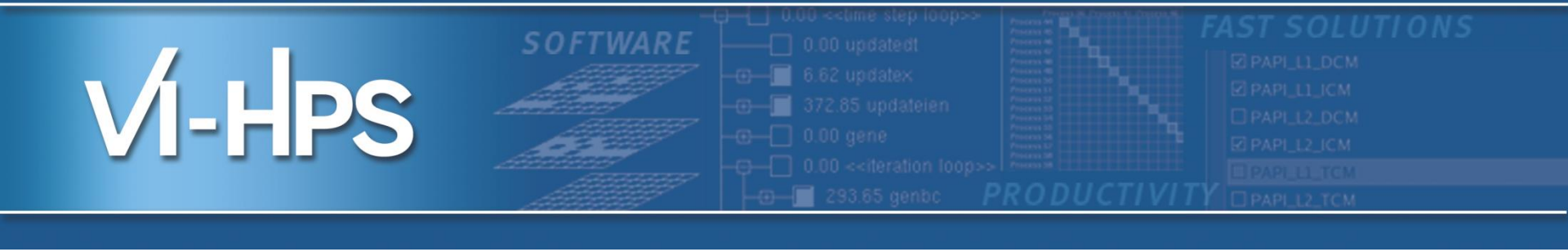

Score-P – A Joint Performance Measurement Run-Time Infrastructure for Periscope, Scalasca, TAU, and Vampir

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Fragmentation of Tools Landscape

- Several performance tools co-exist
- Separate measurement systems and output formats
- Complementary features and overlapping functionality
- Redundant effort for development and maintenance
- Limited or expensive interoperability
- Complications for user experience, support, training

SILC Project Idea

- Start a community effort for a common infrastructure
  - Score-P instrumentation and measurement system
  - Common data formats OTF2 and CUBE4
- Developer perspective:
  - Save manpower by sharing development resources
  - Invest in new analysis functionality and scalability
  - Save efforts for maintenance, testing, porting, support, training
- User perspective:
  - Single learning curve
  - Single installation, fewer version updates
  - Interoperability and data exchange
- SILC project funded by BMBF
- Close collaboration PRIMA project funded by DOE

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Partners

- Forschungszentrum Jülich, Germany
- German Research School for Simulation Sciences, Aachen, Germany
- Gesellschaft für numerische Simulation mbH Braunschweig, Germany
- RWTH Aachen, Germany
- Technische Universität Dresden, Germany
- Technische Universität München, Germany
- University of Oregon, Eugene, USA

Score-P Functionality

- Provide typical functionality for HPC performance tools
- Support all fundamental concepts of partner's tools

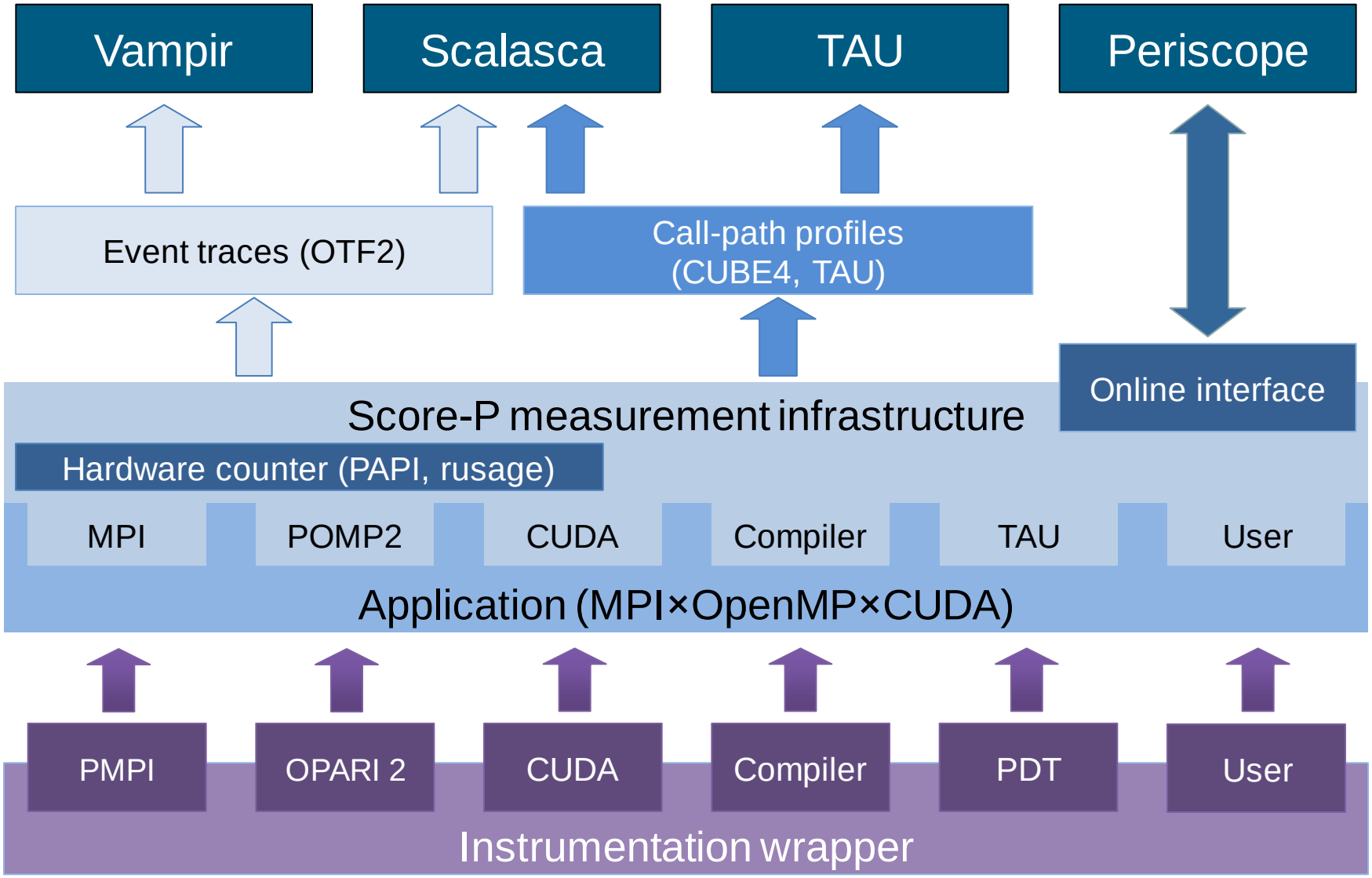
- Instrumentation (various methods)
- Flexible measurement without re-compilation:
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data

- MPI, OpenMP, and hybrid parallelism (and serial)
- Enhanced functionality (OpenMP 3.0, CUDA, highly scalable I/O)

Design Goals

- Functional requirements
  - Generation of call-path profiles and event traces
  - Using direct instrumentation, later also sampling
  - Recording time, visits, communication data, hardware counters
  - Access and reconfiguration also at runtime
  - Support for MPI, OpenMP, basic CUDA, and all combinations
    - Later also OpenCL/HMPP/PTHREAD/…
- Non-functional requirements
  - Portability: all major HPC platforms
  - Scalability: petascale
  - Low measurement overhead
  - Easy and uniform installation through UNITE framework
  - Robustness
  - Open Source: New BSD License

Score-P Architecture

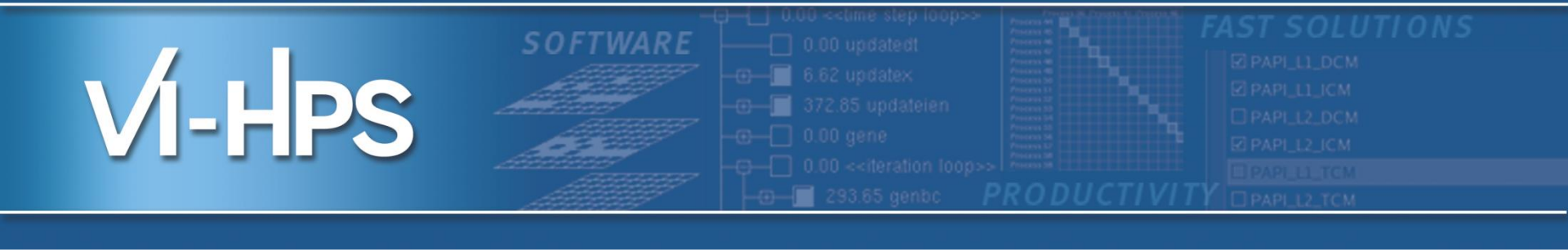


Future Features and Management

- Scalability to maximum available CPU core count
- Support for OpenCL, HMPP, PTHREAD
- Support for sampling, binary instrumentation
- Support for new programming models, e.g., PGAS
- Support for new architectures

- Ensure a single official release version at all times which will always work with the tools
- Allow experimental versions for new features or research

- Commitment to joint long-term cooperation



Score-P hands-on: NPB-MZ-MPI / BT

Performance Analysis Steps

1. Reference preparation for validation
2. Program instrumentation
3. Summary measurement collection
4. Summary analysis report examination
5. Summary experiment scoring
6. Summary measurement collection with filtering
7. Filtered summary analysis report examination
8. Event trace collection
9. Event trace examination & analysis

- Load modules:

```
% module use /lrz/sys/smuc_tools/modules

% module load UNITE
UNITE loaded

% module load scorep
scorep/1.1-ibmpoe-intel-papi loaded

% module load cube4
cube4/4.1.2v4-intel loaded

% module load tau
tau/2.21.4-ibmpoe-intel-papi loaded

% module load vampir
vampir/7.6.2 loaded
```

- Edit config/make.def to adjust build configuration
  - Modify specification of compiler/linker: MPIF77

```
#           SITE- AND/OR PLATFORM-SPECIFIC DEFINITIONS
#----------------------------------------------------------------------
# Items in this file may need to be changed for each platform.
#----------------------------------------------------------------------
...
#----------------------------------------------------------------------
# The Fortran compiler used for MPI programs
#----------------------------------------------------
#MPIF77 = mpif77

# Alternative variants to perform instrumentation
...
MPIF77 = scorep --user mpif77

# This links MPI Fortran programs; usually the same as ${MPIF77}
FLINK   = $(MPIF77)
...
```

Uncomment the Score-P compiler wrapper specification

NPB-MZ-MPI / BT Instrumented Build

- Return to root directory and clean-up

```
% make clean
```

- Re-build executable using Score-P compiler wrapper

```
% make bt-mz CLASS=B NPROCS=4
cd BT-MZ; make CLASS=B NPROCS=4 VERSION=
make: Entering directory 'BT-MZ'
cd ../sys; cc  -o setparams setparams.c -lm
../sys/setparams bt-mz 4 B
scorep --user mpif77 -c  -O3 -openmp bt.f
 [...]
cd ../common;  scorep --user mpif77 -c  -O3 -fopenmp timers.f
scorep --user mpif77 -O3 -openmp -o ../bin.scorep/bt-mz_B.4 \
bt.o initialize.o exact_solution.o exact_rhs.o set_constants.o \
adi.o rhs.o zone_setup.o x_solve.o y_solve.o exch_qbc.o \
solve_subs.o z_solve.o add.o error.o verify.o mpi_setup.o \
../common/print_results.o ../common/timers.o
Built executable ../bin.scorep/bt-mz_B.4
make: Leaving directory 'BT-MZ'
```

Measurement Configuration: scorep-info

- Score-P measurements are configured via environmental variables:

```
% scorep-info config-vars --full
SCOREP_ENABLE_PROFILING
  Description: Enable profiling
 [...]
SCOREP_ENABLE_TRACING
  Description: Enable tracing
 [...]
SCOREP_TOTAL_MEMORY
  Description: Total memory in bytes for the measurement system
 [...]
SCOREP_EXPERIMENT_DIRECTORY
  Description: Name of the experiment directory
 [...]
SCOREP_FILTERING_FILE
  Description: A file name which contain the filter rules
 [...]
SCOREP_METRIC_PAPI
  Description: PAPI metric names to measure
 [...]
SCOREP_METRIC_RUSAGE
  Description: Resource usage metric names to measure
 [... More configuration variables ...]
```

Summary Measurement Collection

- Change to the directory containing the new executable before running it with the desired configuration

```
% cd bin.scorep
% export SCOREP_EXPERIMENT_DIRECTORY=scorep_bt-mz_B_4x4_sum
% export OMP_NUM_THREADS=4
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 Number of zones:   8 x   8
 Iterations: 200    dt:   0.000300
 Number of active processes:     4

 Use the default load factors with threads
 Total number of threads:     16   (  4.0 threads/process)

 Calculated speedup =     15.96

 Time step    1

 [... More application output ...]
```

BT-MZ Summary Analysis Report Examination

- Creates experiment directory ./scorep_bt-mz_B_4x4_sum containing
  - a record of the measurement configuration (scorep.cfg)
  - the analysis report that was collated after measurement (profile.cubex)

```
% ls
bt-mz_B.4  scorep_bt-mz_B_4x4_sum
% ls scorep_bt-mz_B_4x4_sum
profile.cubex  scorep.cfg
```

- Interactive exploration with CUBE / ParaProf

```
% cube scorep_bt-mz_B_4x4_sum/profile.cubex

            [CUBE GUI showing summary analysis report]

% paraprof scorep_bt-mz_B_4x4_sum/profile.cubex

          [TAU ParaProf GUI showing summary analysis report]
```

Congratulations!?

- If you made it this far, you successfully used Score-P to
  - instrument the application
  - analyze its execution with a summary measurement, and
  - examine it with one the interactive analysis report explorer GUIs
- ... revealing the call-path profile annotated with
  - the “Time” metric
  - Visit counts
  - MPI message statistics (bytes sent/received)
- ... 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

BT-MZ Summary Analysis Result Scoring

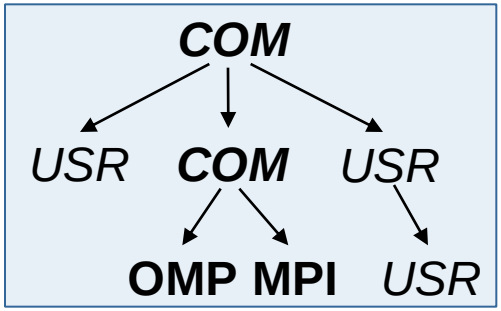
- Report scoring as textual output

```
% scorep-score scorep_bt-mz_B_4x4_sum/profile.cubex
Estimated aggregate size of event trace (total_tbc):      39223255064 bytes
Estimated requirements for largest trace buffer (max_tbc):  9865345520 bytes
(hint: When tracing set SCOREP_TOTAL_MEMORY > max_tbc to avoid intermediate flushes
 or reduce requirements using file listing names of USR regions to be filtered.)

flt type         max_tbc         time      % region
     ALL      9865345520      3051.65  100.0 ALL
     USR      9846360168       969.25   31.8 USR
     OMP        17803776      2026.84   66.4 OMP
     COM         1087800        13.32    0.4 COM
     MPI           93776        42.24    1.4 MPI
```

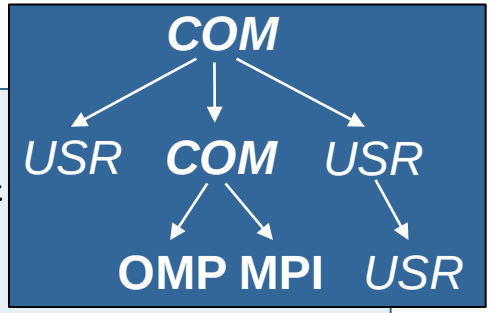
36.5 GB total memory
9.2 GB per rank!

- 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)



BT-MZ Summary Analysis Report Breakdown

- Score report breakdown by region




```
% scorep-score -r scorep_bt-mz_B_4x4_sum/profile.cubex
  [...]
flt type          max_tbc          time      % region
     ALL       9865345520       3051.65  100.0 ALL
     USR       9846360168        969.25   31.8 USR
     OMP         17803776       2026.84   66.4 OMP
     COM          1087800         13.32    0.4 COM
     MPI            93776         42.24    1.4 MPI

     USR       3158128080        222.74    7.3 matvec_sub_
     USR       3158128080        286.41    9.4 matmul_sub_
     USR       3158128080        422.11   13.8 binvcrhs_
     USR        139326768         10.94    0.4 binvrhs_
     USR        139326768         15.78    0.5 lhsinit_
     USR        103563840         11.25    0.4 exact_solution_
     OMP           823296          0.10    0.0 !$omp parallel @exch_qbc..
     OMP           823296          0.09    0.0 !$omp parallel @exch_qbc..
     OMP           823296          0.10    0.0 !$omp parallel @exch_qbc..
  [...]
```

More than 6.3 GB just for these 6 regions

BT-MZ Summary Analysis Score

- Summary measurement analysis score reveals
  - Total size of event trace would be ~36 GB
  - Maximum trace buffer size would be ~9 GB per rank
    - smaller buffer would require flushes to disk during measurement resulting in substantial perturbation
  - 99.8% of the trace requirements are for USR regions
    - purely computational routines never found on COM call-paths common to communication routines or OpenMP parallel regions
  - These USR regions contribute around 32% of total time
    - however, much of that is very likely to be measurement overhead for 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

BT-MZ Summary Analysis Report Filtering

- Report scoring with prospective filter listing
  6 USR regions

```
% cat ../config/scorep.filt
SCOREP_REGION_NAMES_BEGIN EXCLUDE
binvcrhs*
matmul_sub*
matvec_sub*
exact_solution*
binvrhs*
lhs*init*
timer_*

% scorep-score -f ../config/scorep.filt scorep_bt-mz_B_4x4_sum/profile.cubex
Estimated aggregate size of event trace (total_tbc):       75957944 bytes
Estimated requirements for largest trace buffer (max_tbc): 18989504 bytes
(hint: When tracing set SCOREP_TOTAL_MEMORY > max_tbc to avoid intermediate flushes
 or reduce requirements using file listing names of USR regions to be filtered.)
```

72MB of memory in total, 18 MB per rank!

BT-MZ Summary Analysis Report Filtering

- Score report breakdown by region

```
% scorep-score -r -f ../config/scorep.filt \
> scorep_bt-mz_B_4x4_sum/profile.cubex
flt type         max_tbc         time      % region
 *   ALL        18989504      2082.40   68.2 ALL-FLT
 +   FLT      9846356040       969.25   31.8 FLT
 -   OMP        17803776      2026.84   66.4 OMP-FLT
 *   COM         1087800        13.32    0.4 COM-FLT
 -   MPI           93776        42.24    1.4 MPI-FLT
 *   USR            4152         0.00    0.0 USR-FLT

 +   USR      3158128080       222.74    7.3 matvec_sub_
 +   USR      3158128080       286.41    9.4 matmul_sub_
 +   USR      3158128080       422.11   13.8 binvcrhs_
 +   USR       139326768        10.94    0.4 binvrhs_
 +   USR       139326768        15.78    0.5 lhsinit_
 +   USR       103563840        11.25    0.4 exact_solution_
 -   OMP          823296         0.10    0.0 !$omp parallel @exch_qbc.f
 -   OMP          823296         0.09    0.0 !$omp parallel @exch_qbc.f
 -   OMP          823296         0.10    0.0 !$omp parallel @exch_qbc.f
 [...]
```

Filtered routines marked with '+'

BT-MZ Filtered Summary Measurement

- Set new experiment directory and re-run measurement with new filter configuration

```
% export SCOREP_EXPERIMENT_DIRECTORY=scorep_bt-mz_B_4x4_sum_with_filter
% export SCOREP_FILTERING_FILE=../config/scorep.filt
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 Number of zones:   8 x   8
 Iterations: 200    dt:   0.000300
 Number of active processes:     4

 Use the default load factors with threads
 Total number of threads:     16   (  4.0 threads/process)

 Calculated speedup =     15.96

 Time step    1

 [... More application output ...]
```

BT-MZ Tuned Summary Analysis Report Score

- Scoring of new analysis report as textual output

```
% scorep-score scorep_bt-mz_B_4x4_sum_with_filter/profile.cubex
Estimated aggregate size of event trace (total_tbc):       75957944 bytes
Estimated requirements for largest trace buffer (max_tbc): 18989504 bytes
(hint: When tracing set SCOREP_TOTAL_MEMORY > max_tbc to avoid intermediate flushes
 or reduce requirements using file listing names of USR regions to be filtered.)

flt type         max_tbc         time      % region
     ALL        18989504       968.60  100.0 ALL
     OMP        17803776       950.62   98.1 OMP
     COM         1087800        10.42    1.1 COM
     MPI           93776         7.56    0.8 MPI
     USR            4152         0.00    0.0 USR
```

- Significant reduction in runtime (measurement overhead)
  - Not only reduced time for USR regions, but MPI/OMP reduced too!
- Further measurement tuning (filtering) may be appropriate
  - e.g., use “timer_*” to filter timer_start_, timer_read_, etc.

Advanced Measurement Configuration: Metrics

- Recording hardware counters via PAPI

```
% export SCOREP_METRIC_PAPI=PAPI_TOT_INS,PAPI_FP_INS
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 [... More application output ...]
```

- Also possible to record them only per rank

```
% export SCOREP_METRIC_PAPI_PER_PROCESS=PAPI_L3_DCM
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 [... More application output ...]
```

- Recording operating system resource usage

```
% export SCOREP_METRIC_RUSAGE_PER_PROCESS=ru_maxrss,ru_stime
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 [... More application output ...]
```

- Available PAPI metrics
  - Preset events: common set of events deemed relevant and useful for application performance tuning
    - Abstraction from specific hardware performance counters, mapping onto available events done by PAPI internally

```
% papi_avail
```

  - Native events: set of all events that are available on the CPU (**platform dependent**)

```
% papi_native_avail
```

Note:
Due to hardware restrictions
- number of concurrently recorded events is limited
- there may be invalid combinations of concurrently recorded events

- Available resource usage metrics

```
% man getrusage
 [... Output ...]

struct rusage {
    struct timeval ru_utime; /* user CPU time used */
    struct timeval ru_stime; /* system CPU time used */
    long   ru_maxrss;        /* maximum resident set size */
    long   ru_ixrss;         /* integral shared memory size */
    long   ru_idrss;         /* integral unshared data size */
    long   ru_isrss;         /* integral unshared stack size */
    long   ru_minflt;        /* page reclaims (soft page faults) */
    long   ru_majflt;        /* page faults (hard page faults) */
    long   ru_nswap;         /* swaps */
    long   ru_inblock;       /* block input operations */
    long   ru_oublock;       /* block output operations */
    long   ru_msgsnd;        /* IPC messages sent */
    long   ru_msgrcv;        /* IPC messages received */
    long   ru_nsignals;      /* signals received */
    long   ru_nvcsw;         /* voluntary context switches */
    long   ru_nivcsw;        /* involuntary context switches */
};

 [... More output ...]
```

Note:
(1) Not all fields are maintained on each platform.
(2) Check scope of metrics (per process vs. per thread)

Advanced Measurement Configuration: Metrics

- Edit jobscript/supermig/scorep.ll to adjust configuration
  - Modify specification of metrics and buffer size

```
# Score-P configuration
export SCOREP_EXPERIMENT_DIRECTORY=scorep_experiment
export SCOREP_FILTERING_FILE=../config/scorep.filt
export SCOREP_METRIC_RUSAGE=all
export SCOREP_METRIC_PAPI=PAPI_TOT_CYC,PAPI_TOT_INS,PAPI_FP_INS
#export SCOREP_ENABLE_TRACING=true
```

Uncomment the Score-P metric specifications

Performance Analysis Steps

1. Reference preparation for validation
2. Program instrumentation
3. Summary measurement collection
4. Summary analysis report examination
5. Summary experiment scoring
6. Summary measurement collection with filtering
7. Filtered summary analysis report examination
8. Event trace collection
9. Event trace examination & analysis

Warnings and Tips Regarding Tracing

- Traces can become extremely large and unwieldy
  - Size is proportional to number of processes/threads (width), duration (length) and detail (depth) of measurement
- Traces containing intermediate flushes are of little value

  Uncoordinated flushes result in cascades of distortion
  - Reduce size of trace
  - Increase available buffer space
- Traces should be written to a parallel file system
  - /work or /scratch are typically provided for this purpose
- Moving large traces between file systems is often impractical
  - However, systems with more memory can analyze larger traces
  - Alternatively, run trace analyzers with undersubscribed nodes

BT-MZ Trace Measurement Collection...

- Re-run the application using the tracing mode of Score-P

```
% export SCOREP_EXPERIMENT_DIRECTORY=scorep_bt-mz_B_4x4_trace
% export SCOREP_FILTERING_FILE=../config/scorep.filt
% export SCOREP_ENABLE_TRACING=true
% export SCOREP_ENABLE_PROFILING=false
% export SCOREP_TOTAL_MEMORY=20971520
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 [... More application output ...]
```

- Separate trace file per thread written straight into new experiment directory ./scorep_bt-mz_B_4x4_trace
- Interactive trace exploration with Vampir

```
% vampir scorep_bt-mz_B_4x4_trace/traces.otf2

                        [Vampir GUI showing trace]
```

Advanced Measurement Configuration: MPI

- Record only for subset of the MPI functions events

```
% export SCOREP_MPI_ENABLE_GROUPS=cg,coll,p2p,xnonblock
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark
 [... More application output ...]
```

- All possible sub-groups
  - cg — Communicator and group management
  - coll — Collective functions
  - env — Environmental management
  - err — MPI Error handling
  - ext — External interface functions
  - io — MPI file I/O
  - misc — Miscellaneous
  - perf — PControl
  - p2p — Peer-to-peer communication
  - rma — One sided communication
  - spawn — Process management
  - topo — Topology
  - type — MPI datatype functions
  - xnonblock — Extended non-blocking events
  - xreqtest — Test events for uncompleted requests

Advanced Measurement Configuration: CUDA

- Record CUDA events with the CUPTI interface

```
% export SCOREP_CUDA_ENABLE=gpu,kernel,idle
% mpiexec -n 4 ./bt-mz_B.4

 NAS Parallel Benchmarks (NPB3.3-MZ-MPI) - BT-MZ MPI+OpenMP Benchmark

 [... More application output ...]
```

- All possible recording types
  - runtime CUDA runtime API
  - driver CUDA driver API
  - gpu GPU activities
  - kernel CUDA kernels
  - idle GPU compute idle time
  - memcpy CUDA memory copies (not available yet)

Score-P User Instrumentation API

- Can be used to mark initialization, solver & other phases
  - Annotation macros ignored by default
  - Enabled with [**--user**] flag
- Appear as additional regions in analyses
  - Distinguishes performance of important phase from rest
- Can be of various type
  - E.g., function, loop, phase
  - See user manual for details
- 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

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++

Score-P

- Community instrumentation & measurement infrastructure
  - Instrumentation (various methods)
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data
- Available under New BSD open-source license
- Documentation & Sources:
  - http://www.score-p.org
- User guide also part of installation:
  - <prefix>/share/doc/scorep/{pdf,html}/
- Contact: info@score-p.org
- Bugs: scorep-bugs@groups.tu-dresden.de