MHPC Master in High Performance Computing

DSSC Data Science & Scientific Computing

Foundations of High Performance Computing

Parallel Programming

Parallel debugging and Profiling

Outline

1. **Debugging**, a quick recap
2. Using **gdb in parallel**
3. Open tools to profile, debug and understand your parallel code

Debugging basics

Debugging is the process of finding and fixing flaws in software

Debugging basics : tools

1. Don't insert bugs

   Highly encouraged, but never works

2. Add print statements everywhere

   Highly discouraged, but sometimes it works

3. Command line based debuggers
   1. **gdb**: the gnu debugger
   2. **idb**: the intel debugger

4. Debuggers with GUI
   1. **ddd**: Gnu data display debugger
   2. **IDEs**: eclipse, NetBeans, emacs+gdb, …
   3. **DDT**: ARM/Allinea tool
   4. **TotalView**, …others…

gdb, your friend

You already know about gdb and its basic use.

RECAP: a **debugger** is a program that enables you to take the control of the execution of another program.

gdb is the GNU debugger.

gdb, your friend

- Crash inspections, through core files
- Function call stack
- Stepping through execution flow
- Automatic stopping at specific locations or conditions
- Watching for variables

- Use of GUI may be preferred when working locally
- On remote machines, it might be slower or graphics may not be available

Outline

1. Debugging, a quick recap
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Parallel debugging

The problem is much more complex.
The fundamental additional challenge is the simultaneous execution.

Shared memory paradigm: OpenMP, pthreads
- Multiple threads
- Shared vs private memory regions
- Race conditions

Message-passing paradigm: MPI
- Multiple independent processes (+ possible multithread)
- Communication
- Deadlocks

→ Commercial debuggers
→ Free debuggers, to some extent

gdb, multi-thread capability

```
void *ShowUp(void *thread_id)
{
  printf("Thread #%zd says: \" Hello World! \"\n", (size_t)thread_id);
  pthread_exit(NULL);
}

int main (int argc, char *argv[])
{
   pthread_t threads[NTHREADS];
   int  rc;
   size_t t;

   for(t = 0; t < NTHREADS; t++)
     {

       printf("Creating thread %zd\n", t);
       rc = pthread_create( &threads[t], NULL, ShowUp, (void *)t);

       if (rc)
           {
             printf("return code from pthread_create() is %d\n", rc);
             exit(-1);
           }
   }
   pthread_exit(NULL);
}
```

gdb, multi-thread capability

Let's have a try:

```
:~$ gcc -g -o my_threadprog  my_threadprog.c -lpthread

:~$ gdb ./my_threadprog
```

gdb, multi-thread capability

```
:~$ gdb ./my_threadprog
Reading symbols from my_threadprog...done.

(gdb) r

(gdb) Starting program: my_threadprog

[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
Creating thread 0
[New Thread 0x7ffff77ef700 (LWP 24144)]
Thread #0 says: " Hello World! "
Creating thread 1
[New Thread 0x7ffff6fee700 (LWP 24145)]
Thread #1 says: " Hello World! "
Creating thread 2
[New Thread 0x7fffeffff700 (LWP 24146)]
Thread #2 says: " Hello World! "
Creating thread 3
[New Thread 0x7ffff65d6700 (LWP 24147)]
Thread #3 says: " Hello World! "
[Thread 0x7fffeffff700 (LWP 24146) exited]
[Thread 0x7ffff6fee700 (LWP 24145) exited]
[Thread 0x7ffff77ef700 (LWP 24144) exited]
[Thread 0x7ffff7fac700 (LWP 24140) exited]
[Inferior 1 (process 24140) exited normally]
(gdb) Quit
(gdb)
```

gdb, multi-thread capability

It is necessary to explicitly set up gdb for multi-thread debugging

```
(gdb) set pagination off
(gdb) target-async on
(gdb) non-stop on
```

In **`all-stop`** mode, whenever the execution stops, *all* the threads stop (wherever they are).
Whenever you restart the execution, *all* the threads re-start: however, gdb can not single-step all the threads in the steplock. Some threads may execute several instructions even if you single-stepped the thread under focus with *step* or *next* commands.

`non-stop` mode means that when you stop a thread, all the other ones continue running until they finish or they reach some breakpoint that you pre-defined

→ **live demo**

PARALLEL DEBUGGING

A good approach:

- Write a (possibly good) code natively parallel but able to run in serial, which means with 1 MPI task
- Profile, debug and optimize that code first
- If multi-threaded, deal with thread sync / races with 1 MPI task
- Deal with communications, synchronization and race/deadlock conditions on a *small* number of MPI tasks
- Profile, debug and optimize communications on a *small* number of MPI tasks
- Try a full-size run

gdb, with MPI / 1

It is still possible to use gdb directly, called from mpirun:

```
:~$ mpirun -np <NP> -e gdb ./program
```

Because gdb has multi-thread capability.
However, depending on your system that may not properly work with MPI.

gdb, with MPI / 2

The simplest way to use gdb with a parallel program is :

```
:~$ mpirun -np <NP> xterm –hold -e gdb ./program
```

Which launches <NP> xterm windows with running gdb processes in which you can run

```
(gdb) run <arg_1> <arg_2> … <arg_n>
```

..**most likely *this* will not work**, because HPC environments are hostile to *X* for several reasons.

gdb, with MPI / *3*

Another handy possibility is to open as many connections as processes on different terminals on your local machine, and *attach* gdb to the already running MPI processes

```
:~$ mpirun -np <NP> ./program
```

Followed by:

```
:~$ gdb -p <PID_of_MPI_task_n>
```

For each MPI task you want to follow.

gdb, with MPI / *3*

You still have **2 issues**:

1. ***Where*** to run gdb, if `xterm` is not available and you do not want to use it in multi-thread mode ?

   You may consider using `screen` (practical example in few minutes)

2. ***How*** the MPI tasks should be convinced to wait for gdb to step in ?

   → *Next slides*

gdb, in parallel / 4

NOTE

A possible issue for **attacching** gdb to a running process is that you **may not have the capability to do that** on a Linux system.

Look in the `/proc/sys/kernel/yama/ptrace_scope` file...

gdb, in parallel / 4

NOTE

A pos… …hat
you **m**… …em.

Look i… …

```
0 ("classic ptrace permissions")
       No additional restrictions on operations that perform
       PTRACE_MODE_ATTACH checks (beyond those imposed by the
       commoncap and other LSMs).

       The use of PTRACE_TRACEME is unchanged.

1 ("restricted ptrace") [default value]
       When performing an operation that requires a
       PTRACE_MODE_ATTACH check, the calling process must either have
       the CAP_SYS_PTRACE capability in the user namespace of the
       target process or it must have a predefined relationship with
       the target process.  By default, the predefined relationship
       is that the target process must be a descendant of the caller.

       A target process can employ the prctl(2) PR_SET_PTRACER
       operation to declare an additional PID that is allowed to
       perform PTRACE_MODE_ATTACH operations on the target.  See the
       kernel source file Documentation/admin-guide/LSM/Yama.rst (or
       Documentation/security/Yama.txt before Linux 4.13) for further
       details.

       The use of PTRACE_TRACEME is unchanged.

2 ("admin-only attach")
       Only processes with the CAP_SYS_PTRACE capability in the user
       namespace of the target process may perform PTRACE_MODE_ATTACH
       operations or trace children that employ PTRACE_TRACEME.

3 ("no attach")
       No process may perform PTRACE_MODE_ATTACH operations or trace
       children that employ PTRACE_TRACEME.
```

gdb, in parallel / 4

NOTE

Solutions:

1. Get the capability
2. As root type:
   `echo 0 > /proc/sys/kernel/yama/ptrace_scope`
3. Set the `kernel.yama.ptrace_scope` variable in the file `/etc/sysctl.d/10-ptrace.conf` to 0

The last solution turns off the security measure permanently, it is not a good idea (at least on a facility)

gdb, in parallel / 5

We are left with the problem of *attaching* the gdb to a running process (or several running processes).

How can we do that ?

There is a classical trick, that requires to insert some small additional code in your program

```
int wait = 1

while(wait)
   sleep(1);
```

The MPI processes will wait indefinitely until you do not change the value of wait *from inside dbg attached to each process.*

gdb, in parallel / 6

Let’s say that you MPI program start with:

```
int main(int argc, char **argv)
{
 int Me, Size;

 MPI_Init(&argc, &argv);

 MPI_Comm_rank(MPI_COMM_WORLD,
&Me);
 MPI_Comm_size(MPI_COMM_WORLD,
&Size);

  …
```

and that you insert the following code snippets right after it →

Attaching gdb...

```
#ifdef DEBUGGER
 int   Wait = 1;
 pid_t my_pid;
 char  my_host_name[200];

 gethostname(my_host_name, 200);
 my_pid = getpid();

 for(int i = 0; i < Size; i++)
  {
   if(i == Me)
     printf("task with PID %d on host %s is waiting\n", my_pid, my_host_name);
    MPI_Barrier(MPI_COMM_WORLD);
  }

 while(Wait)
  sleep(1);

 MPI_Barrier(MPI_COMM_WORLD);
#endif
```

Attaching gdb…

Some more flexibility

```
char *env_ptr;
 if( ( (env_ptr = getenv("DEBUG_THIS")) != NULL) &&
    (strncasecmp(env_ptr, "YES", 3) == 0) )
  {
    int   Wait = 1;
    pid_t my_pid;
    char  my_host_name[200];

    gethostname(my_host_name, 200);
    my_pid = getpid();

    < ... >
    while(Wait)
       sleep(3);

    MPI_Barrier(MPI_COMM_WORLD);
  }
```

Attaching gdb…

Even more flexibility

```
char *env_ptr;
 if( ( (env_ptr = getenv("DEBUG_THIS")) != NULL) &&
    (strncasecmp(env_ptr, "YES", 3) == 0) )
  {
    int   Wait = 1;
    pid_t my_pid;
    char  my_host_name[200];

    gethostname(my_host_name, 200);
    my_pid = getpid();
    < ... >
    if(me == 0)
      while(Wait)
         sleep(3);

    MPI_Barrier(MPI_COMM_WORLD);
  }
```

All the MPI tasks but the 0^{th} will wait at the barrier.
This way, you can avoid to attach to *all* the tasks and unlock only the 0^{th} .

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The parallel ecosystem

Understanding the details of a large parallel/multi-threaded code is not an easy task.

BUGS

- Bottlenecks
- Inefficiencies
- Deadlocks
- Race conditions
- Errors in memory addressing

All usually have subtle dependencies on the specific run you perform

(those that do not are more easily found and fixed)

OPTMIZATION

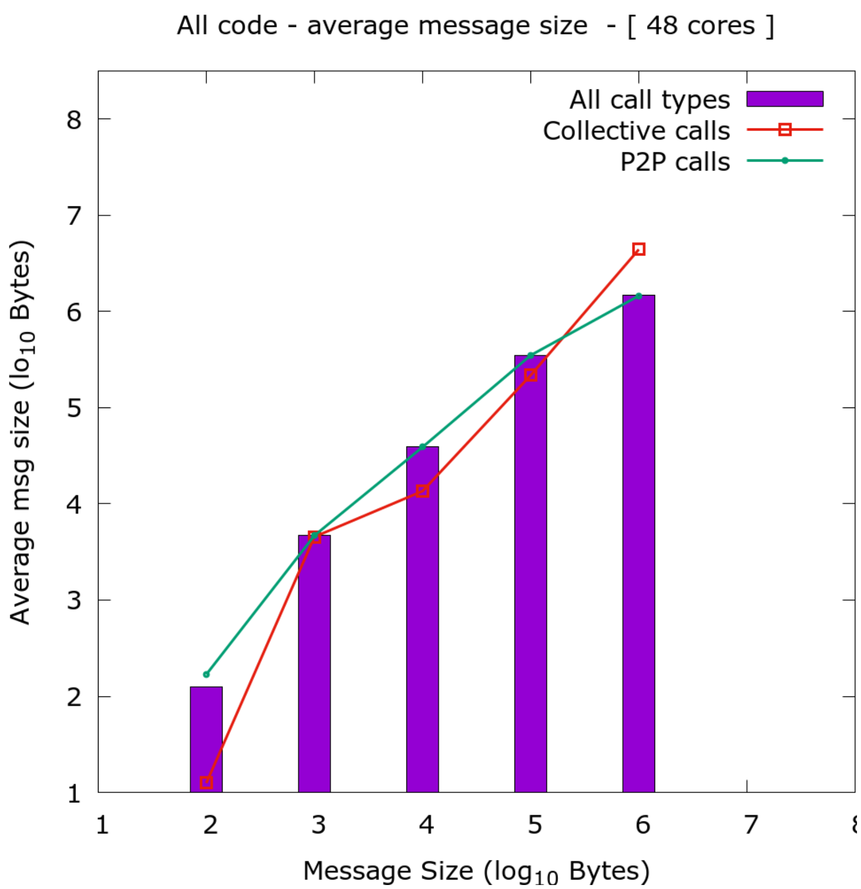
- Cache inefficiencies
- Loop optimizations
- Performance counters

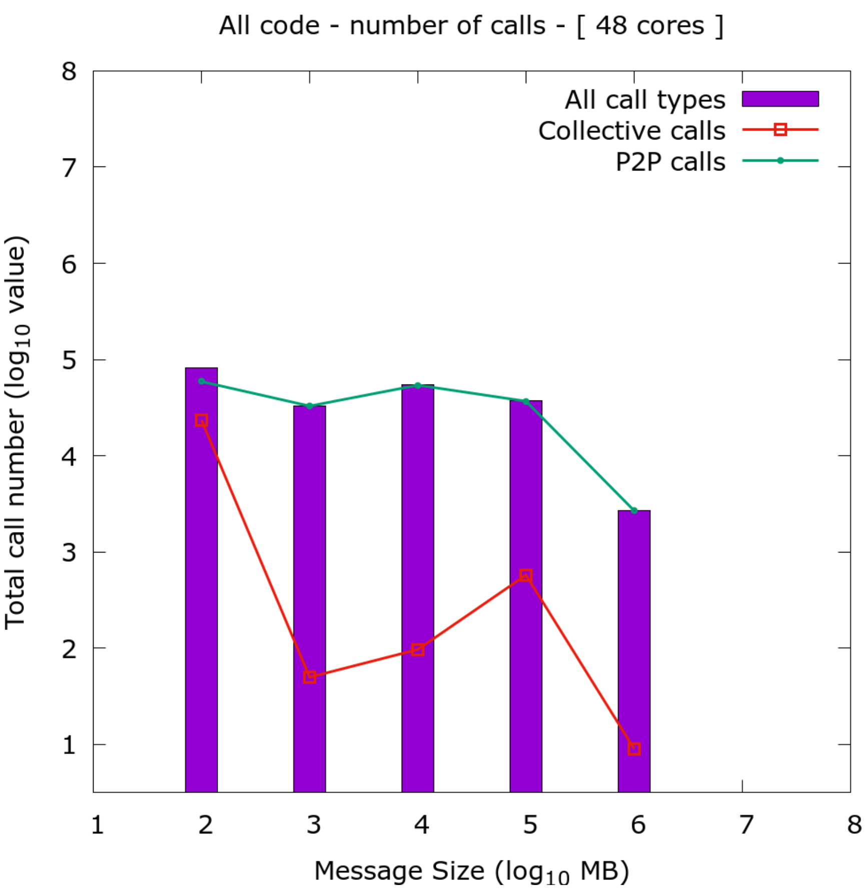
Very tough to trace and profile by hands

(sometimes still unavoidable)

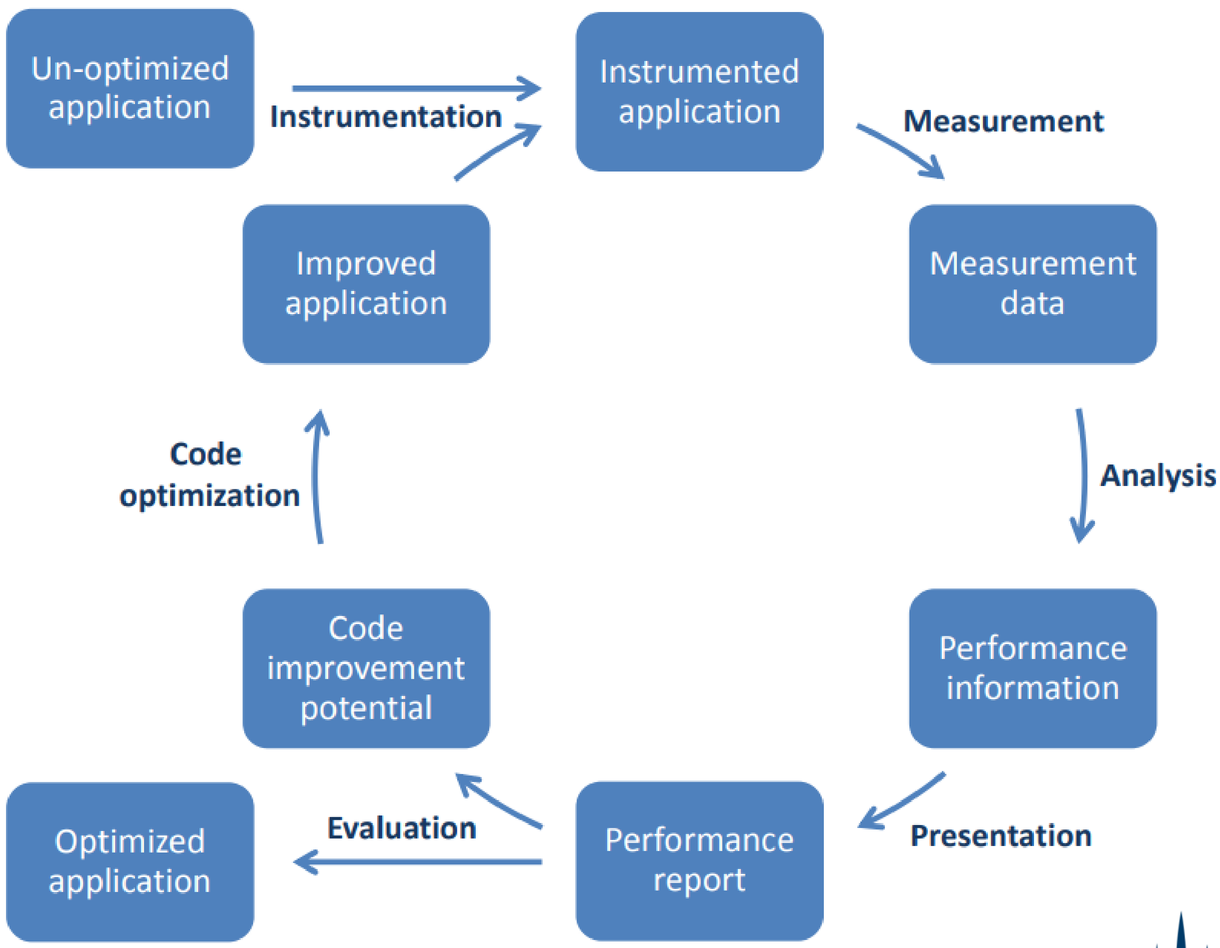
The parallel ecosystem

A small example of a communication profiling





The parallel ecosystem



Scalable performance measurement infrastructure for parallel codes

The parallel ecosystem

INSTRUCTIONATION

- manual
- automatic
- link to pre-instrumented libs

COLLECTION

- profile
- event traces →more sophisticated analysis

ANALYSIS

- post-mortem
- online

The parallel ecosystem

There are several very sophisticated open tools, that are mainly outcomes of project research on high-productivity supercomputing.

Many of them are clustered in “ecosystems”, and several of those ecosystems, or some of their components, can talk each other

MpiP

Score-P

Scalable performance measurement infrastructure for parallel codes

scalasca

Virtual Inst – High productivity supercomp.

HPCToolkit

Rice University

Open|SpeedShop

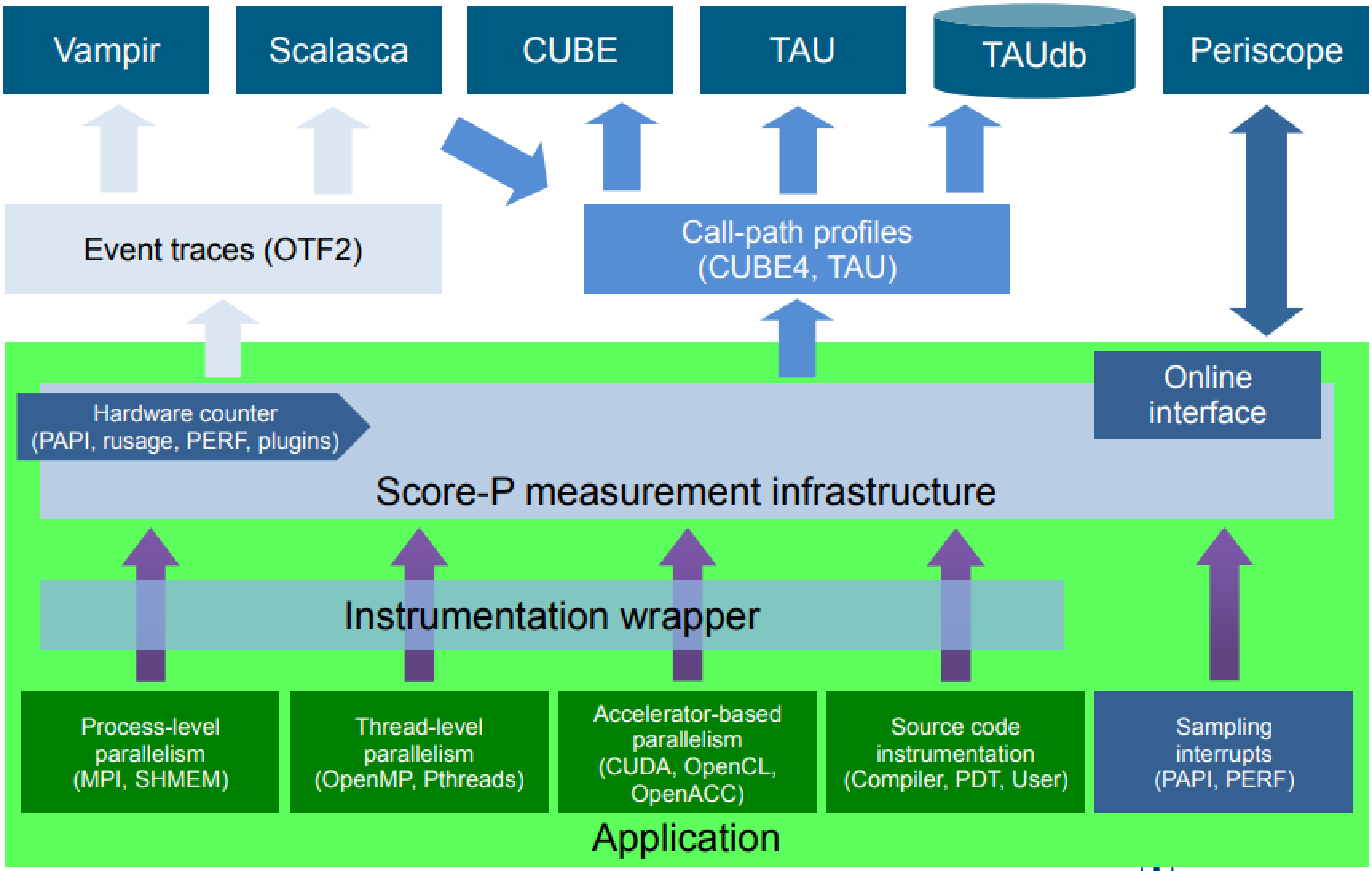
Krell Inst., LANL, LLNL, SNL

PTF

Technische Universität München

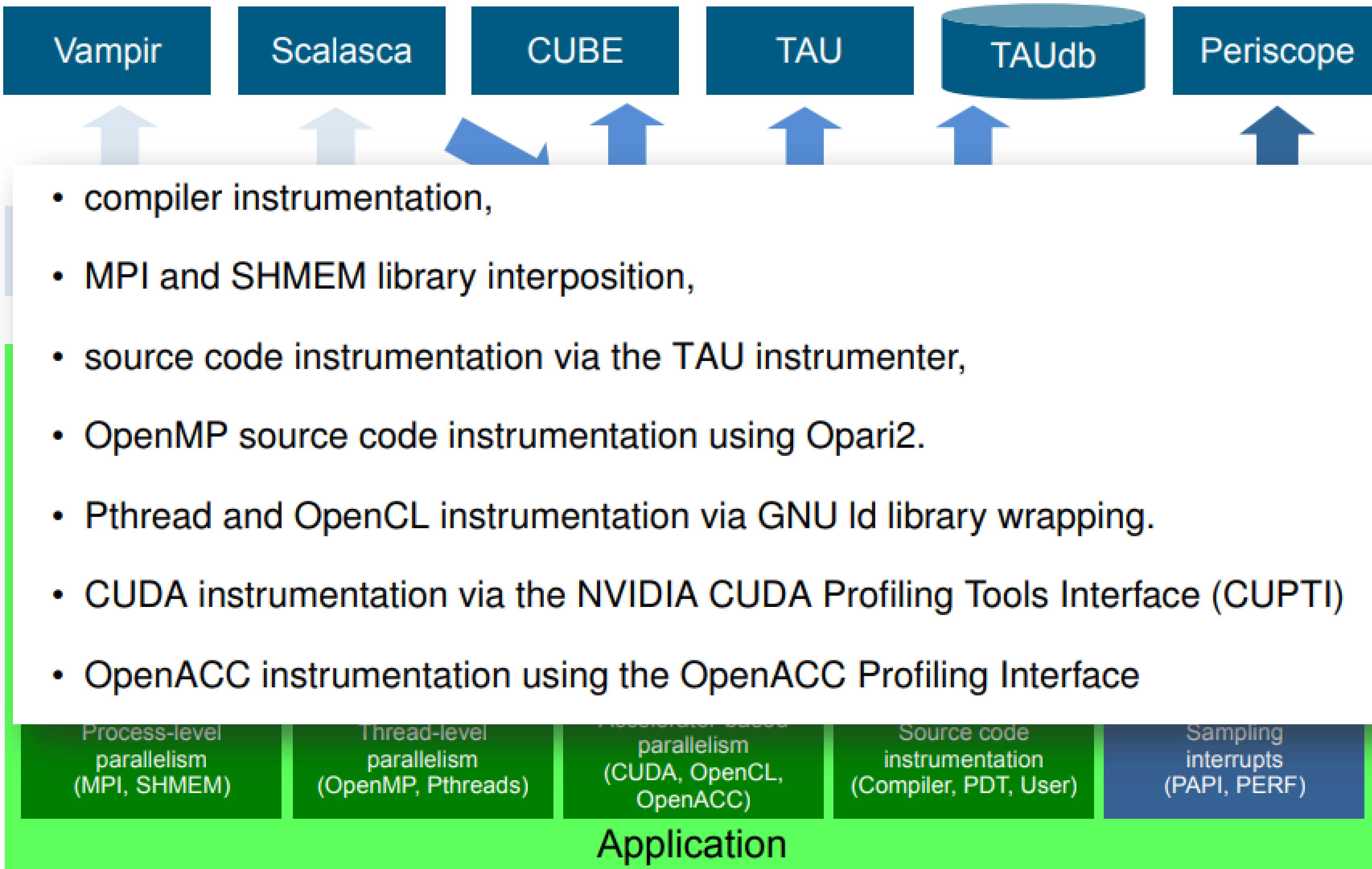
PAPI

The parallel ecosystem



Score-P
Scalable performance measurement infrastructure for parallel codes

The parallel ecosystem



- compiler instrumentation,
- MPI and SHMEM library interposition,
- source code instrumentation via the TAU instrumenter,
- OpenMP source code instrumentation using Opari2.
- Pthread and OpenCL instrumentation via GNU ld library wrapping.
- CUDA instrumentation via the NVIDIA CUDA Profiling Tools Interface (CUPTI)
- OpenACC instrumentation using the OpenACC Profiling Interface

Score-P
Scalable performance measurement infrastructure for parallel codes