION_END( solve )
  ! Some more code...
end subroutine
```

- Requires processing by the C preprocessor
  - For most compilers, this can be automatically achieved by having an uppercase file extension, e.g., `main.F` or `main.F90`

# Score-P user instrumentation API (C/C++)

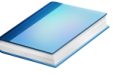


```
#include "scorep/SCOREP_User.h"

void foo()
{
    /* Declarations */
    SCOREP_USER_REGION_DEFINE( solve )

    /* Some code... */
    SCOREP_USER_REGION_BEGIN( solve, "<solver>",
                             SCOREP_USER_REGION_TYPE_LOOP )
    for (i = 0; i < 100; i++)
    {
        [...]
    }
    SCOREP_USER_REGION_END( solve )
    /* Some more code... */
}
```

# Score-P user instrumentation API (C++)



```
#include "scorep/SCOREP_User.h"

void foo()
{
    // Declarations

    // Some code...
    {
        SCOREP_USER_REGION( "<solver>",
                           SCOREP_USER_REGION_TYPE_LOOP )
        for (i = 0; i < 100; i++)
        {
            [...]
        }
    }
    // Some more code...
}
```

# Score-P measurement control API



- Can be used to temporarily disable measurement for certain intervals
  - Annotation macros ignored by default
  - Enabled with `--user` flag

```
#include "scorep/SCOREP_User.inc"

subroutine foo(...)
  ! Some code...
  SCOREP_RECORDING_OFF()
  ! Loop will not be measured
  do i=1,100
    [...]
  end do
  SCOREP_RECORDING_ON()
  ! Some more code...
end subroutine
```

Fortran (requires C preprocessor)

```
#include "scorep/SCOREP_User.h"

void foo(...) {
  /* Some code... */
  SCOREP_RECORDING_OFF()
  /* Loop will not be measured */
  for (i = 0; i < 100; i++) {
    [...]
  }
  SCOREP_RECORDING_ON()
  /* Some more code... */
}
```

C / C++

# Enriching measurements with performance counters



- Record metrics from PAPI:

```
% export SCOREP_METRIC_PAPI=PAPI_TOT_CYC
% export SCOREP_METRIC_PAPI_PER_PROCESS=PAPI_L3_TCM
```

- Use PAPI tools to get available metrics and valid combinations:

```
% papi_avail
% papi_native_avail
```

- Record metrics from Linux perf:

```
% export SCOREP_METRIC_PERF=cpu-cycles
% export SCOREP_METRIC_PERF_PER_PROCESS=LLC-load-misses
```

- Use the `perf` tool to get available metrics and valid combinations:

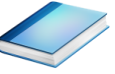
```
% perf list
```

- Write your own metric plugin

- Repository of available plugins: <https://github.com/score-p>

Only the master thread records the metric (assuming all threads of the process access the same L3 cache)

# Mastering C++ applications



- Automatic compiler instrumentation greatly disturbs C++ applications because of frequent/short function calls => Use sampling instead
- Novel combination of sampling events and instrumentation of MPI, OpenMP, ...
  - Sampling replaces compiler instrumentation (instrument with `--nocompiler` to further reduce overhead) => Filtering not needed anymore
  - Instrumentation is used to get accurate times for parallel activities to still be able to identify patterns of inefficiencies
- Supports profile and trace generation

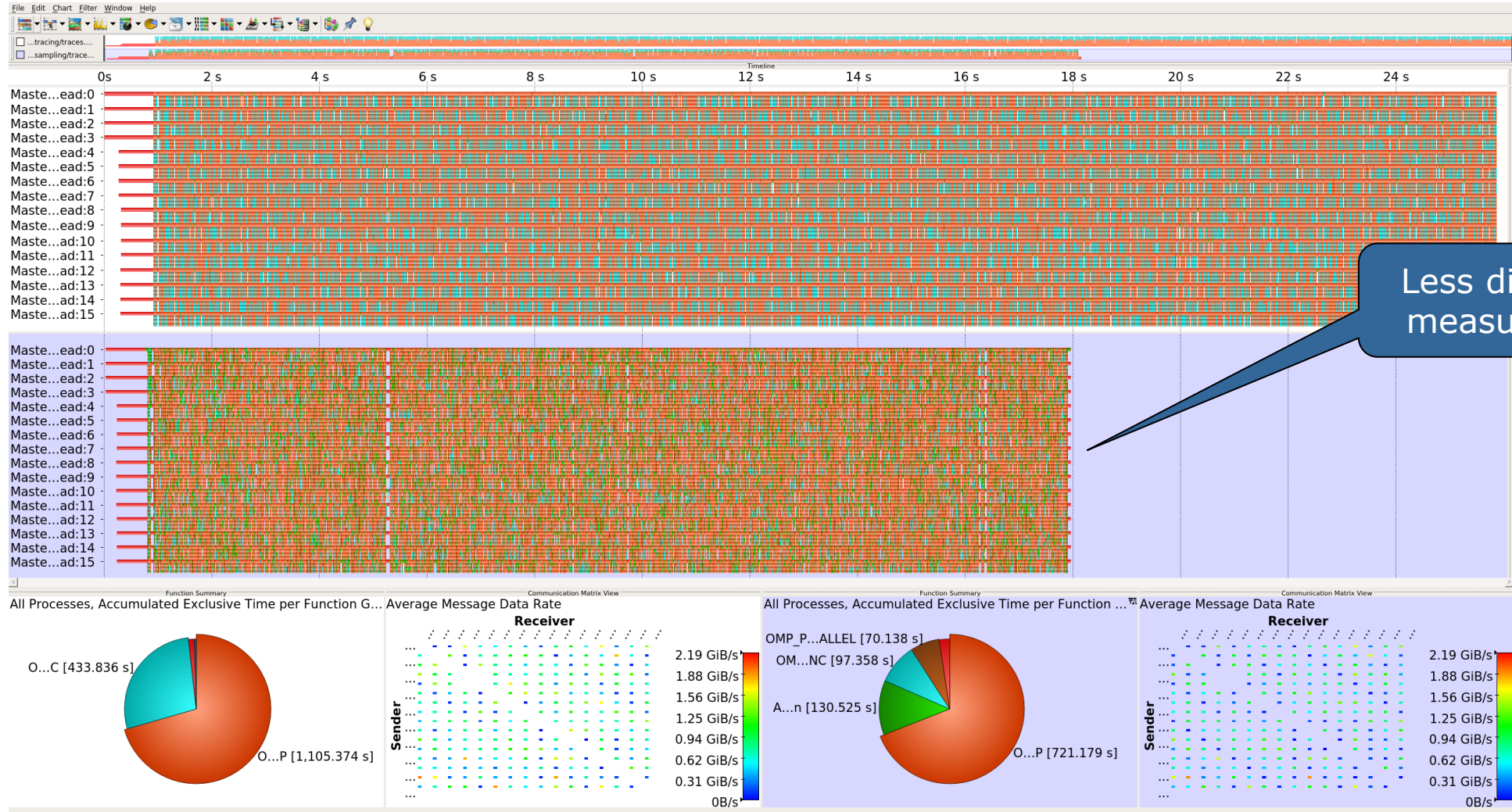
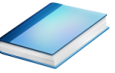
```
% export SCOREP_ENABLE_UNWINDING=true
% # use the default sampling frequency
% #export SCOREP_SAMPLING_EVENTS=perf_cycles@2000000

% OMP_NUM_THREADS=4 mpiexec -np 4 ./bt-mz_W.4
```

- Set new configuration variable to enable sampling

- Only x86-64 supported currently

# Mastering C++ applications



# Wrapping calls to 3<sup>rd</sup> party libraries



- Enables users to install library wrappers for any C/C++ library
- Intercept calls to a library API
  - no need to either build the library with Score-P or add manual instrumentation to the application using the library
  - no need to access the source code of the library, header and library files suffice
- Score-P needs to be executed with `--libwrap=...`
- Execute `scorep-libwrap-init` for directions:

Step 1: Initialize the working directory  
Step 2: Add library headers  
Step 3: Create a simple example application  
Step 4: Further configure the build parameters  
Step 5: Build the wrapper  
Step 6: Verify the wrapper  
Step 7: Install the wrapper  
Step 8: Verify the installed wrapper

Only once

Often

Step 9: Use the wrapper

# Wrapping calls to 3<sup>rd</sup> party libraries



- Generate your own library wrappers by telling `scorep-libwrap-init` how you would compile and link an application, e.g. using FFTW

```
% scorep-libwrap-init      \  
>  --name=fftw             \  
>  --prefix=$PREFIX       \  
>  -x c                   \  
>  --cppflags="-O3 -DNDEBUG -openmp -I$FFTW_INC" \  
>  --ldflags="-L$FFTW_LIB" \  
>  --libs="-lfftw3f -lfftw3" \  
>  working_directory
```

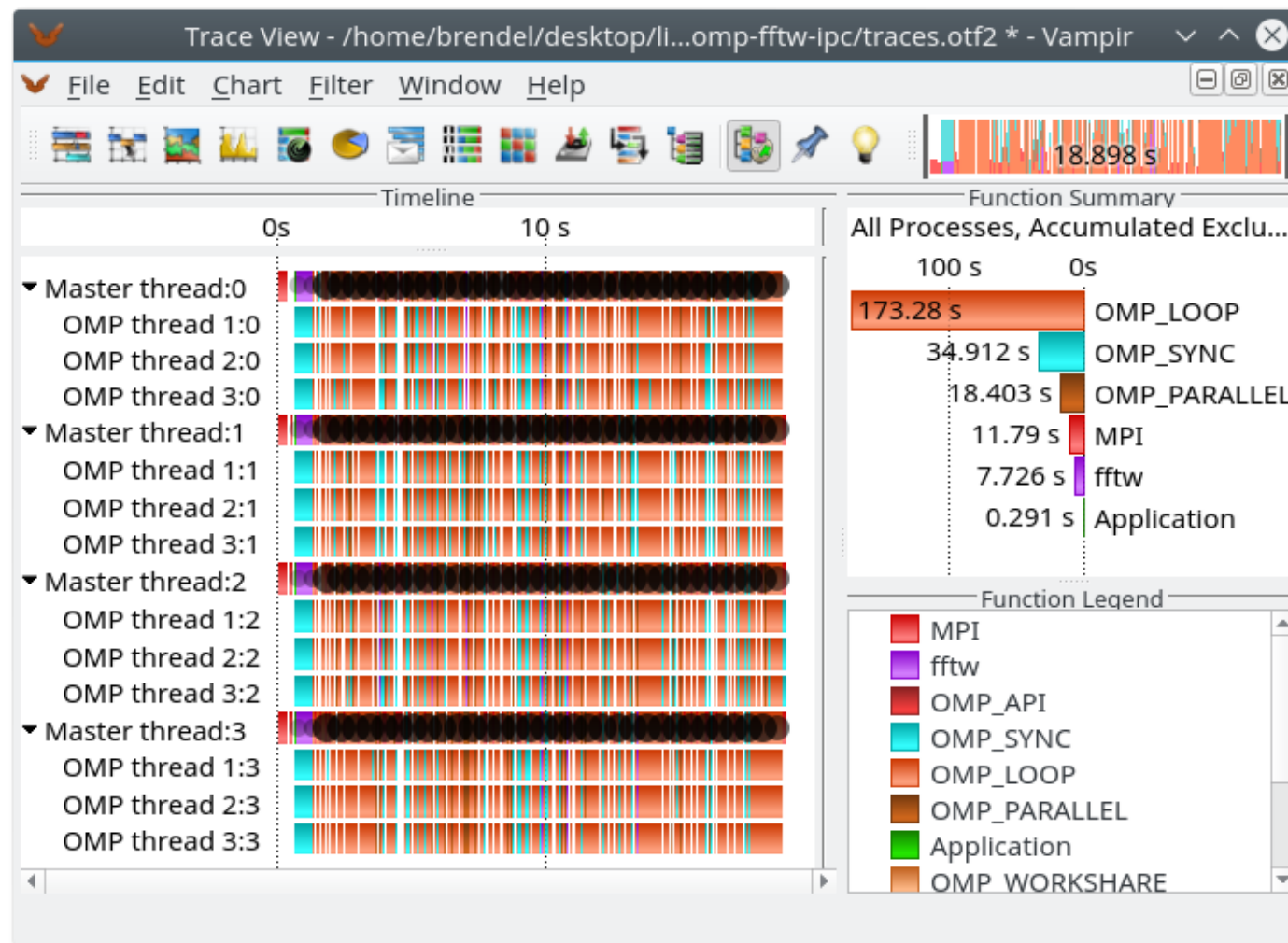
- Generate and build wrapper

```
% cd working_directory  
% ls                # (Check README.md for instructions)  
% make              # Generate and build wrapper  
% make check        # See if header analysis matches symbols  
% make install      #  
% make installcheck # More checks: Linking etc.
```

# Wrapping calls to 3<sup>rd</sup> party libraries



- MPI + OpenMP
- Calls to FFTW library



# Mastering application memory usage

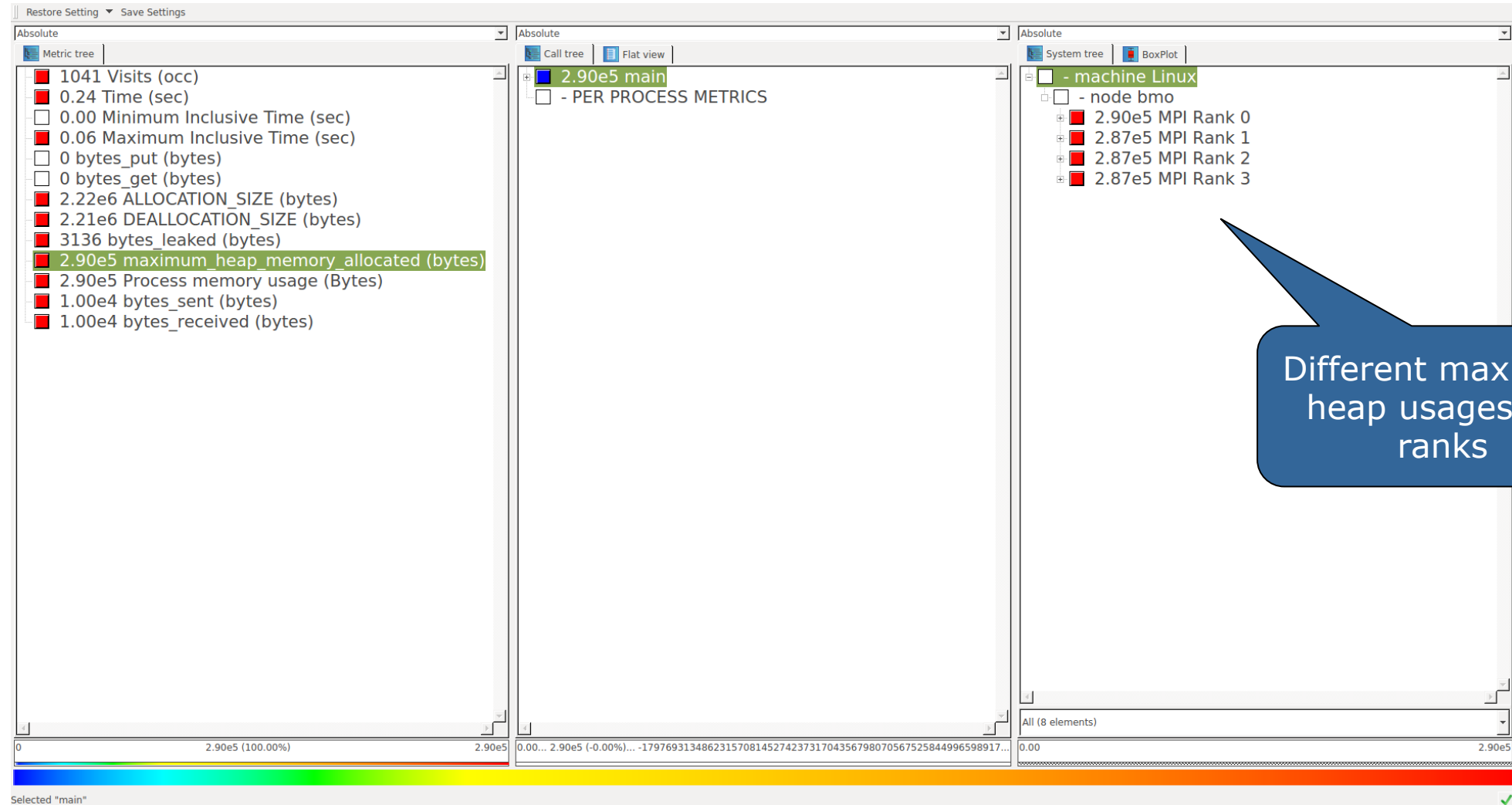
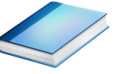


- Determine the maximum heap usage per process
- Find high frequent small allocation patterns
- Find memory leaks
- Support for:
  - C, C++, MPI, and SHMEM (Fortran only for GNU Compilers)
  - Profile and trace generation (profile recommended)
    - Memory leaks are recorded only in the profile
    - Resulting traces are not supported by Scalasca yet

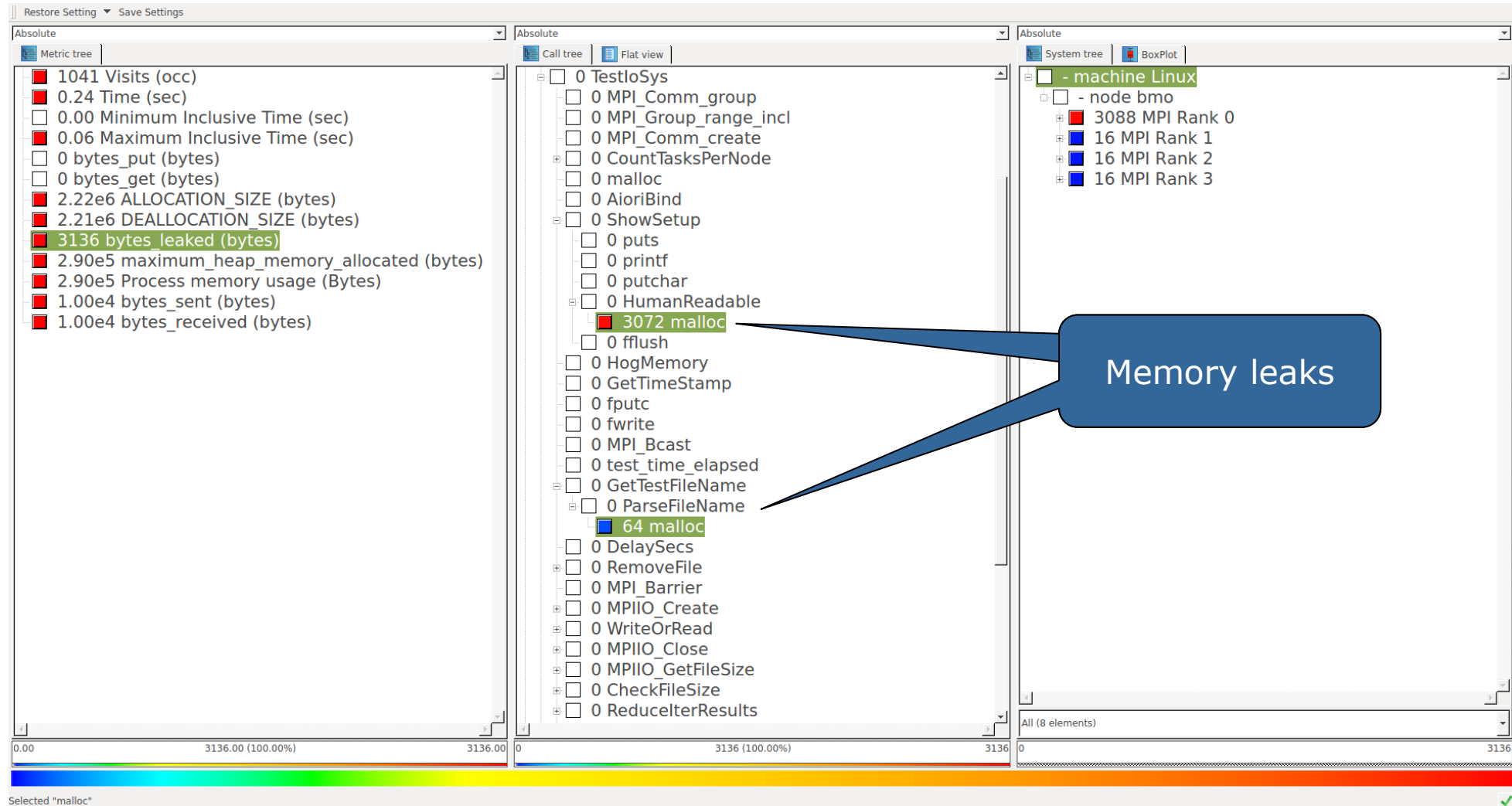
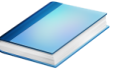
```
% export SCOREP_MEMORY_RECORDING=true  
% export SCOREP_MPI_MEMORY_RECORDING=true  
  
% OMP_NUM_THREADS=4 mpiexec -np 4 ./bt-mz_W.4
```

- Set new configuration variable to enable memory recording

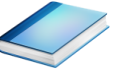
# Mastering application memory usage



# Mastering application memory usage



# Mastering heterogeneous applications



- Record CUDA applications and device activities

```
% export SCOREP_CUDA_ENABLE=runtime, kernel, idle
```

- Record HIP applications and device activities

```
% export SCOREP_HIP_ENABLE=all
```

- Record OpenCL applications and device activities

```
% export SCOREP_OPENCL_ENABLE=api, kernel
```

- Record OpenACC applications

```
% export SCOREP_OPENACC_ENABLE=yes
```

- Can be combined with CUDA if it is a NVIDIA device

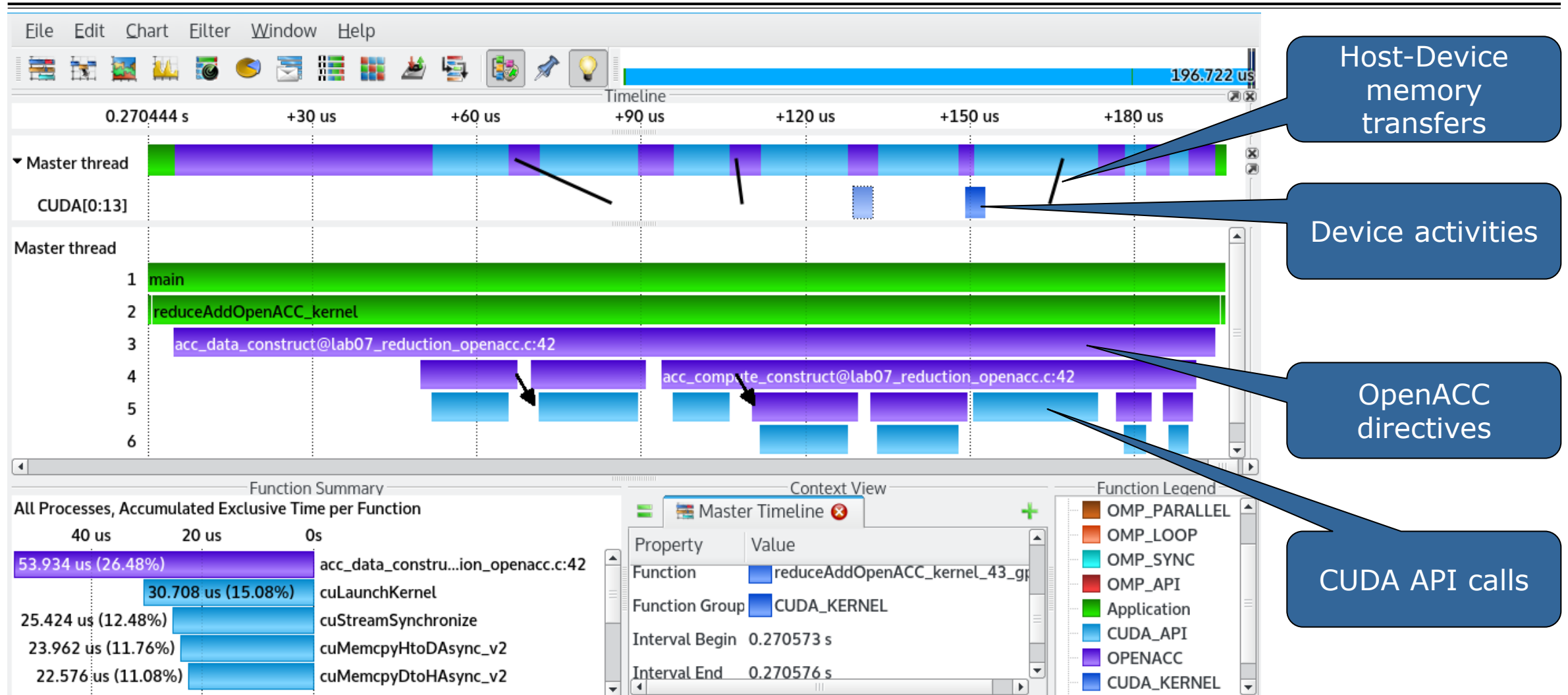
```
% export SCOREP_CUDA_ENABLE=kernel
```

- Check `scorep-info config-vars -full` for a wide range of further options and default values

Idle is an artificial region defined as outside of kernel time

Adding options will increase overhead to a varying degree

# Mastering heterogeneous applications



## Further information

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- Community instrumentation & measurement infrastructure
  - Instrumentation (various methods) and sampling
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data
- Available under 3-clause BSD open-source license
- Documentation & Sources:
  - <https://www.score-p.org>
- User guide also part of installation:
  - `<prefix>/share/doc/scorep/{pdf,html}/`
- Support and feedback: [support@score-p.org](mailto:support@score-p.org)
- Subscribe to [news@score-p.org](mailto:news@score-p.org), to be up to date