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

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

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

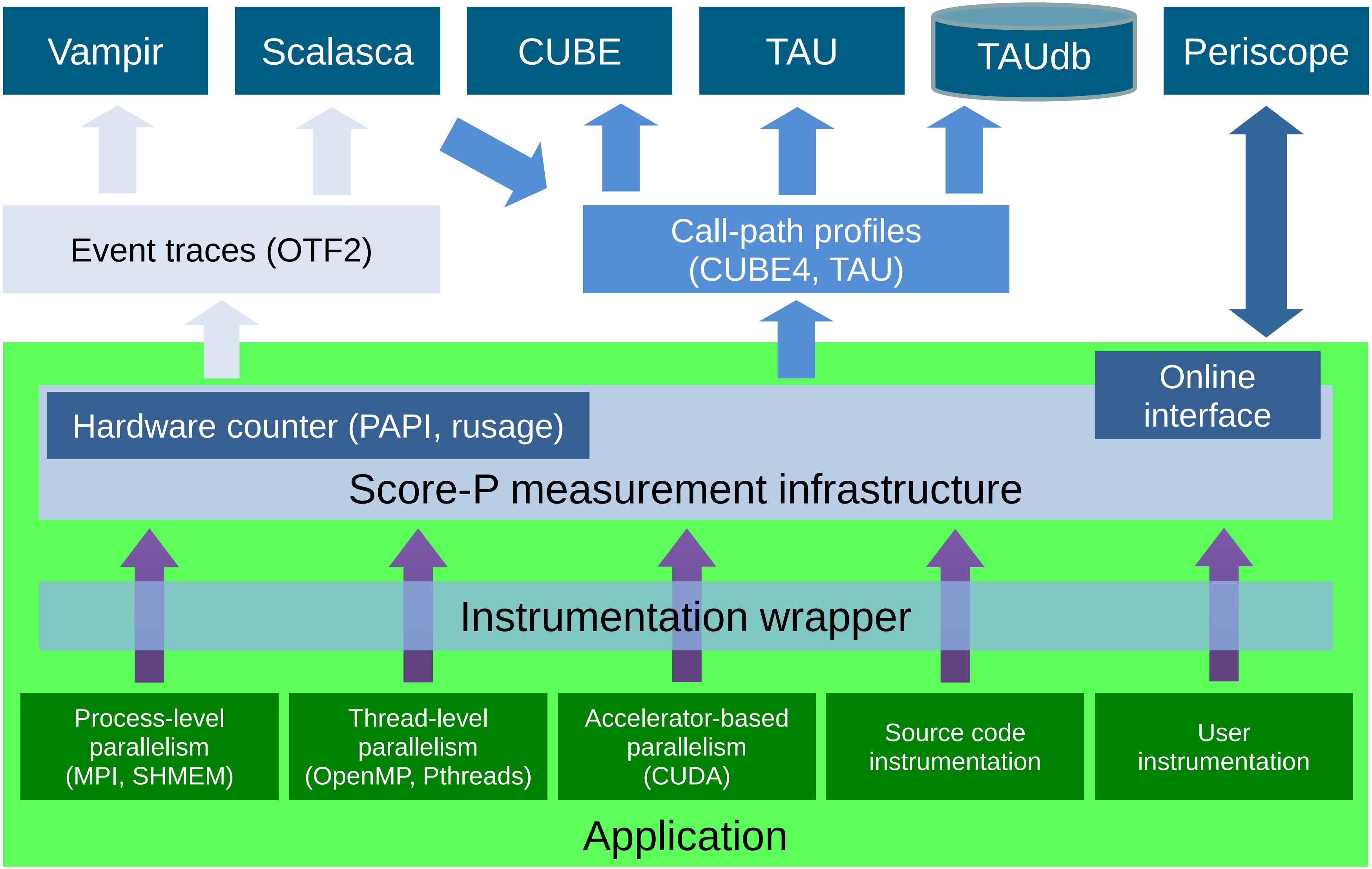
GEFÖRDERT VOM

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 Architecture



Score-P Functionality

- Provide typical functionality for HPC performance tools
- Instrumentation (various methods)
  - Multi-process paradigms (MPI, SHMEM)
  - Thread-parallel paradigms (OpenMP, POSIX threads)
  - Accelerator-based paradigms (CUDA)
  - And their combination
- Flexible measurement without re-compilation:
  - Basic and advanced profile generation
  - Event trace recording
  - Online access to profiling data
- Highly scalable I/O functionality

- Support all fundamental concepts of partner's tools

Non-functional Requirements

- Portability: support all major HPC platforms (e.g., Linux, IBM Blue Gene and AIX, SGI, Cray, Fujitsu K/FX10, ARM)
- Scalability: petascale, supporting platforms with more than 100K cores
- Low measurement overhead: typically less than 5%
- Robustness and QA: Nightly Builds, Continuous Integration Testing Framework
- Easy and uniform installation through UNITE framework
- Open Source: New BSD License

Future Features and Management

- Scalability to maximum available CPU core count
- Support for sampling, binary instrumentation
- Support for new programming models
- 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

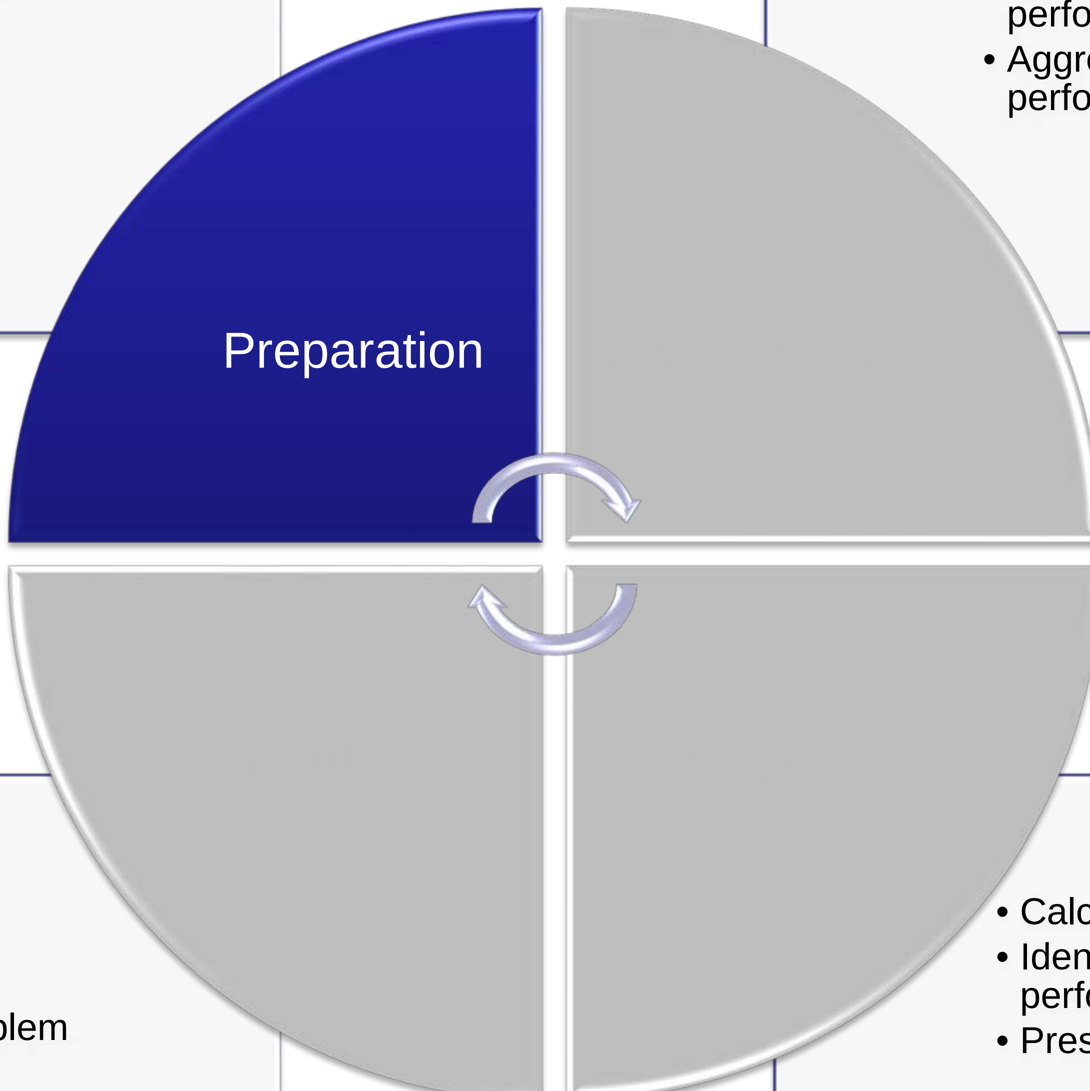
- Commitment to joint long-term cooperation

Score-P application measurement hands-on: NPB-OMP / BT

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

Performance Analysis Steps

1. Reference preparation for validation
2. **Program instrumentation**
3. Summary measurement collection
4. Summary analysis report examination
5. Summary experiment scoring
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NPB-OMP / Setup Environment

- Load modules (Intel compilers)

```
% module load intel-compilers/14.0.0

% module load score-p/1.3/intel11.1_intelMPI4.0.0
```

- or use modules for GCC compiler

```
% module load gcc/4.9.2

% module load score-p/1.3/gcc4.8.2_intelMPI4.0.0
```

- Edit config/make.def to adjust build configuration
  - Modify specification of compiler/linker: F77

```
#               SITE- AND/OR PLATFORM-SPECIFIC DEFINITIONS
#---------------------------------------------------------------------
# Items in this file may need to be changed for each platform.
#---------------------------------------------------------------------
OPENMP = -openmp
#---------------------------------------------------------------------
# The Fortran compiler used for OpenMP programs
#---------------------------------------------------------------------
#F77 = ifort

# Alternative variants to perform instrumentation
...
F77 = scorep  ifort

# This links OMP Fortran programs; usually the same as ${F77}
FLINK   = $(F77)
...
```

Uncomment the Score-P compiler wrapper specification

NPB-OMP / BT Instrumented Build

- Return to root directory and clean-up

```
% make clean
```

- Re-build executable using Score-P compiler wrapper

```
% make bt CLASS=B
cd BT; make CLASS=B VERSION=
make: Entering directory 'BT'
cd ../sys; cc  -o setparams setparams.c -lm
../sys/setparams bt B
scorep ifort -O –g -openmp bt.f
 [...]
cd ../common; scorep ifort –O -g -openmp timers.f
scorep ifort –O -g -openmp -o ../bin.scorep/bt_B \
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_B
make: Leaving directory 'BT'
```

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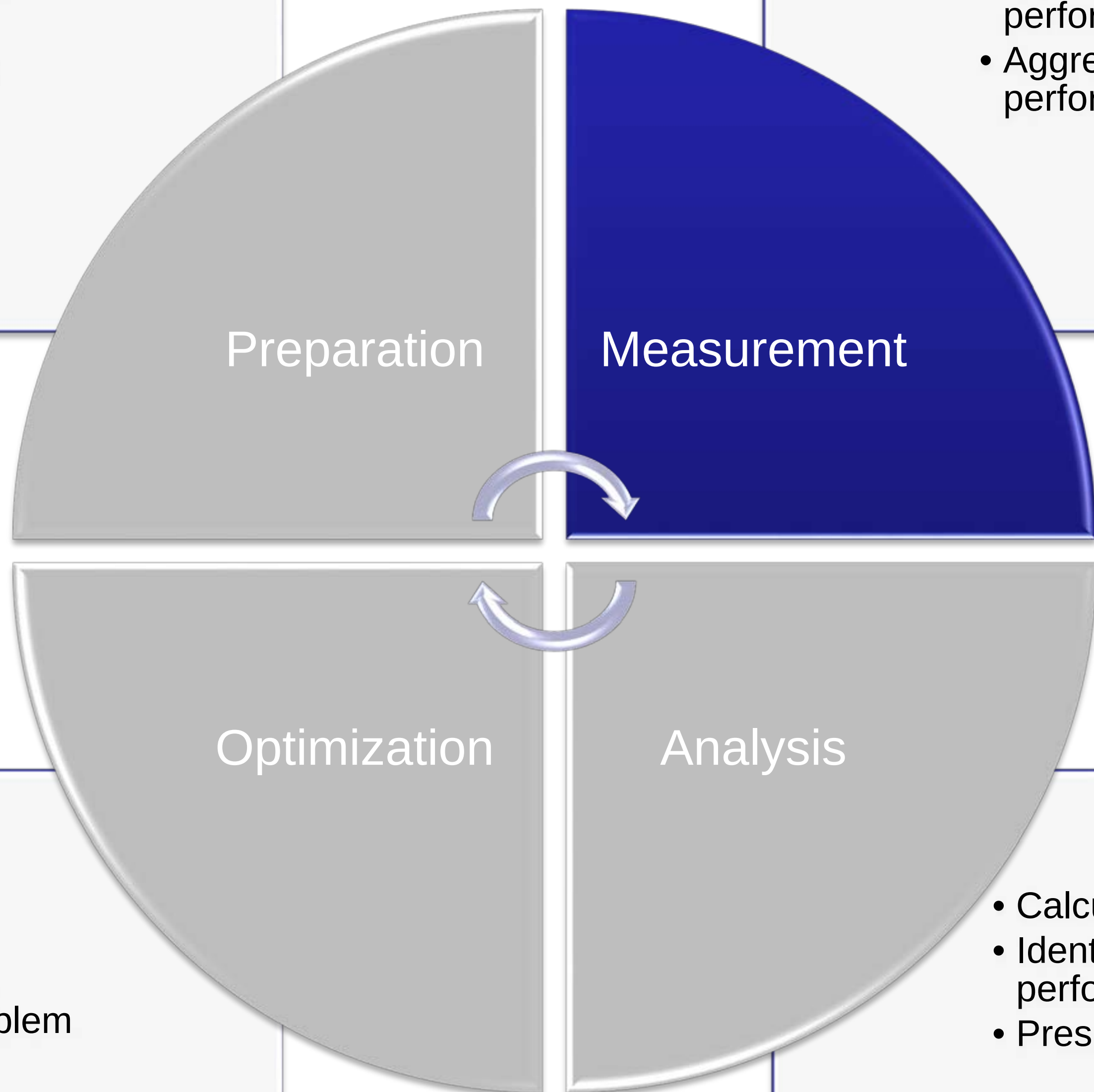
- Insert extra code (probes/hooks)

- Collection of performance data
- Aggregation of performance data



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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 ...]
```

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

```
% cd bin.scorep
% cp ../jobscript/intel/run.pbs .
% vim run.pbs
```

```
...
#
# Score-P configuration
#
module load score-p

export SCOREP_EXPERIMENT_DIRECTORY=scorep_sum
...
```

- Launch instrumented application

```
% qsub run.pbs
% qstat –u $USER
% cat run.o<id>

 NAS Parallel Benchmarks (NPB3.3-OMP) - BT Benchmark

 Size:   102x 102x 102
 Iterations: 200    dt:   0.000300
 Number of available threads:     12

 Time step    1
 Time step   20

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

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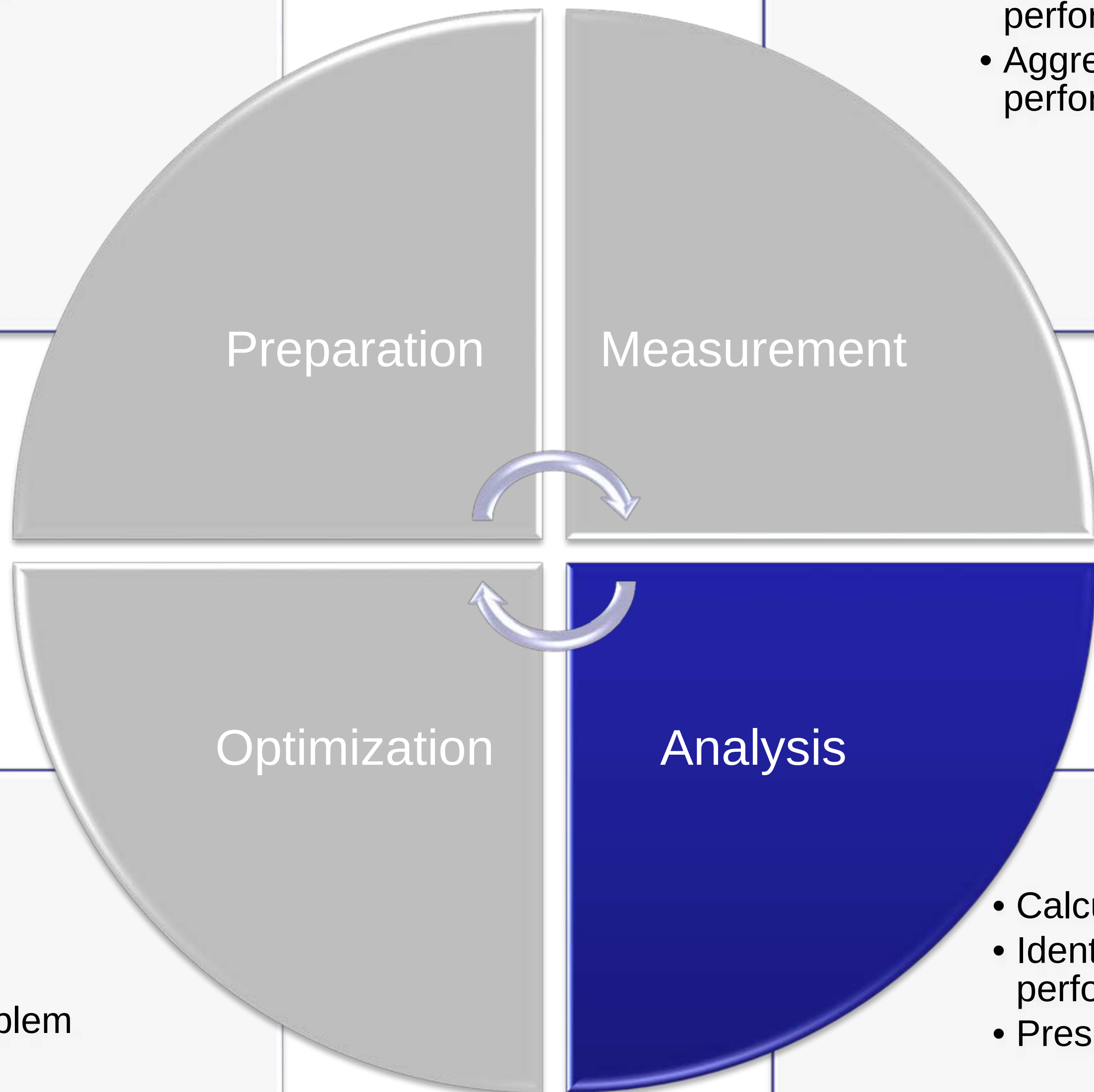

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BT Summary Analysis Report Examination

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

```
% ls
bt_B  scorep_sum
% ls scorep_sum
profile.cubex  scorep.cfg
```

- Interactive exploration with CUBE

```
% cube scorep_sum/profile.cubex

              [CUBE 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 an 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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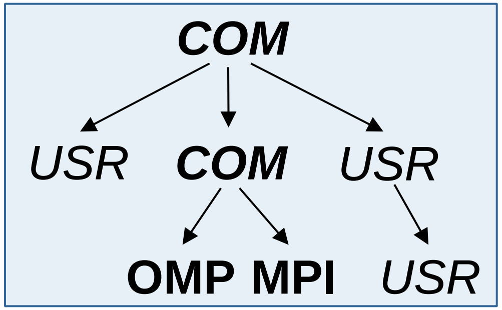
- Report scoring as textual output

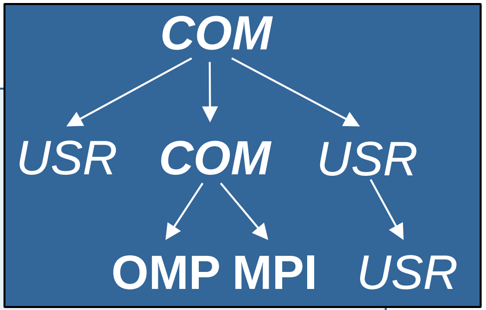
```
% scorep-score scorep_sum/profile.cubex
Estimated aggregate size of event trace:                   35967144402 bytes
Estimated requirements for largest trace buffer (max_tbc): 4545841910 bytes
(hint: When tracing set SCOREP_TOTAL_MEMORY > max_tbc to avoid intermediate flushes
 or reduce requirements using file listing names of USR regions to be filtered.)

flt type         max_tbc         time       % region
     ALL      9046029930       799.89   100.0 ALL
     USR      9025830154       383.72    48.0 USR
     OMP        19113728       411.49    51.4 OMP
     COM          997150         0.75     0.1 COM
     MPI           88898         3.92     0.5 MPI
```

33.5 GB total memory
4.5 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)



- Score report breakdown by region




```
% scorep-score -r scorep_sum/profile.cubex
  [...]
flt type          max_tbc         time      % region
         ALL   4545841910       799.89  100.0 ALL
         USR   4534316886       383.72   48.0 USR
         OMP     10751472       411.49   51.4 OMP
                   567270         0.75    0.1 COM
                   206282         3.92    0.5 MPI

               1452428010       152.50   19.1 binvcrhs_
               1452428010        98.73   12.3 matvec_sub_
         USR   1452428010       117.78   14.7 matmul_sub_
         USR     64472760         5.01    0.6 binvrhs_
         USR     64472760         6.62    0.8 lhsinit_
         USR     48082848         3.07    0.4 exact_solution_
         OMP      1183488         0.04    0.0 !$omp parallel @exch_...
         OMP      1183488         0.04    0.0 !$omp parallel @exch_...
         OMP      1183488         0.04    0.0 !$omp parallel @exch_...
 [...]
```

More than
4 GB just for
these 6 regions

BT-MZ Summary Analysis Score

- Summary measurement analysis score reveals
  - Total size of event trace would be ~34 GB
  - Maximum trace buffer size would be ~4.5 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

- 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_sum/profile.cubex
Estimated aggregate size of event trace:                   82119842 bytes
Estimated requirements for largest trace buffer (max_tbc): 11528962 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.)
```

77 MB of memory in total,
10 MB per rank!

BT-MZ Summary Analysis Report Filtering

- Score report breakdown by region

```
% scorep-score -r -f ../config/scorep.filt  scorep_sum/profile.cubex
flt type          max_tbc         time      % region
 *   ALL         20203582       416.17   52.0 ALL-FLT
 +   FLT       9025826370       383.72   48.0 FLT
 -   OMP         19113728       411.49   51.4 OMP-FLT
 *   COM           997150         0.75    0.1 COM-FLT
 -   MPI            88898         3.92    0.5 MPI-FLT
 *   USR             3806         0.00    0.0 USR-FLT

 +   USR       2894950740       152.50   19.1 binvcrhs_
 +   USR       2894950740        98.73   12.3 matvec_sub_
 +   USR       2894950740       117.78   14.7 matmul_sub_
 +   USR        127716204         5.01    0.6 binvrhs_
 +   USR        127716204         6.62    0.8 lhsinit_
 +   USR         94933520         3.07    0.4 exact_solution_
 -   OMP          1183488         0.04    0.0 !$omp parallel @exch_...
 -   OMP          1183488         0.04    0.0 !$omp parallel @exch_...
 -   OMP          1183488         0.04    0.0 !$omp parallel @exch_...
  [...]
```

Filtered routines marked with ‘+’

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BT-MZ Filtered Summary Measurement

- Set new experiment directory and re-run measurement with new filter configuration
  – Edit job script

```
% vim run.pbs
```

  – Adjust configuration

```
...
% export SCOREP_EXPERIMENT_DIRECTORY=scorep_sum_with_filter
% export SCOREP_FILTERING_FILE=../config/scorep.filt
...
```

  – Submit job

```
% qsub run.pbs
```

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BT-MZ Tuned Summary Analysis Report Score

- Scoring of new analysis report as textual output

```
% scorep-score scorep_sum_with_filter/profile.cubex
Estimated aggregate size of event trace:                   82119842 bytes
Estimated requirements for largest trace buffer (max_tbc): 11528962 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        20203582        218.95  100.0 ALL
     OMP        19113728        216.94   99.1 OMP
     COM          997150          0.73    0.3 COM
     MPI           88898          1.27    0.6 MPI
     USR            3806          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_L2_TCM,PAPI_FP_OPS
```

- Also possible to record them only per rank

```
% export SCOREP_METRIC_PAPI_PER_PROCESS=PAPI_L3_TCM
```

- Recording operating system resource usage

```
% export SCOREP_METRIC_RUSAGE_PER_PROCESS=ru_maxrss,ru_stime
```

- 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)

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BT Trace Measurement Collection...

- Re-run the application using the tracing mode of Score-P
  - Edit run.pbs to adjust configuration

```
% export SCOREP_EXPERIMENT_DIRECTORY=scorep_trace
% export SCOREP_FILTERING_FILE=../config/scorep.filt
% export SCOREP_ENABLE_TRACING=true
% export SCOREP_ENABLE_PROFILING=false
% export SCOREP_TOTAL_MEMORY=50M
% export SCOREP_METRIC_PAPI=PAPI_L2_TCM,PAPI_FP_OPS
```

  - Submit job

```
% qsub run.pbs
```

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

```
% vampir scorep_trace/traces.otf2
```

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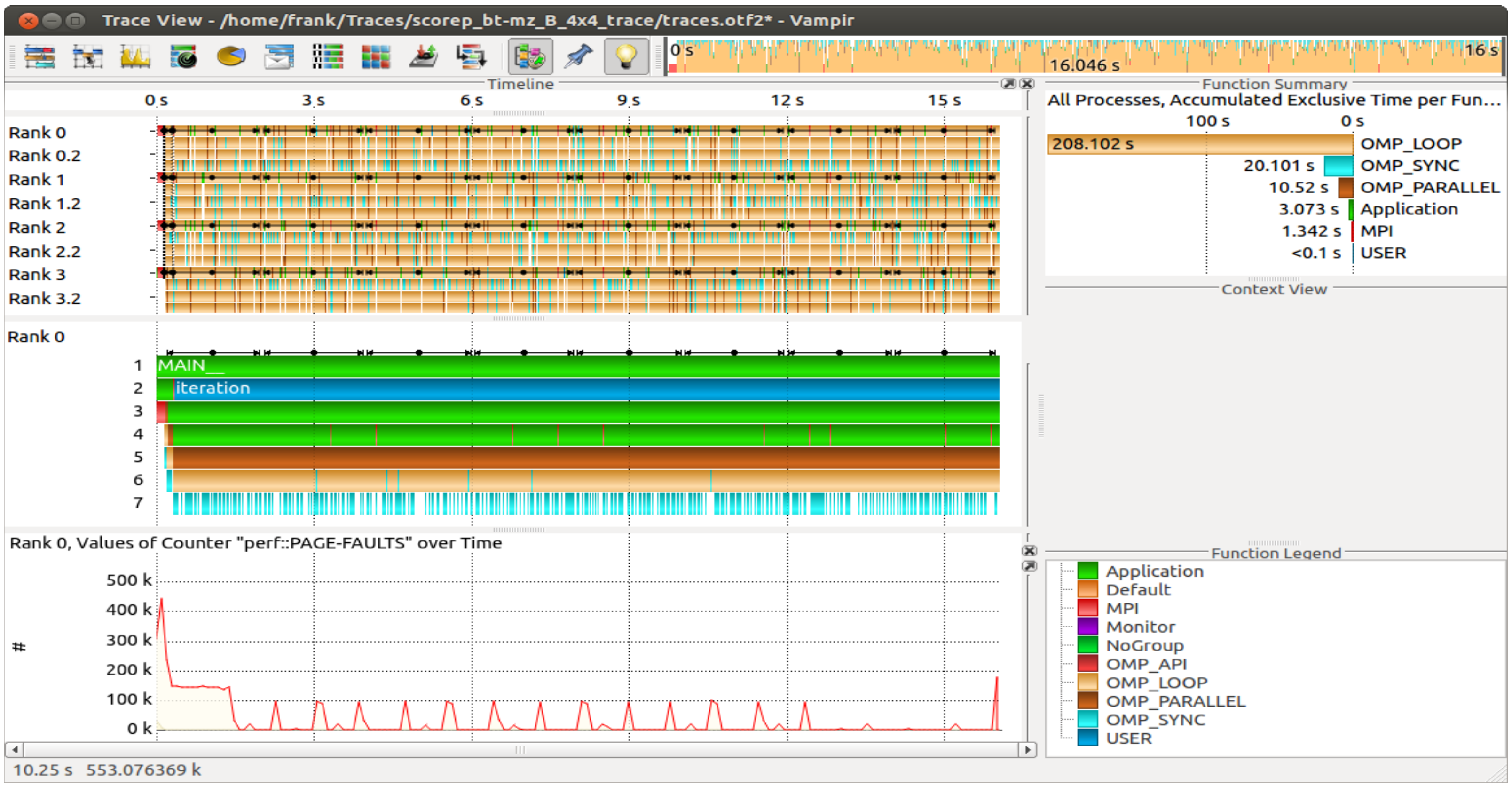
- Interactive trace exploration with Vampir

```
% vampir scorep_bt-mz_B_8x4_trace/traces.otf2
```



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

- Disable OPARI instrumentation of fine-grained OpenMP constructs

```
% PREP="scorep --opari='--disable=flush,locks'"
```

- Comma-separated list of constructs
  - atomic
  - critical
  - master
  - flush
  - single
  - ordered
  - locks
  - sync (all of the above)
  - region (explicit POMP annotations)

Advanced Measurement Configuration: MPI

- Record only for subset of the MPI functions events

```
% export SCOREP_MPI_ENABLE_GROUPS=cg,coll,p2p,xnonblock
```

- 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

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: support@score-p.org