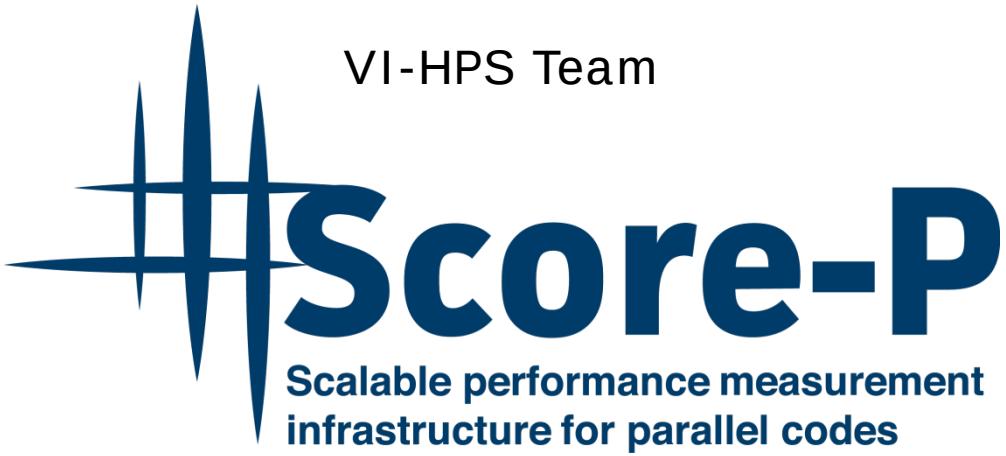
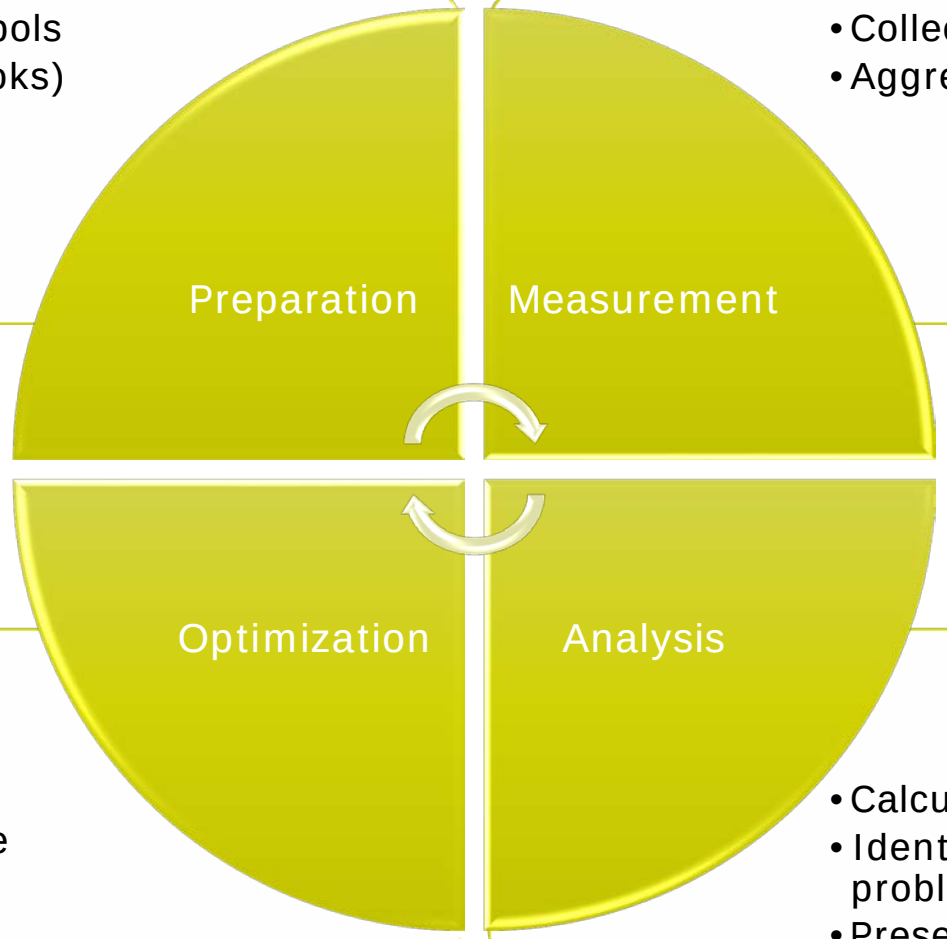
Score-P – A Joint Performance Measurement Run-Time Infrastructure for Periscope, Scalasca, TAU, and Vampir

VI-HPS Team



Performance engineering workflow

- Prepare application with symbols
- Insert extra code (probes/hooks)



- Collection of performance data
- Aggregation of performance data

- Modifications intended to eliminate/reduce performance problem

- Calculation of metrics
- Identification of performance problems
- Presentation of results

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

Vampir	Scalasca	TAU	Periscope
VampirTrace OTF	EPILOG / CUBE	TAU native formats	Online measurement

Score-P 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
- Project funded by BMBF
- Close collaboration PRIMA project funded by DOE

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·

Partners

- Forschungszentrum Jülich, Germany
- Gesellschaft für numerische Simulation mbH Braunschweig, Germany
- RWTH Aachen, Germany
- Technische Universität Darmstadt, 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

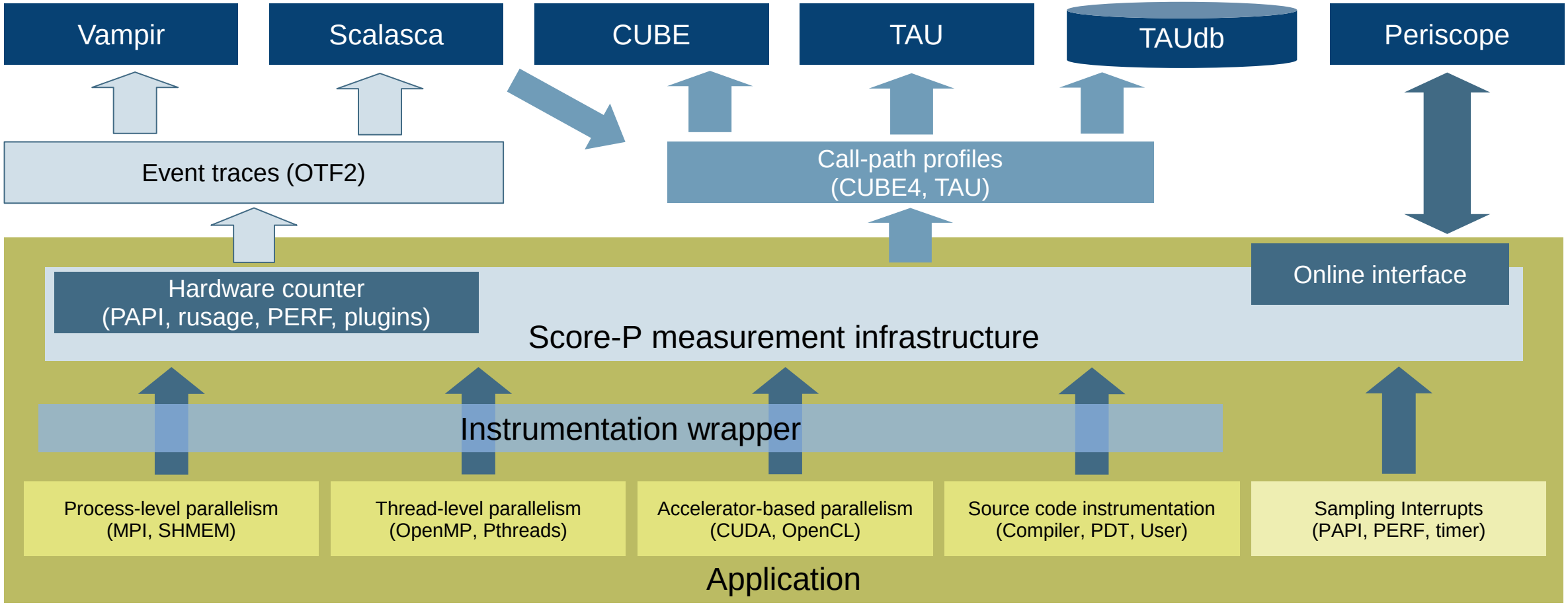
- Instrumentation (various methods)
- Flexible measurement without re-compilation:
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data

- MPI/SHMEM, OpenMP/Pthreads, and hybrid parallelism (and serial)
- Enhanced functionality (CUDA, OpenCL, 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, SHMEM, OpenMP, Pthreads, CUDA, OpenCL and their valid combinations
- Non-functional requirements
  - Portability: all major HPC platforms
  - Scalability: petascale
  - Low measurement overhead
  - Robustness
  - Open Source: New BSD License

Score-P Overview



Future Features and Management

- Scalability to maximum available CPU core count
- 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

Hands-on:
NPB-MZ-MPI / BT

Performance Analysis Steps

- 0.0 Reference preparation for validation

- 1.0 Program instrumentation
- 1.1 Summary measurement collection
- 1.2 Summary analysis report examination

- 2.0 Summary experiment scoring
- 2.1 Summary measurement collection with filtering
- 2.2 Filtered summary analysis report examination

- 3.0 Event trace collection
- 3.1 Event trace examination & analysis

NPB-MZ-MPI / BT Instrumentation

```
% source /home/S11505/shared/tools/setup.sh
% cd $HOME/NPB3.3-MZ-MPI
```

- Setup tools environment and return to tutorial exercise source directory

NPB-MZ-MPI / BT Instrumentation

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

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

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

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

Uncomment the Score-P compiler wrapper specification

NPB-MZ-MPI / BT Instrumented Build

```
% cd $HOME/NPB3.3-MZ-MPI
% make clean

% make bt-mz CLASS=B NPROCS=8
cd BT-MZ; make CLASS=B NPROCS=8 VERSION=
make: Entering directory 'BT-MZ'
cd ../sys; cc  -o setparams setparams.c -lm
../sys/setparams bt-mz 4 B
scorep mpifrtpx -c  -O3 -Kopenmp bt.f
 [...]
cd ../common;  scorep mpifrtpx -c  -O3 -Kopenmp timers.f
scorep mpifrtpx –O3 -Kopenmp -o ../bin.scorep/bt-mz_B.8 \
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.8
make: Leaving directory 'BT-MZ‘
```

- Return to exercise directory and clean-up previous build
- Re-build executable using Score-P compiler wrapper

Summary Measurement Collection

```
% cd bin.scorep
% cp ../jobscript/fx10/scorep.sh .
% cat scorep.sh
export NPB_MZ_BLOAD=0
export OMP_NUM_THREADS=4
CLASS=B
NPROCS=8
EXE=./bt-mz_$CLASS.$NPROCS

export SCOREP_EXPERIMENT_DIRECTORY=scorep_8x4_sum
#export SCOREP_FILTERING_FILE=../config/scorep.filt
#export SCOREP_METRIC_PAPI=PAPI_TOT_INS,PAPI_TOT_CYC
#export SCOREP_TOTAL_MEMORY=300M

# launch
mpiexec -np $NPROCS $EXE

% pjsub ./scorep.sh
```

- Change to the directory with the new executable
- Copy the new jobscript with settings for Score-P measurement configuration
- Check/adjust settings

Leave these lines commented out for now

- Submit job

Measurement Configuration: scorep-info

```
% 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 ...]
```

- Score-P measurements are configured via environmental variables
- Execute **scorep-info** for a complete list

Summary Measurement Collection

```
% less scorep.sh.o<jobid>

 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:     8

 Use the default load factors with threads
 Total number of threads:     32  (  4.0 threads/process)

 Calculated speedup =     31.99

 Time step    1

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

- Check the output of the application run

BT-MZ Summary Analysis Report Examination

```
% ls
bt-mz_B.8  scorep.sh  scorep.sh.o<jobid> scorep_8x4_sum
% ls scorep_8x4_sum
profile.cubex  scorep.cfg
```

```
% cube scorep_8x4_sum/profile.cubex

      [CUBE GUI showing summary analysis report]
```

- Creates experiment directory
  - A record of the measurement configuration (scorep.cfg)
  - The analysis report that was collated after measurement (profile.cubex)
- Interactive exploration with CUBE

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

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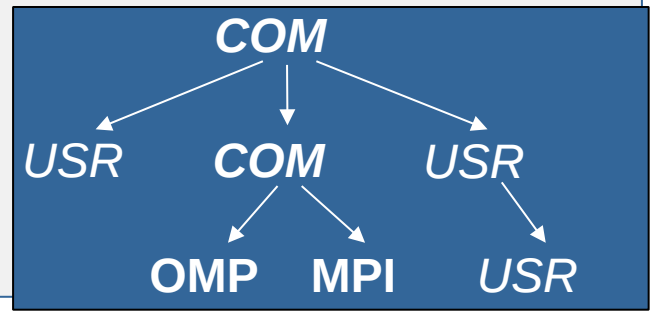
BT-MZ Summary Analysis Result Scoring

```
% scorep-score scorep_8x4_sum/profile.cubex

Estimated aggregate size of event trace:                   159 GB
Estimated requirements for largest trace buffer (max_buf):  20 GB
Estimated memory requirements (SCOREP_TOTAL_MEMORY):        20 GB
(hint: When tracing set SCOREP_TOTAL_MEMORY=20GB to avoid intermediate flushes
 or reduce requirements using USR regions filters.)

flt     type     max_buf[B]        visits time[s] time[%] time/visit[us]  region
         ALL 21,377,442,117 6,554,106,201 4946.18   100.0           0.75  ALL
         USR 21,309,225,314 6,537,020,537 2326.51    47.0           0.36  USR
         OMP     65,624,896    16,327,168 2607.63    52.7         159.71  OMP
         COM      2,355,080       724,640    2.49     0.1           3.43  COM
         MPI        236,827        33,856    9.56     0.2         282.29  MPI
```



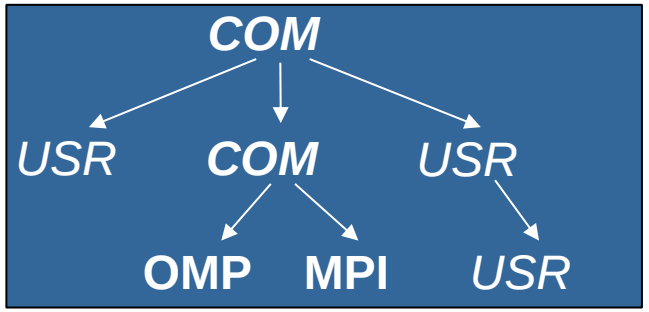
- Report scoring as textual output

159 GB total memory
20 GB per rank!

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

BT-MZ Summary Analysis Report Breakdown

```
% scorep-score -r scorep_8x4_sum/profile.cubex
  [...]
  [...]
flt type     max_buf[B]         visits time[s] time[%] time/visit[us] region
     ALL 21,377,442,117 6,554,106,201 4946.18   100.0         0.75  ALL
     USR 21,309,225,314 6,537,020,537 2326.51    47.0         0.36  USR
     OMP     65,624,896    16,327,168 2607.63    52.7       159.71  OMP
     COM      2,355,080       724,640    2.49     0.1         3.43  COM
     MPI        236,827        33,856    9.56     0.2       282.29  MPI

     USR  6,883,222,086 2,110,313,472  651.44    13.2         0.31  matvec_sub_
     USR  6,883,222,086 2,110,313,472  720.38    14.6         0.34  matmul_sub_
     USR  6,883,222,086 2,110,313,472  881.32    17.8         0.42  binvcrhs_
     USR    293,617,584    87,475,200   29.93     0.6         0.34  binvrhs_
     USR    293,617,584    87,475,200   33.03     0.7         0.38  lhsinit_
     USR    101,320,128    31,129,600    7.78     0.2         0.25  exact_solution_
```



More than
18 GB just for these 6 regions

BT-MZ Summary Analysis Score

- Summary measurement analysis score reveals
  - Total size of event trace would be ~159 GB
  - Maximum trace buffer size would be ~20 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

```
% 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 –c 2  scorep_8x4_sum/profile.cubex

Estimated aggregate size of event trace:                   521 MB
Estimated requirements for largest trace buffer (max_buf):  66 MB
Estimated memory requirements (SCOREP_TOTAL_MEMORY):        78 MB
(hint: When tracing set SCOREP_TOTAL_MEMORY=78MB to avoid \
>intermediate flushes
 or reduce requirements using USR regions filters.)
```

- Report scoring with prospective filter listing 6 USR regions

521 MB of memory in total, 66 MB per rank!

(Including 2 metric values)

BT-MZ Summary Analysis Report Filtering

```
% scorep-score -r -f ../config/scorep.filt  scorep_8x4_sum/profile.cubex
flt type     max_buf[B]         visits time[s] time[%] time/visit[us] region
 -   ALL 21,377,442,117 6,554,106,201 4946.18   100.0           0.75 ALL
 -   USR 21,309,225,314 6,537,020,537 2326.51    47.0           0.36 USR
 -   OMP     65,624,896    16,327,168 2607.63    52.7         159.71 OMP
 -   COM      2,355,080       724,640    2.49     0.1           3.43 COM
 -   MPI        236,827        33,856    9.56     0.2         282.29 MPI

 *   ALL     68,216,855    17,085,673 2622.30    53.0         153.48 ALL-FLT
 +   FLT 21,309,225,262 6,537,020,528 2323.88    47.0           0.36 FLT
 -   OMP     65,624,896    16,327,168 2607.63    52.7         159.71 OMP-FLT
 *   COM      2,355,080       724,640    2.49     0.1           3.43 COM-FLT
 -   MPI        236,827        33,856    9.56     0.2         282.29 MPI-FLT
 *   USR             52             9    2.63     0.1      292158.12 USR-FLT

 +   USR  6,883,222,086 2,110,313,472  651.44    13.2           0.31 matvec_sub_
 +   USR  6,883,222,086 2,110,313,472  720.38    14.6           0.34 matmul_sub_
 +   USR  6,883,222,086 2,110,313,472  881.32    17.8           0.42 binvcrhs_
 +   USR    293,617,584    87,475,200   29.93     0.6           0.34 binvrhs_
 +   USR    293,617,584    87,475,200   33.03     0.7           0.38 lhsinit_
 +   USR    101,320,128    31,129,600    7.78     0.2           0.25 exact_solution_
```

- Score report breakdown by region

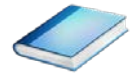
Filtered routines marked with '+'

BT-MZ Filtered Summary Measurement

```
% vim scorep.sh
export NPB_MZ_BLOAD=0
export OMP_NUM_THREADS=4
CLASS=B
NPROCS=8
EXE=./bt-mz_$CLASS.$NPROCS

export SCOREP_EXPERIMENT_DIRECTORY=scorep_8x4_sum_filter
export SCOREP_FILTERING_FILE=../config/scorep.filt
#export SCOREP_METRIC_PAPI=PAPI_TOT_INS,PAPI_TOT_CYC
#export SCOREP_TOTAL_MEMORY=300M

# launch
mpiexec -np $NPROCS $EXE

% pjsub ./scorep.sh
```

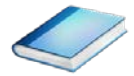
- Set new experiment directory and re-run measurement with new filter configuration
- Submit new job

Score-P:
Advanced Measurement Configuration



Score-P

Advanced Measurement Configuration: Metrics



- 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

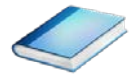
Advanced Measurement Configuration: Metrics

```
% man getrusage
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 */
};
```

- Available resource usage metrics
- Note:

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

Advanced Measurement Configuration: CUDA

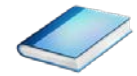


- Record CUDA events with the CUPTI interface

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

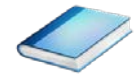
- All possible recording types
  - runtime CUDA runtime API
  - driver CUDA driver API
  - gpu GPU activities
  - kernel CUDA kernels
  - idle GPU compute idle time
  - memcpy CUDA memory copies

Score-P User Instrumentation API



- Can be used to mark initialization, solver & other phases
  - Annotation macros ignored by default
  - Enabled with [--user] flag of instrumenter
  - Defines SCOREP_USER_ENABLE
- 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++

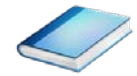
Score-P User Instrumentation API (Fortran)



```
#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
```

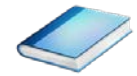
- Requires processing by the C preprocessor

Score-P User Instrumentation API (C/C++)



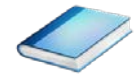
```
#include "scorep/SCOREP_User.h"

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 Cpreprocessor)

```
#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++

Further Information

- 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}/`
- Support and feedback: support@score-p.org
- Subscribe to news@score-p.org, to be up to date