How to get most of OMPT (OpenMP Tools Interface)

Hands-on

Clone instructions:
bit.ly/OMPT-Handson

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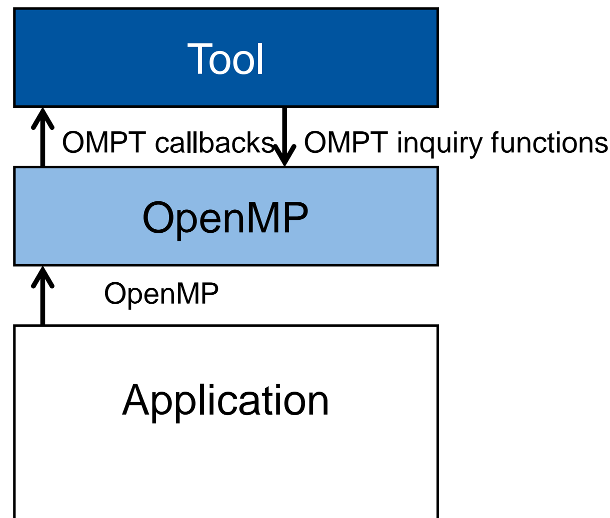
What is OMPT?

Tools interface in the OpenMP spec

- Makes your tool compatible with any standard compliant OpenMP runtime

- Invokes callbacks for defined OpenMP events (e.g. “parallel-begin”)
- Maintains tool data for OpenMP scopes (e.g. “parallel-blob”)
- Provides signal-safe inquiry functions to learn about OpenMP runtime information



Available runtime implementations, roadmap

- IBM lightweight OpenMP runtime:
  - OMPT implementation is available on early-access systems (e.g. LLNL)
  - Successfully used with OMPT-based ARCHER tool
- LLVM/OpenMP runtime:
  - https://github.com/OpenMPToolsInterface/LLVM-openmp
  - towards_tr4 branch is up-to-date with currently voted internal OpenMP spec
    - TR4 + fixes
  - Just recently fixed some performance issues
  - Starting review process after LLVM release is finished

  - Reference OMPT-tool: runtime/test/ompt/callback.h
- From the spec point of view:
  - The internal spec evolved (LLVM runtime is up-to-date with internal spec)
  - Interface almost stable, but we expect some tiny improvements for SC'17 release

Agenda

- Basic OMPT usage
- OMPT-based tracing/profiling tool
- Use multiple OMPT tools at the same time
- OMPT-based sampling tool
- OMPT for accelerators

Using OMPT

All sources available at http://bit.ly/OMPT-Handson:

git clone --recursive https://git.rwth-aachen.de/OpenMPTools/OMPT-Examples.git

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cmake required!

OMPT-Examples $ bash bootstrap.sh

OMPT tool initialization (example1/hello.c)

```
#include <stdio.h>
#include <omp.h>
#include "initialization.h"

int main()
{
  #pragma omp parallel num_threads(2)
  {
    printf("Hello from thread %i of %i!\n", omp_get_thread_num(),
                        omp_get_num_threads());
  }
  return 0;
}
```

This builds the tool statically into the application

Important for static tool, if OpenMP runtime of the compiler has no OMPT support

- $CC –fopenmp –L../INSTALL/lib/ hello.c
- ./a.out

```
libomp init time: 0.001135
Hello from thread 0 of 2!
Hello from thread 1 of 2!
application runtime: 0.001877
```

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Execute example1 with static tool:
example1 $ make run-static

OMPT tool initialization (example1/initialization.h)

```
typedef struct my_ompt_fns_t { ompt_initialize_t i; ompt_finalize_t f;
  double time; double init;} my_ompt_fns_t;

int ompt_initialize (ompt_function_lookup_t lookup, ompt_fns_t* fns)
{
  my_ompt_fns_t* data = (my_ompt_fns_t*) fns;
  data->init = omp_get_wtime();
  printf("libomp init time: %f\n", data->init - data->start);
  return 1; //success: activates tool
}
void ompt_finalize (ompt_fns_t* fn
{
  my_ompt_fns_t* data = (my_ompt_fns_t*) fns;
  printf("application runtime: %f\n", omp_get_wtime() - data->init);
}
ompt_fns_t* ompt_start_tool (unsigned int omp_version, const char
*runtime_version)
{
  static my_ompt_fns_t data = {&ompt_initialize, &ompt_finalize, 0, 0};
  data.start = omp_get_wtime();
  return (ompt_fns_t*) &data; //success: registers tool
}
```

2 3 1

§4.6: Tool callbacks may not use OpenMP directives or call any runtime library routines described in Section 3.

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Bringing the tool into the game

- Link tool statically into the application
- Link tool dynamically into the application
  - Make sure tool is linked before the OpenMP runtime (check ldd)
  - If OpenMP runtime is linked statically, tool must be loaded before OpenMP runtime is initialized
  - For some compilers take care of „as-needed“!
- Ld-preload the shared tool library
- Use OMP_TOOL_LIBRARIES environmental variable to let the runtime load the shared tool library

- If you load multiple tools with the different mechanisms, it is not specified which tool is found.
- If a detected tool returns NULL on ompt_start_tool, the runtime continues to detect another tool.

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Execute example1 with all mechanisms:
example1 $ make run

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OMPT runtime entry points (example2/callback.c)

```
static ompt_get_thread_data_t ompt_get_thread_data;
static ompt_get_unique_id_t ompt_get_unique_id;

//…
int ompt_initialize(
  ompt_function_lookup_t lookup,
  ompt_fns_t* fns)
{
  ompt_set_callback_t ompt_set_callback = (ompt_set_callback_t)
                                lookup("ompt_set_callback");
  ompt_get_thread_data = (ompt_get_thread_data_t)
                                lookup("ompt_get_thread_data");
  ompt_get_unique_id = (ompt_get_unique_id_t) lookup("ompt_get_unique_id");

  //…
}
```

Function for registering callbacks (next slide)

Unique integer identifier across OpenMP threads

Thread-local storage for OpenMP threads

Registering callback functions (example2/callback.c)

```
#define register_callback_t(name, type)
do{
  type f_##name = &on_##name;                                    \
  if (ompt_set_callback(name, (ompt_callback_t)f_##name) ==     \
      ompt_set_never)                                            \
    printf("0: Could not register callback '" #name "'\n");     \
}while(0)

#define register_callback(name) register_callback_t(name, name##_t)

int ompt_initialize(ompt_function_lookup_t lookup, ompt_fns_t* fns)
{
  //…
  register_callback(ompt_callback_implicit_task);
  register_callback(ompt_callback_parallel_begin);
  register_callback(ompt_callback_parallel_end);
  // register_callback_t(ompt_callback_sync_region_wait,
                         ompt_callback_sync_region_t);
  //…
  return 1; //success
}
```

Ensure matching function signature, before casting to void*

Some function signatures are reused for multiple callbacks

Implementing callback functions (example2/callback.c)

```
static void on_ompt_callback_implicit_task( ompt_scope_endpoint_t endpoint,
ompt_data_t *parallel_data, ompt_data_t *task_data, unsigned int team_size,
unsigned int thread_num )
{
  uint64_t tid = ompt_get_thread_data()->value;
  switch(endpoint)
  {
    case ompt_scope_begin:
      counter[tid].cc.implicit_task_scope_begin += 1;
      task_data->value = ompt_get_unique_id();
      break;
    case ompt_scope_end:
      counter[tid].cc.implicit_task_scope_end += 1;
      break;
  }
}
```

Some callbacks are used for begin- and end-event

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Execute example2:
example2 $ make run

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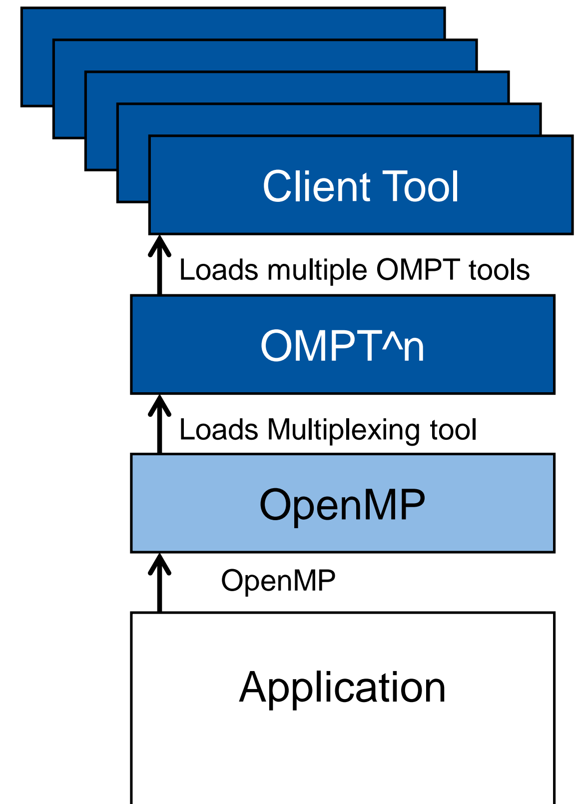
OMPT Multiplex

All sources available at (and already included in the Hands-on):

git clone https://git.rwth-aachen.de/OpenMPTools/OMPT-Multiplex.git

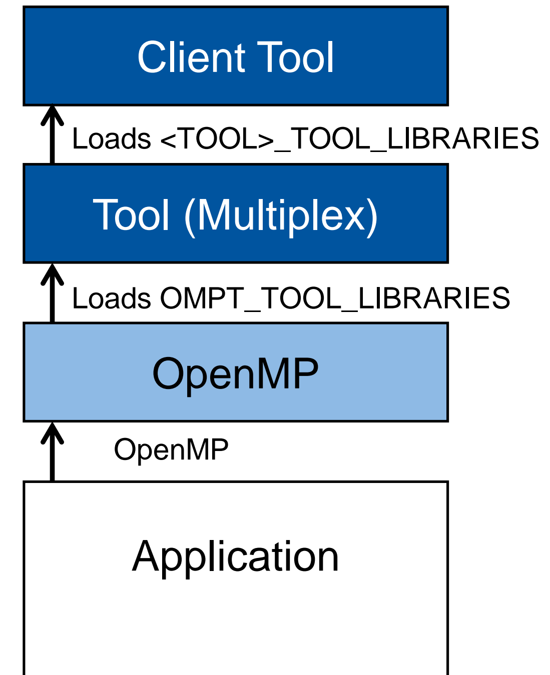
Sometimes a single tool is not enough

- Similar as in P^nMPI, the initial idea was to create an OMPT tool, that can load multiple client tools
- Configuration file to specify the details about client tools
- Data-blob is a vector of data-blobs
- OMPT^n coordinates the access to tool specific data-blobs
- Needs to provide specialized inquiry functions for all clients



Cascading OMPT tools

- OMPT-Multiplex
  - A tool can load another tool like the OpenMP runtime would do
  - Implemented as header-only
  - Looks for <Tool-name>_TOOL_LIBRARIES, to load another tool and execute ompt_start_tool
  - Unlimited cascading of tools possible

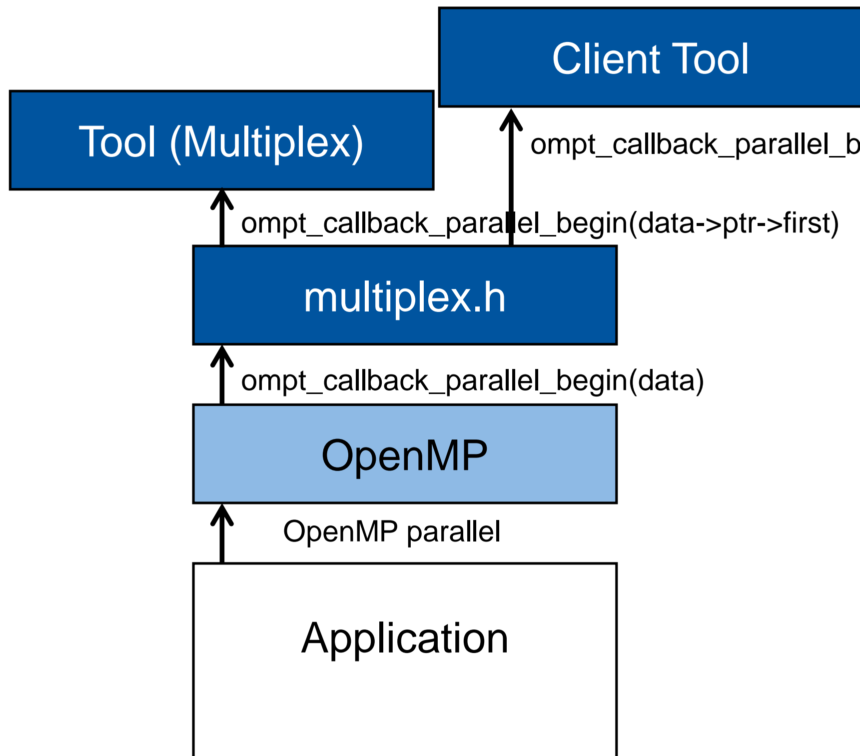


- Limitation:
  - Loading the same tool twice results in infinite recursion and SEGFAULT
    - ➢ Build two versions of the same tool with different TOOL_LIBRARIES-var

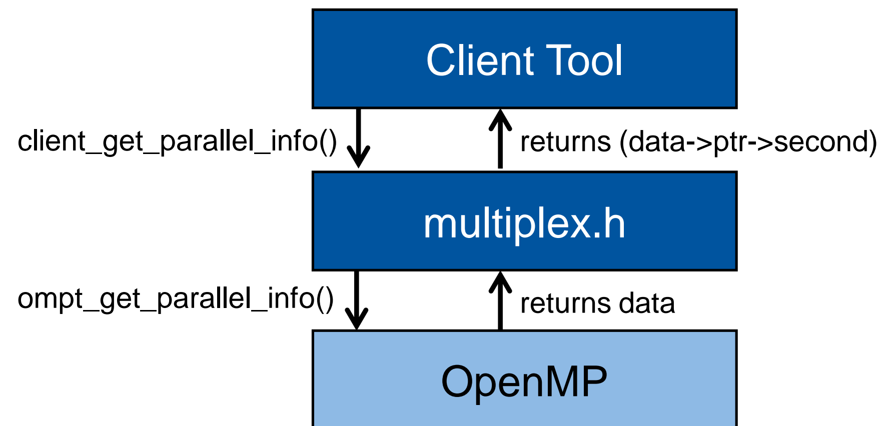
- License: MIT license to allow broad usage

Details on multiplexing OMPT

- Multiplexing of callback invocation



- Multiplexing of runtime entry points
  - The lookup-function provides specialized runtime entry points for own and client tool



OMPT-Multiplex basic usage (example3/Makefile)

- Just define the intended name for TOOL_LIBRARIES-var and include the header in the tool source file, that implements ompt_start_tool:

```
#define CLIENT_TOOL_LIBRARIES_VAR “COUNT_TOOL_LIBRARIES"
#include <ompt_multiplex.h>
```

- Even easier, define and include the header at compile time (see Makefile):

```
$(CC) -DCLIENT_TOOL_LIBRARIES_VAR=\"COUNT_TOOL_LIBRARIES\" \
-include ompt_multiplex.h callback.c -fPIC -c -o callback.o
```

- OMPT-Multiplex manages an individual data-pointer for each tool
- Callbacks are delivered first to the own tool, then to the client tool
- OMPT-Multiplex registers callbacks only for those that are registered by any of the tools

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Execute example3:
example3 $ make run

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OMPT-Multiplex advanced usage (example4/initialization.h)

- The basic mode needs to allocate ompt_data_t[2] for any new OpenMP scope
  - Entry for own data, entry for client data
- The advanced mode allows to add a field for the client data into the own data-blob
- Define an accessor for the client data field:

```
#define OMPT_MULTIPLEX_CUSTOM_GET_CLIENT_THREAD_DATA
#define OMPT_MULTIPLEX_CUSTOM_GET_CLIENT_PARALLEL_DATA
#define OMPT_MULTIPLEX_CUSTOM_GET_CLIENT_TASK_DATA
#define CLIENT_TOOL_LIBRARIES_VAR "INIT_TOOL_LIBRARIES"
#include <ompt_multiplex.h>
```

- The Init-tool doesn‘t use the data-blob at all, so the client should access the data stored in the OpenMP runtime

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Execute example4:
example4 $ make run

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OMPT-Multiplex advanced usage 2 (example4/callback.c)

- We expect the tool to free the data-blob in the scope-end callback, therefore the client is called first for these events
- In general, the advanced mode only makes sense, if a tool stores objects in the data-pointer.
- Provide a delete function, to avoid the inverted callback invocation order:

```
static ompt_data_t* get_client_data(ompt_data_t*);
static void delete_data(ompt_data_t*);
#define OMPT_MULTIPLEX_CUSTOM_DELETE_THREAD_DATA delete_data
#define OMPT_MULTIPLEX_CUSTOM_GET_CLIENT_THREAD_DATA get_client_data
//…
typedef struct my_ompt_data{
  uint64_t own;
  ompt_data_t client;
} my_ompt_data_t;

ompt_data_t* get_client_data(ompt_data_t* data){
  return &(((my_ompt_data_t*)data->ptr)->client);}
void delete_data(ompt_data_t* data){free(data->ptr);}
```

Delete not implemented yet

Asynchronous tool activity

OMPT States (example5/sample.cc)

- OMPT enumerate states:

```
std::map<int, std::string> ompt_state_map;
int ompt_initialize(…){ …
  int state = omp_state_undefined;
  const char *state_name;
  ompt_enumerate_states_t ompt_enumerate_states = (ompt_enumerate_states_t)
           lookup("ompt_enumerate_states");
  while (ompt_enumerate_states(state, &state, &state_name)) {
    ompt_state_map[state] = std::string(state_name);
  }
…}
```

- Store a copy of the state-map in the thread-blob (see thread-begin)

OMPT sampling tool (example5/sample.c)

- The signal handler:

```
static void handler(int sig, siginfo_t *si, void *uc)
{
if (!ompt_get_thread_data || !ompt_get_state) return;
  ompt_data_t *data = ompt_get_thread_data();
  if (!data) return;
  threadData *thread_data = (threadData*)(data->ptr);
  ompt_wait_id_t waitId;
  omp_state_t state = ompt_get_state(&waitId);
  thread_data->ompt_thread_state_map[state]++;
}
```

Might be NULL at shutdown!

Always access ptr! Hard to debug if you access data.

Gives a rough idea about the state of the OpenMP thread.

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Execute example5:
example5 $ make run-sample

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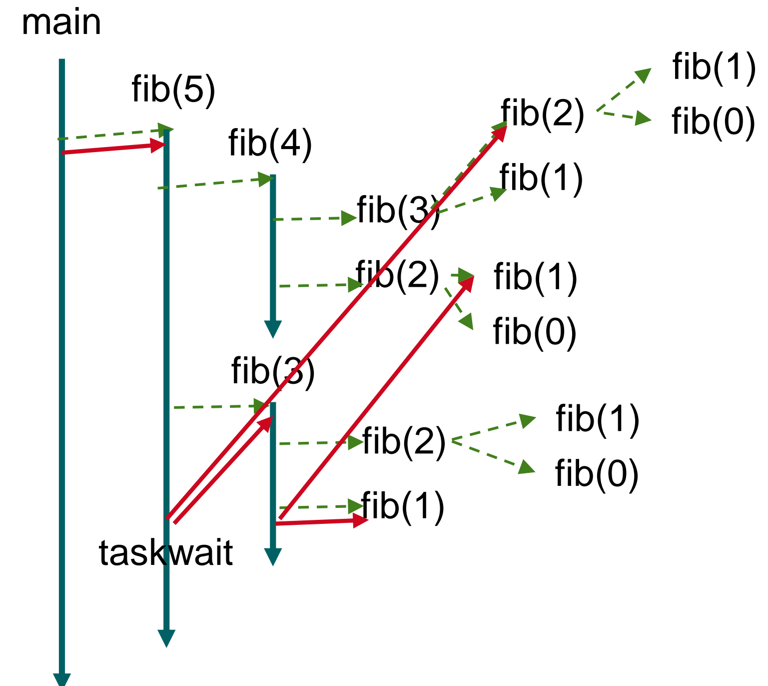
OMPT stack trace support

- Stack traces of OpenMP tasking applications are confusing
- OMPT can help cleaning up the stack trace
- OMPT can give additional stack information

```
int fib(int i){
  if i<=1 return 1;
  int a,b;
  #pragma omp task shared(a)
    a = fib(i-1);
  #pragma omp task shared(b)
    b = fib(i-2);
  #pragma omp taskwait
  return a+b;
}
int main(){
  int result;
  #pragma omp parallel sections
    result = fib(5);
  return result;
}
```



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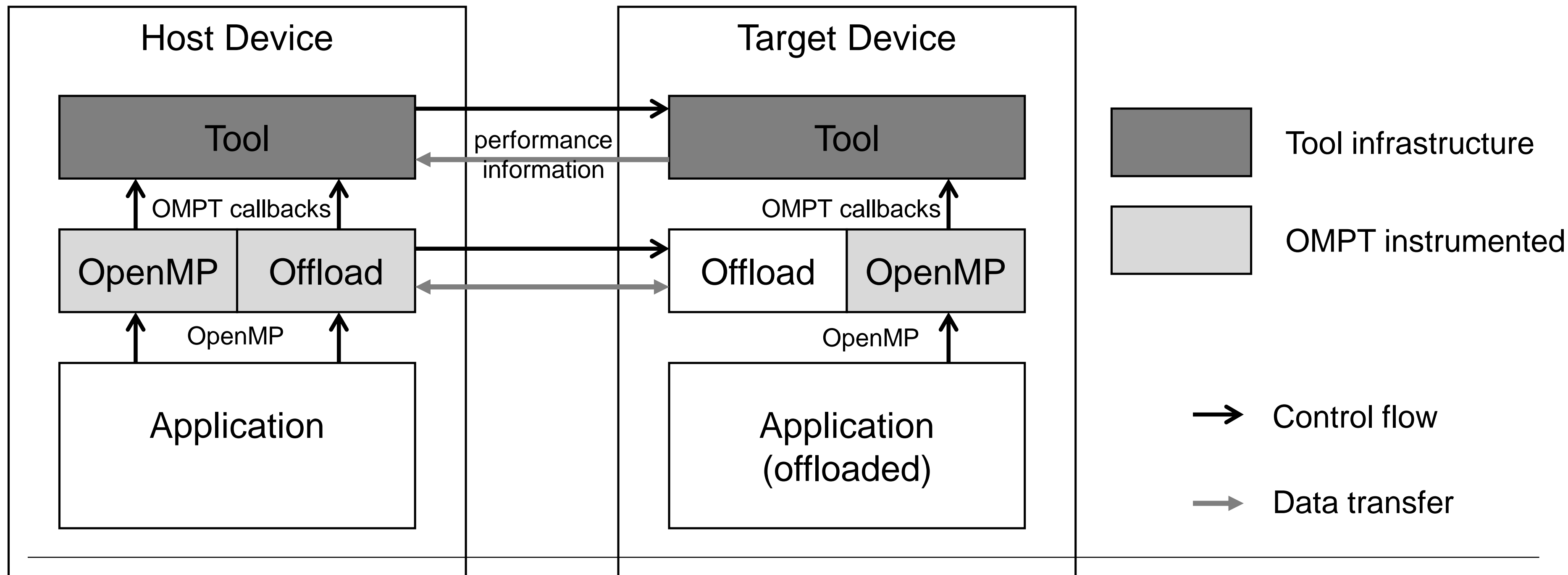
Execute example5:
example5 $ make run-sample-dt

OMPT for OpenMP Devices

OMPT target support

Tracing on Device with cross-compiled Tool

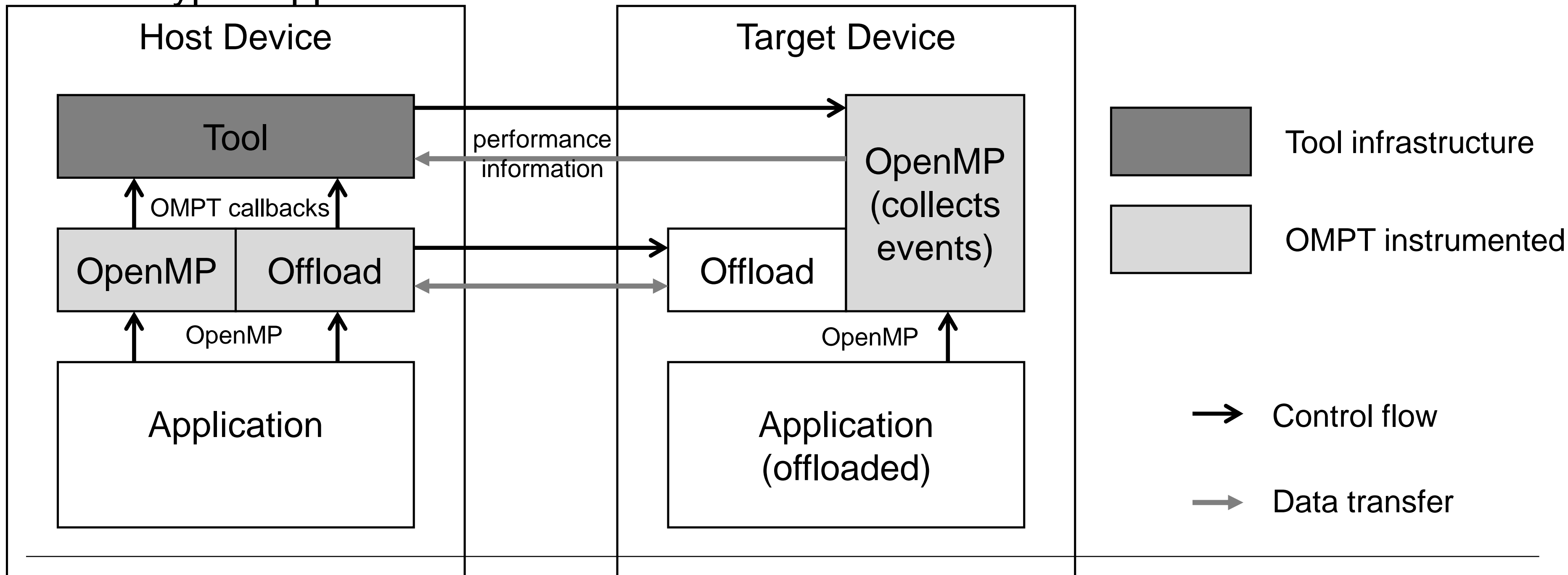
- All OMPT events can also occur on a target device
- Alternative 1: Additional library / tool on device to collect data on device



OMPT target support

Tracing on Device with Tracing API

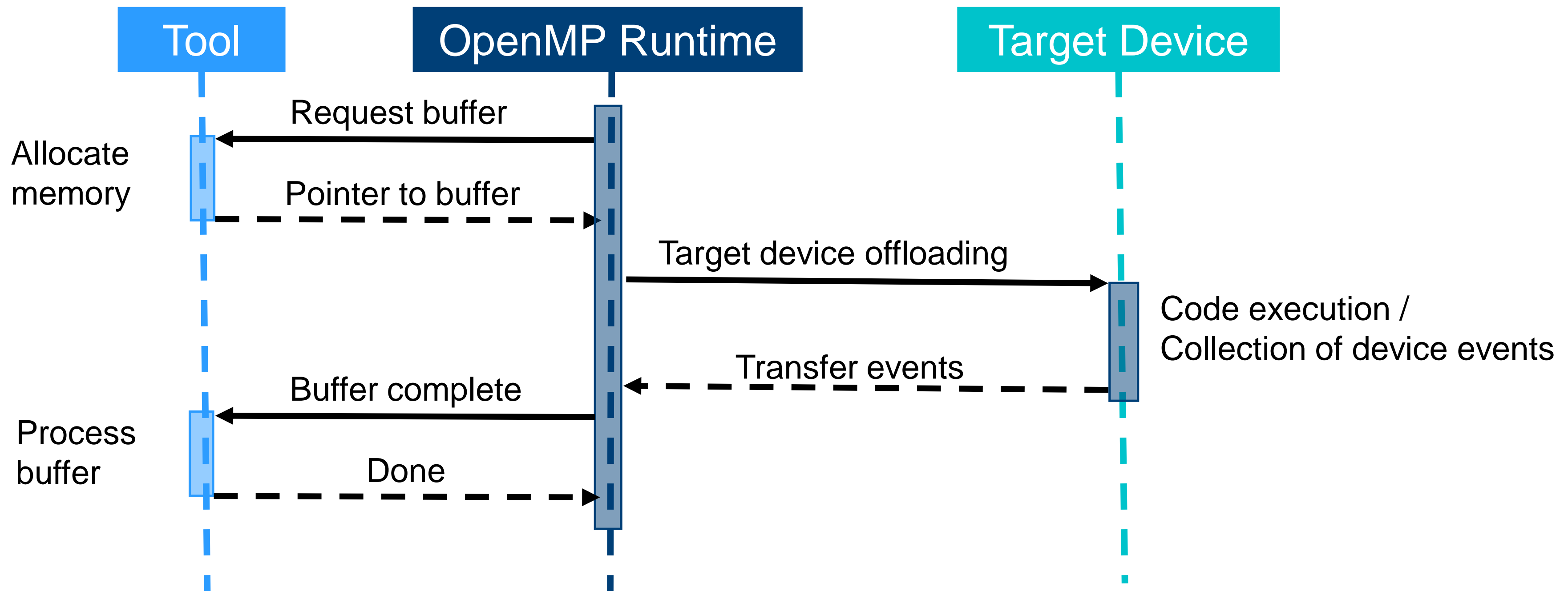
- Alternative 2: Asynchronous buffer handling with OMPT
- With buffering API
  - No additional (vendor/hardware-dependent) library required anymore
  - Device-sided events are collected within the runtime
- Prototype support in Score-P



OMPT target support

Tracing on Device with Tracing API

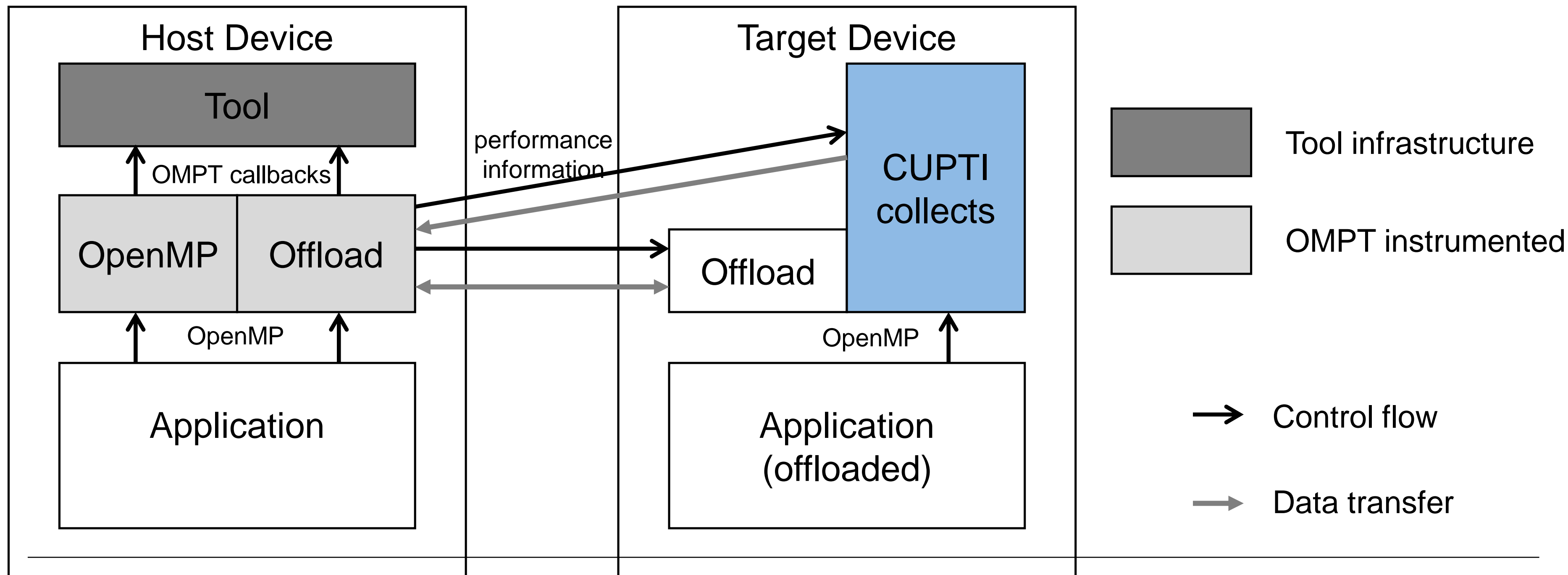
- Execution call sequence



- Initial support for
  - FPGAs in Nano++ / Extrae (Llort et al., IWOMP 2016)
  - Intel Xeon Phi in LLVM / liboffload (https://github.com/OpenMPToolsInterface)

OMPT native target support

- Wrapper for a native accelerator tracing API (like CUPTI)
- Correlate HW counter to OpenMP scopes (e.g., target regions)
- Native record includes a descripting string, a start and an end time
  - Allows a time line representation, which is meaningful to a user
  - Useful even if the tool does not fully understand the native record
- Prototype support in HPC Toolkit



Conclusions

- OMPT ready to build your host-focused tool on it
  - Implementation for devices is coming
- Event driven callback interface supports tracing/profiling tools
- Interface allows to stack multiple tools, even though not specified
  - Header-only implementation of OMPT-Multiplex is available
- Asynchronous inquiry functions support introspection with sampling tool
- OMPT for accelerators provides multiple workflows
  - Integrating native event information and OpenMP specific information

Thank you for your attention.

Hands-on

Find slides at:
bit.ly/OMPT-Handson