OMPT: An OpenMP® Tools Application Programming Interface for Performance Analysis

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1   Introduction

Today, it is difficult to produce high quality tools that support performance analysis of OpenMP programs without tightly integrating them with a specific OpenMP runtime implementation. To address this problem, this document defines OMPT—an application programming interface (API) for first-party performance tools.[1] Extending the OpenMP standard with this API will make it possible to construct powerful tools that will support any standard-compliant OpenMP implementation.

1.1   OMPT

The design of OMPT is based on experience with two prior efforts to define a standard OpenMP tools API: the POMP API [3] and the Sun/Oracle Collector API [1, 2]. The POMP API provides support for instrumentation-based measurement. A drawback of this approach is that its overhead can be significant because an operation, e.g., an iteration of an OpenMP worksharing loop, may take less time than tool callbacks monitoring its execution. In contrast, the Sun/Oracle Collector API was designed primarily to support performance measurement using asynchronous sampling. This design enables the construction of tools that attribute costs without the overhead and intrusion of pervasive instrumentation. With the Collector API, tools can use low-overhead asynchronous sampling of application call stacks to record compact call path profiles. However, the Collector API doesn't provide enough instrumentation hooks to provide full tool support for statically-linked executables. OMPT builds upon ideas from both the POMP and Collector APIs. The core of OMPT is a minimal set of features to support tools that employ asynchronous sampling to measure application performance. In addition, OMPT defines interfaces to support *blame shifting* [4, 5]—a technique that shifts attribution of costs from symptoms to causes. Finally, OMPT defines callbacks suitable for instrumentation-based monitoring of runtime events. OMPT can be implemented entirely by a compiler, entirely by an OpenMP runtime system, or with a hybrid strategy that employs a mixture of compiler and runtime support.

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[1]A *first-party* tool runs within the address space of an application process. This differs from a *third-party* tool, e.g., a debugger, which runs as a separate process.

With the exception of one routine for tool control, all functions in the OMPT API are intended for use only by tools rather than by applications. All OMPT API functions have a C binding. A Fortran binding is provided only for the single application-facing tool control function described in Section 8.

1.1.1 Design Objectives

OMPT tries to satisfy several design objectives for a performance tool interface for OpenMP. These objectives are listed in decreasing order of importance.

- The API should enable tools to gather sufficient information about an OpenMP program execution to associate costs with both the program and the OpenMP runtime system.

  - The API should provide an interface sufficient to construct low-overhead performance tools based on asynchronous sampling.
  - The API should enable a profiler that uses call stack unwinding to identify which frames in its call stack are present on behalf of the OpenMP runtime.
  - An OpenMP runtime system should associate the activity of a thread at any point in time with a *state*, e.g., idle, which will enable a performance tool to interpret program behavior.
  - Certain API routines must be defined as *async signal safe* so that they can be invoked in a profiler's signal handler as it processes interrupts generated by asynchronous sampling.

- Incorporating support for the API in an OpenMP runtime system should add negligible overhead to the runtime system if the interface is not in use by a tool.

- The API should define interfaces suitable for constructing instrumentation-based performance tools.

- Adding the API to an OpenMP runtime should not impose an unreasonable development burden on the runtime developer.

- The API should not impose an unreasonable development burden on tool implementers.

To support the OMPT interface for tools, an OpenMP runtime system must maintain information about the state of each OpenMP thread and provide a set of API calls that tools can use to interrogate the OpenMP runtime. Maintaining information about the state of each thread in the runtime system is not free and thus an OpenMP runtime system need not maintain state information unless a tool has registered its interest in this information. Without any explicit request to enable tool support, an OpenMP runtime need not maintain any state for the benefit of tools.

1.1.2 Minimally Compliant Implementation

OMPT has a small set of mandatory features that provide a common foundation for all performance tools. A runtime may also implement additional, optional, OMPT features used by some tools to gather extra information about a program execution. The features required by a minimally compliant implementation are summarized below.

- Maintain a unique numerical ID per OpenMP thread, parallel region, and task region. A minimal implementation may reuse the task ID required by OpenMP for nested locks.

- Maintain pointers into the stack for each OpenMP thread to distinguish frames for user procedures from frames for OpenMP runtime routines. Each OpenMP worker must maintain a pointer to the stack frame of the runtime routine containing its idle loop, if one exists on the stack.

- Maintain a state and a wait condition for each OpenMP thread. Mandatory states are idle, work serial, work parallel, and undefined.

- Provide callbacks to tools when encountering the following events: thread begin/end, parallel region begin/end, task region begin/end, a user-level tool control call, and runtime shutdown.

- Implement several async signal safe inquiry functions to retrieve information from the OpenMP runtime.

- Have the OpenMP runtime initiate a callback to a tool initialization routine as directed by the value of a new OpenMP environment variable (`OMP_TOOL`) and provide a function to register tool callbacks with the runtime.

1.2   Document Roadmap

This document first outlines various aspects of the OMPT tools API. Section 2 describes the state information maintained by the OpenMP runtime system on behalf of OMPT for use by tools. Section 3 describes the OMPT callbacks to notify a tool of various OpenMP runtime events during an execution. Section 4 describes the data structures used by the OMPT interface. Section 5 describes the runtime system inquiry operations supported by OMPT for the benefit of tools. Section 7 describes the OMPT API operations for tool initialization. Section 8 describes the tool control interface available to applications. Section 9 concludes with a few notes about potential future enhancements. Appendix A provides a definition of the complete OMPT interface in C. Appendix B illustrates the information that OMPT maintains about call stacks and the use of OMPT API routines to inspect it; this support enables tools to associate code executed in OpenMP parallel regions with application-level calling contexts. Appendix C outlines some considerations that impact the design of the interface for tool registration.

2   Runtime States

To enable a tool to understand what an OpenMP thread is doing, when a tool registers itself with an OpenMP runtime system, the runtime will maintain state information for each OpenMP thread that can be queried by the tool. The state maintained for each thread by the OpenMP runtime is an approximation of the thread's instantaneous state. OMPT uses the enumeration type `ompt_state_t` for states; Appendix A.1 defines this type. When the state of a thread not associated with the OpenMP runtime is queried, the runtime returns `ompt_state_undefined`.

For each OpenMP thread the runtime maintains not only a state but also an `ompt_wait_id_t` identifier. When a thread is waiting for a lock, critical region, ordered, or atomic, and the thread is in a wait state, then the thread's `wait_id` field identifies the lock, critical construct, ordered construct, atomic construct, or internal variable upon which the thread is waiting. The semantics of the values used for a `wait_id` are implementation defined. A thread's `wait_id` is undefined if the thread is not in a wait state.

States are classified as *mandatory*, *optional*, or *flexible*. Flexible states provide an OpenMP runtime with leeway to determine if and when to report transitions to a flexible state. For example, consider when a thread acquires a lock. One compliant runtime may transition a thread's state to `ompt_state_wait_lock` (flexible state) early before the thread attempts to acquire a lock. Another compliant runtime may transition a thread's state to `ompt_state_wait_lock` late, only if the thread begins to spin or block to wait for an unavailable lock. A third compliant runtime may transition a thread's state to `ompt_state_wait_lock` even later, e.g., only after the thread waits for a significant amount of time.

State values 0 to 127 are reserved for current OMPT states and future extensions.

Idle State

`ompt_state_idle` (mandatory)

>   The thread is idle while waiting to work on an OpenMP parallel region.

Work States

`ompt_state_work_serial` (mandatory)

>   The thread is executing code outside all parallel regions.

`ompt_state_work_parallel` (mandatory)

> The thread is executing code within the scope of a parallel region construct.

`ompt_state_work_reduction` (optional)

> The thread is combining partial reduction results from threads in its team. A compliant runtime might never report a thread in this state; a thread combining partial reduction results may report its state as `ompt_state_work_parallel` or `ompt_state_overhead`.

Barrier Wait States

`ompt_state_wait_barrier` (flexible)

> The thread is waiting at either an implicit or explicit barrier. A compliant implementation may have a thread enter this state early, when the thread encounters a barrier, or late, when the thread begins to wait at the barrier. A compliant implementation may never report a thread in this state; instead a thread might report its state as `ompt_state_wait_barrier_implicit` or `ompt_state_wait_barrier_explicit`, as appropriate.

`ompt_state_wait_barrier_implicit` (flexible)

> The thread is waiting at an implicit barrier in a parallel region. A compliant implementation may have a thread enter this state early, when the thread encounters a barrier, or late, when the thread begins to wait at the barrier. A compliant runtime implementation may report `ompt_state_wait_barrier` for implicit barriers.

`ompt_state_wait_barrier_explicit` (flexible)

> The thread is waiting at an explicit barrier in a parallel region. A compliant implementation may have a thread enter this state early, when the thread encounters a barrier, or late, when the thread begins to wait at the barrier. A compliant runtime implementation may report `ompt_state_wait_barrier` for explicit barriers.

Target Wait States

`ompt_state_wait_target`

> The thread is waiting at a target construct. A compliant implementation will have a thread enter this state when the thread begins to wait for a target region to complete.

`ompt_state_wait_target_data` (optional)

> The thread is waiting at a target data construct. A compliant implementation will have a thread enter this state when the thread begins to wait for a target data construct to complete. A compliant runtime implementation may report `ompt_state_wait_target` for target data constructs.

`ompt_state_wait_target_update` (optional)

> The thread is waiting at a target update construct. A compliant implementation will have a thread enter this state when the thread begins to wait for a target update construct to complete. A compliant runtime implementation may report `ompt_state_wait_target` for target update constructs.

Task Wait States

`ompt_state_wait_taskwait` (flexible)

> The thread is waiting at a taskwait construct. A compliant implementation may have a thread enter this state early, when the thread encounters a taskwait construct, or late, when the thread begins to wait for an uncompleted task.

`ompt_state_wait_taskgroup` (flexible)

> The thread is waiting at the end of a taskgroup construct. A compliant implementation may have a thread enter this state early, when the thread encounters the end of a taskgroup construct, or late, when the thread begins to wait for an uncompleted task.

Mutex Wait States

`ompt_state_wait_lock` (`ompt_state_wait_nest_lock`) (flexible)

> The thread is waiting for a lock (nest lock). A compliant implementation may have a thread enter this state early, when a thread encounters a lock (nest lock) `set` routine, or late, when the thread begins to wait for a lock (nest lock).

> Before a thread enters this state, the OpenMP runtime system will update the thread's `ompt_wait_id_t` field to identify the lock (nest lock) being acquired.

`ompt_state_wait_critical` (flexible)

> The thread is waiting to enter a critical region. A compliant implementation may have a thread enter this state early, when the thread encounters a critical construct, or late, when the thread begins to wait to enter the critical region. A compliant implementation may report a thread waiting to enter a critical region in `ompt_state_wait_lock` if waiting for a lock associated with the construct.

> Before a thread enters this state, the OpenMP runtime system will update the thread's `ompt_wait_id_t` field to identify the critical construct or an internal runtime variable (e.g., a lock) associated with the critical construct.

`ompt_state_wait_atomic` (flexible)

> The thread is waiting to enter an atomic region. A compliant implementation may have a thread enter this state early, when the thread encounters an atomic construct, or late, when the thread begins to wait to enter the atomic region. A compliant implementation may report a thread waiting to enter an atomic region in `ompt_state_wait_lock` if waiting for a lock associated with the atomic construct. A compliant implementation may opt to not report this state, for example, when using atomic hardware instructions, which allow non-blocking atomic implementations.

> Before a thread enters this state, the OpenMP runtime system will update the thread's `ompt_wait_id_t` field to identify the atomic construct, a program variable, or an internal runtime variable (e.g., a lock) associated with the atomic construct.

`ompt_state_wait_ordered` (flexible)

> The thread is waiting to enter an ordered region. A compliant implementation may have a thread enter this state early, when the thread encounters an ordered construct, or late, when the thread begins to wait to enter the ordered region. A compliant implementation may report a thread waiting to enter a ordered region in `ompt_state_wait_lock` if waiting for a lock associated with the ordered construct.

> Before a thread enters this state, the OpenMP runtime system will update the thread's `ompt_wait_id_t` field to identify the ordered construct or an internal runtime variable (e.g., a lock) associated with the ordered construct.

Overhead State

`ompt_state_overhead` (optional)

> A thread may be reported as being in the overhead state at any point while executing within an OpenMP runtime system, e.g., while preparing a parallel region, preparing a new explicit task, preparing a worksharing region, or preparing to execute iterations of a parallel loop. It is compliant to report some or all OpenMP runtime overhead as work.

`ompt_state_undefined` (mandatory)

> This state is reserved for threads that are not user threads, initial threads, threads currently in an OpenMP team, or threads waiting to become part of an OpenMP team.

`ompt_state_first` (mandatory)

> This state is a placeholder exclusively reserved for use by the OMPT runtime call `ompt_enumerate_state` (see Section 5.1), which is used to enumerate all available runtime states. A thread will never be reported in this state.

3 Events

This section describes callback events that an OpenMP runtime may provide for use by a tool. OMPT uses the enumeration type `ompt_event_t` for events; Appendix A.2 defines this type. A tool need not register a callback for any particular event. In most cases, an OpenMP runtime system will not make any callback unless a tool has registered to receive it. The exception to this rule is begin/end event pairs. To implement event notifications efficiently, a runtime may assume that for certain begin/end event pairs if one event of the pair has a callback registered, the other will have a callback defined as well. When this exception applies, it will be noted for affected events.

Callbacks for different events may have different type signatures. The type signature for an event's callback is noted with the event definition. Appendix A.4 defines type signatures for callback events.

There are two classes of events: mandatory events and optional events. Mandatory events must be implemented in any compliant OpenMP runtime implementation. Optional events are grouped in sets of related events. Except for begin/end pairs as noted, support for any particular optional event can be included or omitted at the discretion of a runtime system implementer.

3.1 Mandatory Events

The following callback events are mandatory and must be supported by a compliant OpenMP runtime system.

Threads

`ompt_event_thread_begin`

> The OpenMP runtime invokes this callback in the context of an initial thread just after it initializes the OpenMP runtime for itself, or in the context of a new thread created by the OpenMP runtime system just after the thread initializes itself. In either case, this callback must be the first callback for a thread and must occur before the thread executes any OpenMP tasks. The type of the thread (`ompt_thread_initial`, `ompt_thread_worker`, or `ompt_thread_other`) is passed as an argument to the callback. This callback has type signature `ompt_thread_type_callback_t`.

`ompt_event_thread_end`

> The OpenMP runtime invokes this callback after an OpenMP thread completes all of its tasks but before the thread is destroyed. The callback executes in the context of the OpenMP thread. This callback must be the last callback event for any thread of type `ompt_thread_worker`; it is optional for other types of threads. This callback has type signature `ompt_thread_type_callback_t`.

Parallel Regions

How should we handle degenerate regions (e.g, a nested region where nesting is disabled, or a region that will execute serially because there are no other threads available to help execute it?

`ompt_event_parallel_begin`

> The OpenMP runtime invokes this callback after a task encounters a parallel construct but before any implicit task starts to execute the parallel region's work. The callback executes in the context of the task that encountered the parallel construct. This callback has type signature `ompt_new_parallel_callback_t`, and includes a parameter that indicates the number of threads requested by the user. A tool may use this value as an upper bound on the number of threads that will participate in the team.

`ompt_event_parallel_end`

> The OpenMP runtime invokes this callback after a parallel region executes its closing synchronization barrier but before resuming execution of the parent task. The callback executes in the context of the task that encountered the parallel construct. This callback has type signature `ompt_parallel_callback_t`.

Tasks

`ompt_event_task_begin`

> The OpenMP runtime invokes this callback after a task encounters a task construct but before the new explicit task executes. The callback executes in the context of the task that encountered the task construct. This callback has type signature `ompt_new_task_callback_t`.

`ompt_event_task_end`

> The OpenMP runtime invokes this callback after an explicit task completes but before the thread resumes execution of another task. The callback executes in the context of an arbitrary task on the thread that completed the explicit task. This callback has type signature `ompt_task_callback_t`.

`ompt_event_target_task_begin`

> The OpenMP runtime invokes this callback after a task encounters a target construct but before the target task executes. The callback executes in the context of the task that encountered the target construct. This callback has type signature `ompt_new_target_task_callback_t`.

`ompt_event_target_task_end`

> The OpenMP runtime invokes this callback after a target task completes but before the thread resumes execution of another task. The callback executes in the context of an arbitrary task on the thread that completed the target task. This callback has type signature `ompt_task_calltack_t`. The task id passed to the callback belongs to the target task.

Application Tool Control

`ompt_event_control`

> If the user program calls `ompt_control`, the OpenMP runtime invokes this callback. The callback executes in the environment of the user control call; the arguments passed to the callback are the values passed by the user to `ompt_control`. This callback has type signature `ompt_control_callback_t`.

Termination

`ompt_event_runtime_shutdown`

> The OpenMP runtime system invokes this callback before it shuts down the runtime system. This callback enables a tool to clean up its state and record or report its measurement data, as appropriate. A runtime may later restart and reinitialize the tool by calling the tool initializer function (`ompt_tool`, described in Section 7.2) again. This callback has type signature `ompt_callback_t`.

3.2 Optional Events

This section describes two sets of events. The first set of events is intended primarily for use by sampling-based performance tools that employ a strategy known as *blame shifting* to attribute waiting to activity in contexts that cause other threads to wait rather than contexts in which waiting is observed. The second set of events, in combination with other mandatory and optional events, enables instrumentation-based tools to receive notification for any or all OpenMP runtime events as they occur.

Support for these events is optional. An OpenMP runtime system remains compliant even if it supports none of the events in this section.

3.2.1 Events for Blame Shifting (Optional)

This section describes callback events used by sampling-based performance tools that employ *blame shifting* to transfer blame for waiting from contexts where waiting is observed to contexts responsible for the waiting.[2] Using these callbacks, a tool employing blame shifting can attribute time that a thread spends waiting for a lock to the context of the lock holder. Similarly, time that threads spend waiting at a barrier can be attributed back to code being executed by working threads while other threads wait.

The events listed immediately below are used by an OpenMP runtime to notify a tool when various kinds of idling begin and end. Since idling indicates the absence of any activity, a thread will not receive any event notification between begin and end notifications for idling.

Idle State Entry/Exit

`ompt_event_idle_begin`

> The OpenMP runtime invokes this callback when a thread starts to idle outside a parallel region. The callback executes in the environment of the idling thread. This callback has type signature `ompt_thread_callback_t`.
>
> *Note: If this callback is registered, the callback for* `ompt_event_idle_end` *must also be registered.*

`ompt_event_idle_end`

> The OpenMP runtime invokes this callback when a thread finishes idling outside a parallel region. The callback executes in the environment of the thread that is about to resume useful work. This callback has type signature `ompt_thread_callback_t`.
>
> *Note: If this callback is registered, the callback for* `ompt_event_idle_begin` *must also be registered.*

Barrier Idling

`ompt_event_wait_barrier_begin`

> The OpenMP runtime invokes this callback when an implicit task starts to wait in a barrier region. One barrier region may generate multiple pairs of barrier begin and end callbacks in a task, e.g., if waiting at the barrier occurs in multiple stages or if another task is scheduled on this thread while it waits at the barrier. The callback executes in the context of an implicit task waiting for a barrier region to complete. This callback has type signature `ompt_parallel_callback_t`.
>
> *Note: If this callback is registered, the callback for* `ompt_event_wait_barrier_end` *must also be registered.*

`ompt_event_wait_barrier_end`

> The OpenMP runtime invokes this callback when an implicit task finishes waiting in a barrier region. One barrier region may generate multiple pairs of barrier begin and end callbacks in a task, e.g., if waiting at the barrier occurs in multiple stages or if another task is scheduled on this thread while

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[2]The utility of blame shifting has previously been demonstrated for attributing idling while waiting to steal work in a work-stealing runtime [4], and spin waiting to acquire a lock [5].

it waits at the barrier. The callback executes in the context of an implicit task waiting for a barrier region to complete. This callback has type signature `ompt_parallel_callback_t`.

Note: If this callback is registered, the callback for `ompt_event_wait_barrier_begin` *must also be registered.*

Taskwait Idling

`ompt_event_wait_taskwait_begin`

The OpenMP runtime invokes this callback when a thread starts to wait in a taskwait region. One taskwait region may generate multiple pairs of taskwait begin and end callbacks if another task is scheduled on this thread while it waits at the taskwait. This callback executes in the context of the task that encountered the taskwait construct. This callback has type signature `ompt_parallel_callback_t`.

Note: If this callback is registered, the callback for `ompt_event_wait_taskwait_end` *must also be registered.*

`ompt_event_wait_taskwait_end`

The OpenMP runtime invokes this callback when a task finishes waiting in a taskwait region. One taskwait region may generate multiple pairs of taskwait begin and end callbacks if another task is scheduled on this thread while it waits in the taskwait region. This callback executes in the context of the task that encountered the taskwait construct. This callback has type signature `ompt_parallel_callback_t`.

Note: If this callback is registered, the callback for `ompt_event_wait_taskwait_begin` *must also be registered.*

Taskgroup Idling

`ompt_event_wait_taskgroup_begin`

The OpenMP runtime invokes this callback when a task starts to wait for a taskgroup region to complete. One taskgroup region may generate multiple pairs of taskgroup begin and end callbacks if another task is scheduled on this thread while it waits in the taskgroup region. This callback executes in the context of the task that encountered the taskgroup construct. This callback has type signature `ompt_parallel_callback_t`.

Note: If this callback is registered, the callback for `ompt_event_wait_taskgroup_end` *must also be registered.*

`ompt_event_wait_taskgroup_end`

The OpenMP runtime invokes this callback when a task finishes waiting for a taskgroup region to complete. One taskgroup region may generate multiple pairs of taskgroup begin and end callbacks if another task is scheduled on this thread while it waits in the taskgroup region. This callback executes in the context of the task that encountered the taskgroup construct. This callback has type signature `ompt_parallel_callback_t`.

Note: If this callback is registered, the callback for `ompt_event_wait_taskgroup_begin` *must also be registered.*

Lock Release

`ompt_event_release_lock`

The OpenMP runtime system invokes this callback after a task releases a lock. This callback executes in the context of the task that called `omp_unset_lock`; its `wait_id` parameter identifies the released lock. This callback has type signature `ompt_wait_callback_t`.

Note: This callback may be useful to an instrumentation-based tool to terminate an interval beginning with `ompt_event_acquired_lock`.

`ompt_event_release_nest_lock_last`

The OpenMP runtime invokes this callback for certain releases of a nest lock. If a task acquires a nest lock n times, this callback occurs only after the nth release. The inner $n-1$ releases are reported as `ompt_event_release_nest_lock_prev` events. This callback executes in the context of the task that called `omp_unset_nest_lock`; its `wait_id` parameter identifies the nest lock released. This callback has type signature `ompt_wait_callback_t`.

Note: This callback may be useful to an instrumentation-based tool to terminate an interval beginning with `ompt_event_acquired_nest_lock_first`.

Critical Release

`ompt_event_release_critical`

The OpenMP runtime system invokes this callback after a task exits a critical region. This callback executes in the context of the task that encountered the critical construct; its `wait_id` parameter identifies the critical construct or an internal runtime variable (e.g., a lock) associated with the critical construct that was exited. This callback has type signature `ompt_wait_callback_t`.

Note: This callback may be useful to an instrumentation-based tool to terminate an interval beginning with `ompt_event_acquired_critical`.

Ordered Release

`ompt_event_release_ordered`

The OpenMP runtime system invokes this callback after a task exits an ordered region. This callback executes in the context of the task that encountered the ordered construct; its `wait_id` parameter identifies the ordered construct or an internal runtime variable (e.g., a lock) associated with the ordered construct that was exited. This callback has type signature `ompt_wait_callback_t`.

Note: This callback may be useful to an instrumentation-based tool to terminate an interval beginning with `ompt_event_acquired_ordered`.

Atomic Release

`ompt_event_release_atomic`

The OpenMP runtime system invokes this callback after a task completes an atomic region. This callback executes in the context of the task that encountered the atomic construct; its `wait_id` parameter identifies the atomic construct, a program variable, or an internal runtime variable (e.g., a lock) associated with the atomic construct being exited.

If an atomic block is implemented using a hardware instruction, then an OpenMP runtime may choose never to report this event. However, if an atomic region is implemented using any mechanism that involves a software protocol that spin waits or retries, then an OpenMP runtime developer should consider reporting this event to accept blame for any spin waiting or retries that the atomic region causes. Examples of spinning in software include spin waiting for a critical region used to implement atomics, or retrying atomic operations implemented using hardware primitives that may fail. Examples of hardware primitives that could fail with explicit retries in software include transactional instructions, load-linked/store-conditional, or compare-and-swap.

This callback has type signature `ompt_wait_callback_t`.

Note: This callback may be useful to an instrumentation-based tool to terminate an interval beginning with `ompt_event_acquired_atomic`.

3.2.2 Events for Instrumentation-based Measurement Tools (Optional)

The following set of events, in combination with other mandatory and optional events, enables instrumentation-based tools to receive notification for any or all OpenMP runtime events as they occur.

Task Creation and Destruction

`ompt_event_implicit_task_begin`

   The OpenMP runtime system invokes this callback, after an implicit task is fully initialized but before the task executes its work. This callback executes in the context of the new implicit task. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_implicit_task_end`

   The OpenMP runtime system invokes this callback after an implicit task executes its closing synchronization barrier but before returning to idle or the task is destroyed. The callback executes in the context of the implicit task. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_initial_task_begin`

   The OpenMP runtime system invokes this callback, just after an initial implicit task is fully initialized but before it starts to execute. This callback executes in the context of an initial task. This callback has type signature `ompt_task_callback_t`.

`ompt_event_initial_task_end`

   The OpenMP runtime system invokes this callback when an initial implicit task ends but before the task is destroyed. The callback executes in the context of the initial implicit task. This callback has type signature `ompt_task_callback_t`,

`ompt_event_task_switch`

   The OpenMP runtime system invokes this callback after it suspends one task and before it resumes another task. This callback executes in the context of the resumed task. If the suspended task actually completed and its data structure was deallocated, the value of the `suspended_task_id` parameter is 0. This callback has type signature `ompt_task_switch_callback_t`.

Task Dependence Tracking

`ompt_event_task_dependences`

   The OpenMP runtime invokes this callback after an explicit task is created, but before the task begins execution to announce its dependences on data objects. This callback has type signature `ompt_task_dependences_callback_t`.

Lock Creation and Destruction

`ompt_event_init_lock` (`ompt_event_init_nest_lock`)

   The OpenMP runtime system invokes this callback just after a task initializes a lock (nest lock). This callback executes in the context of the task that called `omp_init_lock` (`omp_init_nest_lock`); its `wait_id` parameter identifies the lock. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_destroy_lock` (`ompt_event_destroy_nest_lock`)

   The OpenMP runtime system invokes this callback just before a task destroys a lock (nest lock). This callback executes in the context of the task that called `omp_destroy_lock` (`omp_destroy_nest_lock`); its `wait_id` parameter identifies the lock. This callback has type signature `ompt_wait_callback_t`.

Loops

ompt_event_loop_begin

The OpenMP runtime system invokes this callback after a task encounters a loop construct but before the task executes its first iteration of the loop. This callback executes in the context of the task that encountered the loop. This callback has type signature `ompt_new_workshare_callback_t`.

ompt_event_loop_end

The OpenMP runtime system invokes this callback after a task executes its last iteration of a loop region but before the task executes the loop barrier (wait) or the statement following the loop (nowait). This callback executes in the context of the task that encountered the loop. This callback has type signature `ompt_parallel_callback_t`.

Sections

ompt_event_sections_begin

The OpenMP runtime system invokes this callback before a task executes its first section in a sections region. This callback executes in the context of the task that encountered the sections construct. This callback has type signature `ompt_new_workshare_callback_t`.

ompt_event_sections_end

The OpenMP runtime system invokes this callback after a task executes its last section in a sections region and before the task executes the section barrier (wait) or the statement following the section construct (nowait). This callback executes in the context of the task that encountered the sections construct. This callback has type signature `ompt_parallel_callback_t`.

Single Blocks

ompt_event_single_in_block_begin

The OpenMP runtime system invokes this callback after a task encounters a single construct but before it executes the code block of the single construct. This callback executes in the context of the task that will execute the single code block. This callback has type signature `ompt_new_workshare_callback_t`.

ompt_event_single_in_block_end

The OpenMP runtime system invokes this callback after a task executes the code block of a single construct but before the task executes the single barrier (wait) or the statement following the single construct (nowait). This callback executes in the context of the task that executed the single code block. This callback has type signature `ompt_parallel_callback_t`.

ompt_event_single_others_begin

The OpenMP runtime system invokes this callback when a task that encounters a single construct is not chosen to execute the single code block. This callback executes in the context of the task that encountered the single construct. This callback has type signature `ompt_parallel_callback_t`.

ompt_event_single_others_end

The OpenMP runtime system invokes this callback in a task after that task reports event `ompt_event_single_others_begin` but before the task executes the single barrier (wait) or the statement following the single construct (nowait). This callback executes in the context of the task that encountered the single construct. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_workshare_begin`

> The OpenMP runtime system invokes this callback after a task encounters a workshare construct but before the task executes its first unit of work for the workshare. This callback executes in the context of the task that encountered the workshare construct. This callback has type signature `ompt_new_workshare_callback_t`.

`ompt_event_workshare_end`

> The OpenMP runtime system invokes this callback after a task executes its last unit of work for a workshare and before the task executes the workshare barrier (wait) or the statement following the workshare construct (nowait). This callback executes in the context of the task that encountered the workshare construct. This callback has type signature `ompt_parallel_callback_t`.

Master Blocks

`ompt_event_master_begin`

> The OpenMP runtime system invokes this callback after the implicit task of a master thread encounters a master construct but before the task executes the master region. This callback executes in the context of the master task of a team. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_master_end`

> The OpenMP runtime system invokes this callback after the implicit task of a master thread executed the master region but before the task executes the statement following the master construct. This callback executes in the context of the master task of a team. This callback has type signature `ompt_parallel_callback_t`.

Target Devices

`ompt_event_target_data_begin`

> The OpenMP runtime invokes this callback after a task encounters a target data construct but before the new data environment is created. The callback executes in the context of the task that encountered the target data construct. This callback has type signature `ompt_new_target_data_callback_t`. Arguments to the callback include the ID of the encountering task, the ID of the target device, and the return address of the invocation of a runtime routine to perform the target data operation, which relates the operation to the user program.

`ompt_event_target_data_end`

> The OpenMP runtime invokes this callback when the task that encountered the target data region is done with the target data region. The callback executes in the context of the task that encountered the target data construct. This callback has type signature `ompt_target_callback_t`.

`ompt_event_target_update_begin`

> The OpenMP runtime invokes this callback after a task encounters a target update construct but before the corresponding list items are made consistent with the device data environment. The callback executes in the context of the task that encountered the target data construct. This callback has type signature `ompt_new_target_task_callback_t`.

`ompt_event_target_update_end`

> The OpenMP runtime invokes this callback when the task that encountered the target update construct is done with the target update region. Since updates may execute asynchronously on a device, the callback may occur before the update is complete. The callback executes in the context of the task that encountered the target update construct. This callback has type signature `ompt_task_callback_t`. The task id passed to the callback belongs to the target task.

`ompt_event_target_data_map_begin`

The OpenMP runtime invokes this callback just before a variable is mapped to or from the device data environment. The callback executes in the context of the encountering task, which executes the region. This callback has type signature `ompt_new_data_map_callback_t`.

`ompt_event_target_data_map_end`

The OpenMP runtime invokes this callback immediately after a variable is mapped to or from the device data environment. Since the map operation may execute asynchronously on the device, the map end callback on the host may occur before the map operation is complete. The callback executes in the context of the the encountering task, which executes the region. This callback has type signature `ompt_task_callback_t`. The task id passed to the callback belongs to the encountering task.

`ompt_event_target_data_map_done`

The OpenMP runtime invokes this callback after a variable map operation finishes execution on a device. Since the map operation may execute asynchronously on the device, the map done callback may occur after the map end. The callback executes in the context of an arbitrary task, which may not be the one that initiated the map operation. This callback has type signature `ompt_data_map_done_callback_t`.

Barriers

`ompt_event_barrier_begin`

The OpenMP runtime system invokes this callback before an implicit task begins execution of a barrier region. This callback executes in the context of the implicit task that encountered the barrier construct. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_barrier_end`

The OpenMP runtime system invokes this callback after an implicit task exits a barrier region. This callback executes in the context of the implicit task that encountered the barrier construct. This callback has type signature `ompt_parallel_callback_t`.

Taskwait

`ompt_event_taskwait_begin`

The OpenMP runtime system invokes this callback after a task encounters a taskwait construct but before the task begins execution of the taskwait region. This callback executes in the context of the task that encountered the taskwait construct. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_taskwait_end`

The OpenMP runtime system invokes this callback after a task exits a taskwait region. This callback executes in the context of the task that encountered the taskwait construct. This callback has type signature `ompt_parallel_callback_t`.

Taskgroup

`ompt_event_taskgroup_begin`

The OpenMP runtime system invokes this callback before a task begins execution of a taskgroup region. This callback executes in the context of the task that encountered the taskgroup construct. This callback has type signature `ompt_parallel_callback_t`.

`ompt_event_taskgroup_end`

>   The OpenMP runtime system invokes this callback after a task exits a taskgroup region. This callback executes in the context of the task that encountered the taskgroup construct. This callback has type signature `ompt_parallel_callback_t`.

Locks

`ompt_event_wait_lock`

>   The OpenMP runtime system invokes this callback if a task enters the `ompt_state_wait_lock` state. This callback executes in the context of the task that called `omp_set_lock`; its `wait_id` parameter identifies the lock. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_lock`

>   The OpenMP runtime system invokes this callback just after a task acquires a lock. This callback executes in the context of the task that called `omp_set_lock`; its `wait_id` parameter identifies the lock. This callback has type signature `ompt_wait_callback_t`.

Nest Locks

`ompt_event_wait_nest_lock`

>   The OpenMP runtime system invokes this callback when a task enters the `ompt_state_wait_nest_lock` state. This callback executes in the context of the task that called `omp_set_nest_lock`; its `wait_id` parameter identifies the nest lock. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_nest_lock_first`

>   The OpenMP runtime system invokes this callback just after a task acquires a nest lock for the first time. This callback executes in the context of the task that called `omp_set_nest_lock`; its `wait_id` parameter identifies the nest lock. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_release_nest_lock_prev`

>   The OpenMP runtime system invokes this callback after a task releases a nest lock that is still owned by this task after the release. If a nest lock was acquired n times by the same task, this callback occurs for the inner $n-1$ releases. The nth release is handled by the `ompt_event_release_nest_lock_last` event. This callback executes in the context of the task that called `omp_unset_nest_lock`; its `wait_id` parameter identifies the nest lock unset. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_nest_lock_next`

>   The OpenMP runtime system invokes this callback just after this task acquires a nest lock that was already owned by this task. This callback executes in the context of the task that called `omp_unset_nest_lock`; its `wait_id` parameter identifies the nest lock set. This callback has type signature `ompt_wait_callback_t`.

Critical Sections

`ompt_event_wait_critical`

>   The OpenMP runtime system invokes this callback when this task enters the `ompt_state_wait_critical` state. This callback executes in the context of the task that encountered the critical construct; its `wait_id` parameter identifies the critical construct. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_critical`

> The OpenMP runtime system invokes this callback just after this task enters a critical region. This callback executes in the context of the task that encountered the critical construct; its `wait_id` parameter identifies the critical region being entered. This callback has type signature `ompt_wait_callback_t`.

Ordered Sections

`ompt_event_wait_ordered`

> The OpenMP runtime system invokes this callback when this task enters the `ompt_state_wait_ordered` state. This callback executes in the context of the task that encountered the ordered construct; its `wait_id` parameter identifies the ordered construct. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_ordered`

> The OpenMP runtime system invokes this callback just after this task enters an ordered region. This callback executes in the context of the task that encountered the ordered construct; its `wait_id` parameter identifies a variable associated with the ordered construct. This callback has type signature `ompt_wait_callback_t`.

Atomic Blocks

`ompt_event_wait_atomic`

> The OpenMP runtime system invokes this callback when this task enters the `ompt_state_wait_atomic` state. This callback executes in the context of the task that encountered the atomic construct; its `wait_id` parameter identifies the atomic construct, a program variable, or an internal runtime variable (e.g., a lock) associated with the atomic construct being awaited. This callback has type signature `ompt_wait_callback_t`.

`ompt_event_acquired_atomic`

> The OpenMP runtime system invokes this callback just after this task enters an atomic region. This callback executes in the context of the task that encountered the atomic construct; its `wait_id` parameter identifies the atomic construct, a program variable, or an internal runtime variable (e.g., a lock) associated with the atomic construct being awaited. This callback has type signature `ompt_wait_callback_t`.

Miscellaneous

`ompt_event_flush`

> The OpenMP runtime system invokes this callback just after performing a flush operation. This callback executes in the context of the task that encountered the flush construct. This callback has type signature `ompt_thread_callback_t`.

4 Tool Data Structures

4.1 Thread Identifier (Mandatory)

Each OpenMP thread has an associated `ompt_thread_id_t` that uniquely identifies the thread.

```
typedef uint64_t ompt_thread_id_t;
```

The `ompt_thread_id_t` is unique across all thread instances. A OpenMP thread is assigned an ID when the thread begins. A thread's ID is passed to callbacks associated with the begin/end of the thread. A thread ID can be retrieved on demand by invoking the `ompt_get_thread_id` function (described in Section 5.2). Tools should not assume that `ompt_thread_id_t` values are consecutive or small. The value 0 is reserved to indicate an invalid thread id.

4.2   Parallel Region Identifier (Mandatory)

Each OpenMP parallel region has an associated `ompt_parallel_id_t` that uniquely identifies the region.

```
typedef uint64_t ompt_parallel_id_t;
```

The `ompt_parallel_id_t` for a parallel region is unique across all parallel regions. A parallel region is assigned an ID when the region is created. A parallel region's ID is passed to callbacks associated with begin/end of the parallel region, as well as callbacks that occur in the context of the parallel region. A parallel region ID can be retrieved on demand by invoking the `ompt_get_parallel_id` function (described in Section 5.3). Tools should not assume that `ompt_parallel_id_t` values for adjacent regions are consecutive. The value 0 is reserved to indicate an invalid parallel id.

4.3   Task Region Identifier (Mandatory)

Each OpenMP task region has an associated `ompt_task_id_t` that uniquely identifies the task region. This holds for implicit tasks, including the initial task, as well as for explicit tasks.

```
typedef uint64_t ompt_task_id_t;
```

The `ompt_task_id_t` for a task region is unique across all task regions. A task region is assigned an ID when the region is created. A task region's ID is passed to callbacks associated with begin/end of the task region. A task region's ID can be retrieved on demand by invoking the `ompt_get_task_info` function (described in Section 5.4). Tools should not assume that `ompt_task_id_t` values for adjacent task regions are consecutive. The value 0 is reserved to indicate an invalid task id.
   An initial task will also have its own unique task region ID.

4.4   Wait Identifier (Mandatory)

Each thread instance maintains an `ompt_wait_id_t`. When a thread is waiting for something, the thread's wait ID identifies what the thread is awaiting.

```
typedef uint64_t ompt_wait_id_t;
```

For example, when a thread is waiting for a lock, the thread's wait ID identifies the lock. The thread's wait ID is passed to callbacks associated with wait events, and also can be retrieved on demand by invoking the `ompt_get_state` function (described in Section 5.2). When a thread is not in a wait state, a thread's wait ID has an undefined value. Value 0 is reserved to indicate an undefined wait ID.

4.5   Pointers to Support Classification of Stack Frames (Mandatory)

Each implicit or explicit task region provides an `ompt_frame_t` data structure which contains pointers to OpenMP runtime procedure frames that appear above and below procedure frames associated with user task code.

```
typedef struct ompt_frame_s {
    void *exit_runtime_frame;    /* next frame is user code      */
    void *reenter_runtime_frame; /* user frame that reenters the runtime  */
} ompt_frame_t;
```

The structure's lifetime begins when a task region is created and ends when the task region is destroyed. While the value of the structure is preserved over the lifetime of the task, tools should not assume that the address of a structure remains constant over its lifetime. Frame data is passed to some callbacks; it can also be retrieved asynchronously for a task by invoking the `ompt_get_task_frame` function (described in Section 5.4) in a signal handler. Frame data contains two components:

exit / reenter	reenter = null	reenter = defined
exit = null	case 1) initial task in user code case 2) task that is created but not yet scheduled	task in runtime to create a parallel region or explicit task
exit = defined	non-initial task in (or soon to be in) user code	non-initial task in runtime to create a parallel region or explicit task

Table 1: Meaning of various values for `exit_runtime_frame` and `reenter_runtime_frame`.

`exit_runtime_frame` This value is set once, the first time that a task exits the runtime to begin executing user code. This field points to the stack frame of the runtime procedure that called the user code. This value is NULL until just before the task exits the runtime.

`reenter_runtime_frame` This value is set each time that current task re-enters the runtime to create new (implicit or explicit) tasks. This field points to the stack frame of the user function that invokes a runtime function. This value is set prior to entering the runtime to enter an OpenMP region and cleared when the region ends.

Table 1 describes the meaning of this structure with various values. In the presence of nested parallelism, a tool may observe a sequence of `ompt_frame_t` records for a thread. Appendix B discusses an example that illustrates the use of `ompt_frame_t` records with nested parallelism.

The live range of the `ompt_frame_t` for a given task starts at the `ompt_event_task_begin`, `ompt_event_implicit_task_begin`, or `ompt_event_initial_task_begin` event and lasts until the `ompt_event_task_end`, `ompt_event_implicit_task_end`, or `ompt_event_initial_task_end` event, inclusively.

Advice to tool implementers: A monitoring tool using asynchronous sampling can observe values of `exit_runtime_frame` and `reenter_runtime_frame` at inconvenient times. Tools must be prepared to observe and handle frame exit and reenter values that have not yet been set or reset as the program enters or returns to the runtime.

5   Inquiry Functions for Tools

Inquiry functions retrieve data from the execution environment for the tools. All functions in the inquiry API are marked with `OMPT_API`. These functions should not be global symbols in an OpenMP runtime system implementation to avoid tempting tool developers to call them directly. Section 7.2 describes how a tool will obtain pointers to these inquiry functions. *All inquiry functions are async signal safe.* Note that it is unsafe to call OpenMP Execution Environment Routines within an OMPT callback because doing so may cause deadlock. Specifically, since OpenMP Execution Library Routines are not guaranteed to be async signal safe, they might acquire a lock that may already be held when an OMPT callback is involved.

5.1   Enumerate States Supported by an OpenMP Runtime (Mandatory)

An OpenMP runtime system is allowed to support other states in addition to those described in this document. For instance, a particular runtime system may want to provide more detail about the nature of runtime overhead, e.g., to differentiate between overhead associated with setting up a parallel region and overhead associated with setting up a task. Further, a tool need not report all states defined herein, e.g., if state tracking for a particular state would be too expensive. To enable a tool to identify all states that an OpenMP runtime system implements, OMPT provides the following interface for enumerating all states that a particular runtime system implementation may report.

```
OMPT_API int ompt_enumerate_state(
  ompt_state_t current_state,
  ompt_state_t *next_state,
  const char **next_state_name
);
```

To begin enumerating the states that a runtime system supports, the value `ompt_state_first` should be supplied for `current_state` in the call to `ompt_enumerate_state` that begins the enumeration. The argument `next_state` is a pointer to an `ompt_state_t` that will be set to the code for the next state in the enumeration. The argument `next_state_name` is a pointer to a location that will be filled in with a pointer to the name associated with `next_state`. Subsequent invocations of `ompt_enumerate_state` should pass the code returned in `next_state` by the prior call. Whenever one or more states are left in the enumeration, `ompt_enumerate_state` will return 1. When the last state in the enumeration is passed to `ompt_enumerate_state` as `current_state`, the function will return 0 indicating that the enumeration is complete. An example of how to enumerate the states supported by an OpenMP runtime system is shown below:

```
ompt_state_t state = ompt_state_first;
const char *state_name;
while (ompt_enumerate_state(state, &state, &state_name)) {
  // tool notes that the runtime supports ompt_state_t "state"
  // associated with "state_name"
}
```

5.2 Thread Inquiry (Mandatory)

Function `ompt_get_thread_id` is the inquiry function to determine the thread ID of the current thread.

```
OMPT_API ompt_thread_id_t ompt_get_thread_id(void);
```

This function returns the value 0 if the thread is unknown to the OpenMP runtime. *This function is async signal safe.*

Function `ompt_get_state` is the inquiry function to determine the state of the current thread.

```
OMPT_API ompt_state_t ompt_get_state(
  ompt_wait_id_t *wait_id
);
```

The function returns the state of the current thread and updates the location specified by `wait_id` with the wait identifier associated with the current state, if any, or zero if the wait ID is undefined. One may pass NULL for `wait_id` if the tool does not want a wait ID returned. *This function is async signal safe.*

5.3 Parallel Region Inquiry (Mandatory)

Function `ompt_get_parallel_id` returns the unique ID associated with a parallel region:

```
OMPT_API ompt_parallel_id_t ompt_get_parallel_id(
  int ancestor_level
);
```

Outside a parallel region, `ompt_get_parallel_id` should return 0. If a thread is in the idle state, then `ompt_get_parallel_id` should return 0. In all other cases, the thread should return the ID of the enclosing parallel region, even if the thread is waiting at a barrier.

The function takes an ancestor level as an argument. By specifying different values for ancestor level, one can access information about all enclosing parallel regions. The meaning of different values for the `ancestor_level` argument to `ompt_get_parallel_id` is given in Table 2.

ancestor level	meaning
0	current parallel region
1	parallel region directly enclosing region at ancestor level 0
2	parallel region directly enclosing region at ancestor level 1
...	

Table 2: Meaning of different values for the `ancestor_level` argument to `ompt_get_parallel_id`.

The function returns the value 0 when requesting higher levels of ancestry than exist. *This function is async signal safe.*

Function `ompt_get_parallel_team_size` returns the number of threads associated with a parallel region:

```
OMPT_API int ompt_get_parallel_team_size(
  int ancestor_level
);
```

This function returns the value -1 when requesting higher levels of ancestry than exist. *This function is async signal safe.*

5.4 Task Region Inquiry (Mandatory)

Two inquiry functions provide information about both implicit and explicit tasks:

```
OMPT_API ompt_task_id_t ompt_get_task_info(
  int depth,
  ompt_task_type_t *type
);

OMPT_API ompt_frame_t *ompt_get_task_frame(
  int depth
);
```

Both `ompt_get_task_id` and `ompt_get_task_frame` identify a target task by a depth. Depth 0 refers to the current task. Information about other tasks in the current execution context may be queried at higher depths. *Both functions are async signal safe.*

The function `ompt_get_task_info` returns an ID for the specified task region. If presented with a non-NULL `type` pointer, it will return information about the type of the task at the specified depth. A task may be of the serial, implicit, explicit, or target type.

If a tool requests a task ID at a depth deeper than the dynamic nesting of implicit and explicit tasks in the current execution context, `ompt_get_task_id` will return 0—the value reserved to indicate an invalid task.

Function `ompt_get_task_frame` returns an `ompt_frame_t` record that identifies a contiguous interval of frames on the call stack. This interval of stack frames represents activity by the application rather than the OpenMP runtime system.

Using return values from `ompt_get_task_frame`, a tool that collects the call stack of a thread can analyze frames in the call stack and identify ones that exist on behalf of the runtime system.[3] This capability enables a tool to map from an implementation-level view back to the source-level view familiar to application developers. Appendix B discusses an example that illustrates the use of `ompt_get_task_frame` with multiple threads and nested parallelism.

5.5 Target Device Inquiry (Mandatory)

Function `ompt_get_num_devices` returns the number of visible devices:

---

[3]A frame on the call stack is said to exist on behalf of an OpenMP runtime system if it is a frame for a runtime system routine, or if it belongs to a library function called by a runtime system routine, directly or indirectly.

```
OMPT_API int ompt_get_num_devices(void);
```

This inquiry function is only supported on the host. If the inquiry function is invoked by a thread executing in the scope of a `target`, `target data`, or `target update` construct, the return value is undefined. *This function is async signal safe.*

Function `ompt_get_device_info`, whose type signature is shown below, is used to acquire information about an attached device.

```
OMPT_API int ompt_get_device_info(
    int device_id,
    const char **type,
    ompt_function_lookup_t *lookup
);
```

If `device_id` refers to a valid device, the function will return 0 indicating success; otherwise, it will return a non-zero value and the values of its return parameters are undefined. If a non-NULL pointer is passed for `type`, the runtime will set `*type` to point to a character string that identifies at a minimum the type of the device. It might also indicate the software stack it is running and perhaps even the version number of one or more components in that stack. An example string could be "NVIDIA Tesla M2050, compute capability 2.0, CUDA 5.5." A tool can use such a type string to determine if it has any special knowledge about hardware and software of such a device. If a non-NULL pointer is passed for `lookup`, the runtime will set the value of `*lookup` to point to a function that can be used to look up device-specific API functions. The names of any device-specific API functions and their type signatures are outside the scope of the OMPT specification.

Function `ompt_get_target_device_id` returns the device identifier for the active target device:

```
OMPT_API int ompt_get_target_device_id(void);
```

This inquiry function is only supported on the host. If the inquiry function is invoked by a thread not executing in the scope of a `target`, `target data`, or `target update` construct, then it will return a value of -1. *This function is async signal safe.*

Host and target devices are typically distinct and run independently. If a host and target device are different hardware components, they may use different clock generators. For this reason, there may be no common time base for ordering host-side and device-side events. Function `ompt_get_target_device_time`, with the type signature below returns the current time stamp on the specified target device:

```
OMPT_API ompt_target_device_time_t ompt_get_target_device_time(
    int device_id
);
```

This inquiry function can be used to acquire information that can be used to align time stamps from the target device with time stamps from the host or other devices.

6 Target Device Tracing (Optional)

Target devices typically operate asynchronously with respect to a host. It may not be practical or possible to make event callbacks on a target device. These characteristics motivate a design of a performance monitoring interface for target devices where:

- a target device may execute asynchronously from the host,

- the target device records events that occur during its execution in a trace buffer,

- when a trace buffer fills on a device, the device provides it to the OpenMP runtime on the host,

- the OpenMP runtime interrupts execution on the host by invoking a tool-supplied callback function to request a new trace buffer,

- the OpenMP runtime interrupts execution on the host by invoking a tool-supplied callback function to process and empty a trace buffer as necessary or useful.

return code	meaning
0	error
1	event may occur but no tracing is possible
2	event will never occur in runtime
3	event may occur and will be traced when convenient
4	event may occur and will always be traced if event occurs

Table 3: Meaning of return codes for `ompt_record_set`.

Section 6.1 describes how to enable or disable tracing on a target device for specific OMPT events. Section 6.2 describes how to enable or disable tracing on a target device for specific native events. Section 6.3 describes how to start and stop event tracing on a device.

All functions in the target device tracing control API described in this section are marked with `OMPT_API`. These functions should not be global symbols in an OpenMP runtime system implementation to avoid tempting tool developers to call them directly. Section 7.2 describes how a tool will obtain pointers to these functions.

6.1 Enabling and Disabling Tracing for OMPT Record Types

Function `ompt_record_set_t` allows a tool to enable or disable the recording of one or more types of trace record types:

```
OMPT_API int ompt_record_set(
  int device_id,                    /* target device id          */
  ompt_bool enable,                 /* enable or disable         */
  ompt_record_type_t rtype          /* a record type             */
);
```

The argument `device_id` indicates the target device whose performance monitoring may be altered by invoking this function. The boolean `enable` indicates whether recording of events of type `rtype` may be enabled or disabled by this invocation. Actual record types are specified using positive numbers; an `rtype` of 0 indicates that all record types will be enabled or disabled. If the function `ompt_record_set_t` is called for a device for which recording is currently active, its behavior is undefined.

Table 3 shows the possible return codes for `ompt_record_set`.

6.2 Enabling and Disabling Tracing for Native Record Types

Function `ompt_record_native_set_t` allows a tool to enable or disable the recording of native trace records for a device:

```
OMPT_API int ompt_record_native_set(
  int device_id,                    /* target device id             */
  ompt_bool enable,                 /* enable or disable            */
  void *info,                       /* info for native event        */
  void **status                     /* status of request           */
);
```

The argument `device_id` indicates the target device whose performance monitoring may be altered by invoking this function. The boolean `enable` indicates whether recording of events may be enabled or disabled by this invocation. Native trace records are specified by an `info` structure whose layout is device dependent. Information about a request is returned from `ompt_record_native_set` by setting the `status` to point to a record containing whatever information is appropriate for the request / device pair. If the function `ompt_record_native_set` is called for a device for which recording is currently active, its behavior is undefined.

6.3 Start and Stop Recording Traces

To start recording a tool needs to register a *buffer request* callback that will supply a device with a buffer to deposit events and a *buffer complete* callback that will be invoked by the OpenMP runtime system to empty a buffer containing event records. A device's offloading runtime library is responsible for invoking these callbacks on a thread that is not an OpenMP master or worker. *The buffer request and completion callbacks are not required to be async-signal safe.*

The *buffer request* callback has the following type signature:

```
typedef void (*ompt_buffer_request_callback_t) (
  int device_id,
  ompt_buffer_t **buffer,
  size_t *bytes
);
```

As necessary, the OpenMP runtime will asynchronously invoke `ompt_buffer_request_callback_t` to request a buffer to store event records for device `device_id`. A tool should set `*buffer` to point to a buffer where device events may be recorded and `*bytes` to the length of that buffer. A buffer request callback may set `*bytes` to 0 if it does not want to provide a buffer for any reason. If a callback sets `*bytes` to 0, further recording of events for the device will be disabled until the next invocation of `ompt_recording_start`. This will cause the OpenMP runtime to drop future records for a device until recording is restarted.

The *buffer complete* callback has the following type signature:

```
typedef void (*ompt_buffer_complete_callback_t) (
  int device_id,
  ompt_buffer_t *buffer,
  size_t bytes,
  ompt_buffer_cursor_t begin,
  ompt_buffer_cursor_t end
);
```

The OpenMP runtime triggers `ompt_buffer_complete_callback_t` when no further records will be recorded in an event buffer and all records written to the buffer are valid. The argument `device_id` indicates the device whose events the buffer contains. The argument `buffer` is the address of a buffer previously allocated by the *buffer request* callback. The argument `bytes` indicates the full size of the buffer. The arguments `begin` and `end`, respectively, are opaque cursors that indicates the position at the beginning of the first record in the buffer and the position after the last record in the buffer. If `begin` is equal to `end`, the buffer is empty.

Under normal operating conditions, every event buffer provided to a device by a *buffer request* callback will receive a *buffer complete* callback before the OpenMP runtime shuts down. If an exceptional condition terminates execution of an OpenMP program, the OpenMP runtime may choose to not provide a *buffer complete* callback for buffers provided to any device.

To start and stop tracing for a specific device, a tool calls the functions `ompt_recording_start` and `ompt_recording_stop` with the following type signatures:

```
OMPT_API int ompt_recording_start (
  int device_id,
  ompt_buffer_request_callback_t request,
  ompt_buffer_complete_callback_t complete,
);

OMPT_API int ompt_recording_stop(
  int device_id
);
```

6.4 Processing Trace Records in a Buffer

There are several routines that need to be used together to process event records deposited in a buffer by a device. Function `ompt_buffer_cursor_advance`, with the type signature shown below,

```
OMPT_API int ompt_buffer_cursor_advance(
  ompt_buffer_t *buffer,
  ompt_buffer_cursor_t current,
  ompt_buffer_cursor_t *next
);
```

advances from one record in the specified buffer to the next. It returns 0 if the advance is successful and 1 if `current` indicates a position before the first record of the buffer or a position at or beyond the last record in the buffer.

The function `ompt_record_get_type` enables a tool to inspect the type of a record to determine whether it is both a known type and worth processing further.

```
OMPT_API ompt_record_type_t ompt_record_get_type(
  ompt_buffer_t *buffer,
  ompt_buffer_cursor_t current
);
```

`ompt_record_get_type` returns either `ompt_record_ompt` if the record represents a OMPT event, `ompt_record_notype` if the cursor is out of bounds, or `ompt_record_native` if the record represents a device native record type that does not represent an OMPT event record, Appendix A.6 defines the corresponding enumeration type for `ompt_record_type_t`. Section 6.5 describes the interface to use for accessing native record types.

To inspect the information for an OMPT record, a tool invokes the following function:

```
OMPT_API ompt_record_t *ompt_record_get(
  ompt_buffer_t *buffer,
  ompt_cursor_t current
);
```

This function returns a pointer that may point into the record buffer, or it may point into thread local storage where the information extracted from a record was assembled. The information available for an event depends upon its type. For this purpose, Appendix A.6 defines a union type that will be used to return information for different OMPT event record types. A subsequent call to `ompt_record_get` may overwrite the contents of the fields in the record returned by a prior invocation.

6.5 Processing Native Trace Records in a Buffer

To inspect a native trace record for a device, a tool invokes the following function to obtain a pointer to a trace record in the native format for the device associated with buffer:

```
OMPT_API void *ompt_record_native_get(
  ompt_buffer_t *buffer,
  ompt_cursor_t current
);
```

The pointer returned may point into the trace buffer, or it may point into thread local storage where the information extracted from a trace record was assembled. The information available for a native event depends upon its type. A subsequent call to `ompt_record_native_get` may overwrite the contents of the fields in the record returned by a prior invocation.

Function `ompt_record_native_get_abstract` can be used by a tool to acquire basic information about a native record and handle it even without full support for native records from the associated device.

omp-tool-var value	action
enabled	The OpenMP runtime will call `ompt_tool` before initializing itself.
disabled	The OpenMP runtime will not call `ompt_tool`, regardless of whether a tool is present or not.

Table 4: OpenMP runtime responses to settings of the *omp-tool-var* ICV.

```
OMPT_API ompt_record_native_abstract_t ompt_record_native_get_abstract(
  void *native_record
);
```

A `ompt_record_native_abstract_t` record contains several pieces of information that a tool can use to process a native record that it may not fully understand. The record `kind` field indicates whether the record is informational (`ompt_record_native_kind_info`) or represents an event (`ompt_record_native_kind_event`). Knowing whether a record is informational or represents an event can help a tool determine how to present the record. The record `type` field is a character string that provides a meaningful name a tool might want to use to describe the event to a user. The `start_time` and `end_time` fields are used to place an event in time. The times are relative to the device clock. If an event has no associated `start_time` and/or `end_time`, the value of an unavailable field will be the distinguished value `ompt_time_none`. Thehardware id field, `hwid`, is used to indicate the location on the device where the event occurred. A `hwid` may represent a hardware abstraction such as a core or a hardware thread id. The precise semantics of a `hwid` value for a device is defined by the implementer of the software stack for the device. If there is no `hwid` associated with a record, the value of `hwid` shall be `ompt_hwid_none`. Finally, `target_task_id` indicates the target task with which this record is associated. If there is no associated target task or the associated target task is unknown, `target_task_id` will be 0.

7 Initializing OMPT Support for Tools (Mandatory)

Section 7.1 describes how an OpenMP runtime uses the value of the *omp-tool-var* ICV to decide whether or not an OpenMP runtime will try to register a performance tool prior to runtime initialization. Section 7.2 explains how a registered performance tool initializes itself.

7.1 Tool Registration

The `OMP_TOOL` environment variable sets the *omp-tool-var* ICV, which controls whether or not an OpenMP runtime will try to register a performance tool or not. The value assigned to `OMP_TOOL` is case insensitive and may have leading and trailing white space. The value of this environment variable must be `enabled` or `disabled`. If `OMP_TOOL` is set to any value other than `enabled` or `disabled`, an OpenMP runtime will print a fatal error to the standard error file descriptor indicating that an illegal value had been supplied for `OMP_TOOL` and the program's execution will terminate. If `OMP_TOOL` is not defined, the default value for *omp-tool-var* is `enabled`.

Table 4 describes the action that an OpenMP runtime system will take in response to possible values of *omp-tool-var*. If the value of *omp-tool-var* is `enabled`, the runtime will attempt to register a performance tool by calling the function `ompt_tool` before performing runtime initialization. The signature for `ompt_tool` is shown below:

```
extern "C" {
  ompt_initialize_fn_t ompt_tool(void);
};
```

If an OpenMP runtime calls `ompt_tool` but no tool-provided implementation of `ompt_tool` is present, a weak version of `ompt_tool` provided by the runtime will return NULL. If a tool-provided version of `ompt_tool` is present, it may return NULL indicating that the tool declines to register itself with the runtime; otherwise, the

tool may register itself with the runtime by returning a non-NULL pointer to a function with type signature `ompt_initialize_fn_t`. The type signature for `ompt_initialize_fn_t` is described in Section 7.2. Since only one tool-provided definition of `ompt_tool` will be seen by an OpenMP runtime, only one tool may register itself. If a tool-supplied implementation of `ompt_tool` returns a non-NULL initializer, the OpenMP runtime system will maintain state information for each OpenMP thread and will perform OMPT event callbacks registered during tool initialization.

After a process fork, if OpenMP is re-initialized in the child process, the OpenMP runtime system in the child process will call `ompt_tool` under the same conditions as it would for any process.

7.2 Tool Initialization

When an OpenMP runtime system receives a non-NULL pointer to a tool initializer function with signature `ompt_initialize_fn_t` as the result of a call to `ompt_tool`, the runtime will call the tool initializer immediately after the runtime fully initializes itself. The initializer must be called before beginning execution of any OpenMP construct or completing any execution environment routine invocation. The signature for the tool initializer callback is shown below:

```
typedef void (*ompt_initialize_fn_t) (
  const char *runtime_version,
  unsigned int ompt_version,
  ompt_function_lookup_t lookup
);
```

The first argument to `ompt_initialize` is a version string that unambiguously identifies an OpenMP runtime system implementation. This argument is useful to tool developers trying to debug a statically-linked executable that contains both a tool implementation and an OpenMP runtime system implementation. Knowing exactly what version of an OpenMP runtime system is present in a binary may be helpful when diagnosing a problem, e.g., identifying an old runtime system that may be incompatible with a newer tool.

The second argument `ompt_version` indicates the version of the OMPT interface supported by a runtime system. The version of OMPT described by this document is known as version 2.

The two principal duties of a tool initializer are looking up pointers to all OMPT API functions that the tool uses and to registering tool callbacks. These two operations are described below.

Looking up functions in the OMPT API. The third argument to `ompt_initialize` is `lookup`—a callback that a tool must use to interrogate the runtime system to obtain pointers to OMPT interface functions. The type signature for `lookup` is:

```
typedef ompt_interface_fn_t (*ompt_function_lookup_t)(
  const char *interface_function_name
);
```

The `lookup` callback is necessary because when the OpenMP runtime is dynamically loaded by a shared library, the OMPT interface functions provided by the library may not be visible to a preloaded tool. Within a tool, one uses `lookup` to obtain function pointers to each function in the OMPT API. All functions in the OMPT API are marked with `OMPT_API`. These functions should not be global symbols in an OpenMP runtime system implementation to avoid tempting tool developers to call them directly.

Below, we show how to use the `lookup` function to obtain a pointer to the OMPT API function `ompt_get_thread_id`:

```
ompt_interface_fn_t ompt_get_thread_id_fn = lookup("ompt_get_thread_id");
```

Other functions in the OMPT API may be looked up analogously. If a named function is not available in an OpenMP runtime's implementation of OMPT, `lookup` will return NULL.

return code	meaning
0	callback registration error (e.g., callbacks cannot be registered at this time).
1	event may occur; no callback is possible
2	event will never occur in runtime
3	event may occur; callback invoked when convenient
4	event may occur; callback always invoked when event occurs

Table 5: Meaning of return codes for `ompt_set_callback`.

Registering Callbacks. Tools register callbacks to receive notification of various events that occur as an OpenMP program executes using the OMPT API function `ompt_set_callback`. The signature for this function is shown below

```
OMPT_API int ompt_set_callback(
  ompt_event_t event,
  ompt_callback_t callback
);
```

The function `ompt_set_callback` may only be called within the implementation of `ompt_initialize`. The possible return codes for `ompt_set_callback` and their meaning is shown in Table 5. Registration of supported callbacks may fail if this function is called outside `ompt_initialize`. The `ompt_callback_t` type for a callback does not reflect the actual signature of the callback; OMPT uses this generic type to avoid the need to declare a separate registration function for each actual callback type.

The OMPT API function `ompt_get_callback` may be called at any time to inspect whether a callback has been registered or not.

```
OMPT_API int ompt_get_callback(
  ompt_event_t event,
  ompt_callback_t *callback
);
```

If a callback has been registered, `ompt_get_callback` will return 1 and set `callback` to the address of the callback function; otherwise, `ompt_get_callback` will return 0.

8 Tool Control for Applications (Mandatory)

In OMPT, there is only one application-facing routine: `ompt_control`. An application may call the function `ompt_control` to control tool operation. While tool support for `ompt_control` is optional, the runtime is required to pass a control command to a tool if the tool registered a callback with the `ompt_event_control` event. As an application-facing routine, this function has type signatures for both C and Fortran:

```
C:
    void ompt_control(uint64_t command, uint64_t modifier);


Fortran:
    subroutine ompt_control(command, modifier)
    integer*8 command, modifier
```

A classic use case for `ompt_control` is for an application to start and stop data collection by a tool. A tool may allow an application to turn monitoring on and off multiple times during an execution to monitor only code regions of interest. To simplify use in this common case, OMPT defines four values for `command`:

```
1: start or restart monitoring
2: pause monitoring
```

```
3: flush tool buffers and continue monitoring
4: permanently turn off monitoring
```

A command code of 1 asks a tool to start or restart monitoring if it is off. If monitoring is already on, this command is idempotent. If monitoring has already been turned off permanently, this command will have no effect. A command code of 2 asks a tool to temporarily turn monitoring off. If monitoring is already off, it is idempotent. A command code of 3 asks a tool to flush any performance data that it has buffered and then continue monitoring. A command code of 4 turns monitoring off permanently; the tool may perform finalization at this point and write all of its outputs.

Other values of command and modifier appropriate for any tool will be tool specific. Tool-specific commands codes must be ≥ 64. Tools must ignore command codes that they are not explicitly designed to handle and implement callbacks for such codes as no-ops.

9   Final Notes

Developers of many trace-based tools would prefer to have `ompt_event_implicit_task_begin` and `ompt_event_implicit_task_end` included in the mandatory events. As we acquire more experience with OMPT implementations, perhaps these events will be added to the set of mandatory events, if they don't add much overhead to OpenMP runtime implementations when OMPT is disabled.

Acknowledgments

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A   OMPT Interface Type Definitions

A.1   Runtime States

When OMPT is enabled, an OpenMP runtime system will maintain information about the state of each OpenMP thread. Below we define an enumeration type that specifies the set of runtime states. The purpose of these states is described in Section 2.

```
typedef enum {
  /* work states (0..15) */
  ompt_state_work_serial          = 0x00, /* working outside parallel  */
  ompt_state_work_parallel        = 0x01, /* working within parallel   */
  ompt_state_work_reduction       = 0x02, /* performing a reduction    */

  /* idle (16..31) */
  ompt_state_idle                 = 0x10, /* waiting for work          */

  /* overhead states (32..63) */
  ompt_state_overhead             = 0x20, /* non-wait overhead         */

  /* barrier wait states (64..79) */
  ompt_state_wait_barrier         = 0x40, /* generic barrier           */
  ompt_state_wait_barrier_implicit = 0x41, /* implicit barrier         */
  ompt_state_wait_barrier_explicit = 0x42, /* explicit barrier         */

 /* task wait states (80..95) */
  ompt_state_wait_taskwait        = 0x50, /* waiting at a taskwait     */
  ompt_state_wait_taskgroup       = 0x51, /* waiting at a taskgroup    */

  /* mutex wait states (96..111) */
  ompt_state_wait_lock            = 0x60, /* waiting for lock          */
  ompt_state_wait_nest_lock       = 0x61, /* waiting for nest lock     */
  ompt_state_wait_critical        = 0x62, /* waiting for critical      */
  ompt_state_wait_atomic          = 0x63, /* waiting for atomic        */
  ompt_state_wait_ordered         = 0x64, /* waiting for ordered       */

  /* misc (112.127) */
  ompt_state_undefined            = 0x70, /* undefined thread state    */
  ompt_state_first                = 0x71, /* initial enumeration state */
} ompt_state_t;
```

A.2 Runtime Event Callbacks

When OMPT support for a tool is enabled, OMPT enables a tool to indicate interest in receiving notification about certain OpenMP runtime events by registering callbacks. When those events occur during execution, OMPT will invoke the registered callback in the appropriate thread context. Below we define an enumeration type that specifies the set of event callbacks that may be supported by an OpenMP runtime system. The purpose of these callbacks is described in Section 3.

```
typedef enum {
  /*--- Mandatory Events ---*/
  ompt_event_parallel_begin        = 1,  /* parallel create          */
  ompt_event_parallel_end          = 2,  /* parallel exit            */

  ompt_event_task_begin            = 3,  /* task create              */
  ompt_event_task_end              = 4,  /* task destroy             */

  ompt_event_thread_begin          = 5,  /* thread begin             */
  ompt_event_thread_end            = 6,  /* thread end               */

  ompt_event_control               = 7,  /* support control calls    */

  ompt_event_runtime_shutdown      = 8,  /* runtime shutdown         */

  /*--- Optional Events (blame shifting) ---*/
  ompt_event_idle_begin            = 9,  /* begin idle state         */
  ompt_event_idle_end              = 10, /* end idle state           */

  ompt_event_wait_barrier_begin    = 11, /* begin wait at barrier    */
  ompt_event_wait_barrier_end      = 12, /* end wait at barrier      */
  ompt_event_wait_taskwait_begin   = 13, /* begin wait at taskwait   */
  ompt_event_wait_taskwait_end     = 14, /* end wait at taskwait     */
  ompt_event_wait_taskgroup_begin  = 15, /* begin wait at taskgroup  */
  ompt_event_wait_taskgroup_end    = 16, /* end wait at taskgroup    */

  ompt_event_release_lock          = 17, /* lock release             */
  ompt_event_release_nest_lock_last = 18, /* last nest lock release  */
  ompt_event_release_critical      = 19, /* critical release         */
  ompt_event_release_atomic        = 20, /* atomic release           */
  ompt_event_release_ordered       = 21, /* ordered release          */

  /*--- Optional Events (synchronous events) --- */
  ompt_event_implicit_task_begin   = 22, /* implicit task create     */
  ompt_event_implicit_task_end     = 23, /* implicit task destroy    */

  ompt_event_initial_task_begin    = 24, /* initial task create      */
  ompt_event_initial_task_end      = 25, /* initial task destroy     */

  ompt_event_task_switch           = 26, /* task switch              */

  ompt_event_loop_begin            = 27, /* task at loop begin       */
  ompt_event_loop_end              = 28, /* task at loop end         */

  ompt_event_sections_begin        = 29, /* task at section begin    */
  ompt_event_sections_end          = 30, /* task at section end      */
```

```
ompt_event_single_in_block_begin    = 31, /* task at single begin      */
ompt_event_single_in_block_end      = 32, /* task at single end        */
ompt_event_single_others_begin      = 33, /* task at single begin      */
ompt_event_single_others_end        = 34, /* task at single end        */

ompt_event_workshare_begin          = 35, /* task at workshare begin   */
ompt_event_workshare_end            = 36, /* task at workshare end     */

ompt_event_master_begin             = 37, /* task at master begin      */
ompt_event_master_end               = 38, /* task at master end        */

ompt_event_barrier_begin            = 39, /* task at barrier begin     */
ompt_event_barrier_end              = 40, /* task at barrier end       */

ompt_event_taskwait_begin           = 41, /* task at taskwait begin    */
ompt_event_taskwait_end             = 42, /* task at task wait end     */

ompt_event_taskgroup_begin          = 43, /* task at taskgroup begin   */
ompt_event_taskgroup_end            = 44, /* task at taskgroup end     */

ompt_event_release_nest_lock_prev   = 45, /* prev nest lock release    */

ompt_event_wait_lock                = 46, /* lock wait                 */
ompt_event_wait_nest_lock           = 47, /* nest lock wait            */
ompt_event_wait_critical            = 48, /* critical wait             */
ompt_event_wait_atomic              = 49, /* atomic wait               */
ompt_event_wait_ordered             = 50, /* ordered wait              */

ompt_event_acquired_lock            = 51, /* lock acquired             */
ompt_event_acquired_nest_lock_first = 52, /* 1st nest lock acquired    */
ompt_event_acquired_nest_lock_next  = 53, /* next nest lock acquired   */
ompt_event_acquired_critical        = 54, /* critical acquired         */
ompt_event_acquired_atomic          = 55, /* atomic acquired           */
ompt_event_acquired_ordered         = 56, /* ordered acquired          */

ompt_event_init_lock                = 57, /* lock init                 */
ompt_event_init_nest_lock           = 58, /* nest lock init            */

ompt_event_destroy_lock             = 59, /* lock destruction          */
ompt_event_destroy_nest_lock        = 60, /* nest lock destruction     */

ompt_event_flush                    = 61, /* after executing flush     */

/*--- Mandatory Events (target task events) ---*/
ompt_event_target_task_begin        = 62, /* target begin              */
ompt_event_target_task_end          = 63, /* target end                */

/*--- Optional Events (target data, update, map) ---*/
ompt_event_target_data_begin        = 64, /* target data begin         */
ompt_event_target_data_end          = 65, /* target data end           */

ompt_event_target_update_begin      = 66, /* target update begin       */
ompt_event_target_update_end        = 67, /* target update end         */
```

```
    ompt_event_data_map_begin          = 68, /* before data mapping       */
    ompt_event_data_map_end            = 69, /* after data mapping        */

    ompt_event_task_dependence         = 70  /* new task-dependence       */
} ompt_event_t;
```

A.3 Miscellaneous Type Definitions

This section describes miscellaneous enumeration types used by tool callbacks.

```
typedef enum ompt_thread_type_e {
  ompt_thread_initial  = 1,
  ompt_thread_worker   = 2,
  ompt_thread_other    = 3
} ompt_thread_type_t;

typedef enum  ompt_task_type_e {
  ompt_task_serial     = 1,
  ompt_task_implicit   = 2,
  ompt_task_explicit   = 3,
  ompt_task_target     = 4
} ompt_task_type_t;

typedef enum ompt_invoker_e {
  ompt_invoker_program = 0,          /* program invokes master task  */
  ompt_invoker_runtime = 1           /* runtime invokes master task  */
} ompt_invoker_t;

typedef enum ompt_task_dependence_type_e {
  ompt_task_dependence_type_out   = 1,
  ompt_task_dependence_type_in    = 2,
  ompt_task_dependence_type_inout = 3
} ompt_task_dependence_type_t;

typedef struct {
  void *variable_addr;
  size_tlen;
  ompt_dependence_type_t type;
} ompt_task_dependence_t

typedef enum ompt_target_map_flag_e {
  ompt_target_map_flag_sync = 1,
  ompt_target_map_flag_to = 2
} ompt_target_map_flag_t;

#define ompt_hwid_none (-1)
#define ompt_time_none (~0ULL)
```

A.4   Type Signatures for Tool Callbacks

This section describes type signatures for all callbacks that a tool may register to receive from an OpenMP runtime. Section 3 describes OpenMP runtime events and registration of callback functions with these type signatures.

```
/* initialization */
typedef void (*ompt_interface_fn_t)(
  void
);

typedef ompt_interface_fn_t (*ompt_function_lookup_t)(
  const char *entry_point           /* entry point to look up       */
);

/* threads */
typedef void (*ompt_thread_callback_t) ( /* for thread              */
  ompt_thread_id_t thread_id        /* ID of thread                 */
);

typedef void (*ompt_thread_type_callback_t) ( /* for thread         */
  ompt_thread_type_t thread_type,   /* type of thread               */
  ompt_thread_id_t thread_id        /* ID of thread                 */
);

typedef void (*ompt_wait_callback_t) ( /* for wait                  */
  ompt_wait_id_t wait_id            /* wait ID                      */
);

/* parallel & workshares */
typedef void (*ompt_parallel_callback_t) ( /* for inside parallel   */
  ompt_parallel_id_t parallel_id,   /* ID of parallel region        */
  ompt_task_id_t  task_id           /* ID of task                   */
);

typedef void (*ompt_new_workshare_callback_t) ( /* for workshares   */
  ompt_parallel_id_t parallel_id,   /* ID of parallel region        */
  ompt_task_id_t  task_id,          /* ID of task                   */
  void *workshare_function          /* pointer to outlined function */
);

typedef void (*ompt_new_parallel_callback_t) ( /* for new parallel  */
  ompt_task_id_t parent_task_id,    /* ID of parent task            */
  ompt_frame_t *parent_task_frame,  /* frame data of parent task    */
  ompt_parallel_id_t parallel_id,   /* ID of parallel region        */
  uint32_t requested_team_size,     /* requested number of threads  */
  void *parallel_function,          /* pointer to outlined function */
  ompt_invoker_t invoker            /* who invokes master task?     */
);

typedef void (*ompt_end_parallel_callback_t) (
  ompt_parallel_id_t parallel_id,   /* id of parallel region        */
  ompt_task_id_t task_id,           /* id of task                   */
  ompt_invoker_t invoker            /* who invokes master task?     */
);
```

```
/* tasks */
typedef void (*ompt_task_callback_t) ( /* for tasks              */
  ompt_task_id_t  task_id           /* ID of task                */
);

typedef void (*ompt_task_switch_callback_t) ( /* for task switch   */
  ompt_task_id_t suspended_task_id, /* ID of suspended task      */
  ompt_task_id_t resumed_task_id    /* ID of resumed task        */
  );

typedef void (*ompt_new_task_callback_t) ( /* for new tasks       */
  ompt_task_id_t parent_task_id,    /* ID of parent task         */
  ompt_frame_t *parent_task_frame,  /* frame data for parent task   */
  ompt_task_id_t new_task_id,       /* ID of created task        */
  void *new_task_function           /* pointer to outlined function */
);

typedef void (*ompt_new_target_task_callback_t) (
  ompt_task_id_t parent_task_id,    /* ID of parent task         */
  ompt_frame_t *parent_task_frame,  /* frame data for parent task   */
  ompt_task_id_t target_task_id,    /* ID of target task         */
  int device_id,                    /* ID of the device          */
  void *target_task_function        /* pointer to outlined function */
);

/* target device */
typedef void (*ompt_new_target_data_callback_t) (
  ompt_task_id_t task_id,           /* ID of encountering task      */
  int device_id,                    /* ID of the device          */
  void *target_data_code            /* ptr to target data code      */
);

typedef void (*ompt_new_data_map_callback_t) (
  ompt_task_id_t task_id,           /* ID of encountering task      */
  int device_id,                    /* ID of the device          */
  void *host_addr,                  /* host  address of the data    */
  void *device_addr,                /* device address of the data   */
  size_t bytes,                     /* number of bytes mapped       */
  uint32_t mapping_flags,           /* sync/async, to/from       */
  void *target_map_code             /* ptr to target map code       */
);

typedef void (*ompt_data_map_done_callback_t) (
  ompt_task_id_t task_id,           /* ID of current task          */
  int device_id,                    /* ID of the device          */
  void *host_addr,                  /* host  address of the data    */
  void *device_addr,                /* device address of the data   */
  size_t bytes,                     /* number of bytes mapped       */
  uint32_t mapping_flags            /* sync/async, to/from       */
);

/* task dependences */
```

```
typedef void (*ompt_task_dependences_callback_t) (
  ompt_task_id_t task_id,          /* ID of task with dependences  */
  ompt_task_dependence_t *deps,    /* vector of task dependences   */
  int ndeps                        /* number of dependences        */
);


/* program */
typedef void (*ompt_control_callback_t) ( /* for control          */
  uint64_t command,                /* command of control call      */
  uint64_t modifier                /* modifier of control call     */
);


typedef void (*ompt_callback_t)(    /* for shutdown                 */
  void
);
```

Placeholder callback signature.   The type `ompt_callback_t` is also a placeholder signature used only
by the tool callback registration interface. Only one callback registration function is defined and it expects
that the callback supplied will be cast into type `ompt_callback_t`, regardless of its actual type signature.
This approach avoids the need for a separate registration routine for each unique tool callback signature.

A.5   OMPT Inquiry and Control API

The functions in this section are not global function symbols in an OpenMP runtime system. These functions can be looked up by name using the `ompt_function_lookup_t` function passed to `ompt_initialize`, as described in Section 7.2 and Appendix A.7.

```
/* callback management */
OMPT_API int ompt_set_callback( /* register a callback for an event                */
  ompt_event_t event,          /* the event of interest                           */
  ompt_callback_t callback     /* function pointer for the callback               */
);

OMPT_API int ompt_get_callback( /* return the current callback for an event (if any)   */
  ompt_event_t event,          /* the event of interest                           */
  ompt_callback_t *callback    /* pointer to receive the return value             */
);

/* state inquiry */
OMPT_API int ompt_enumerate_state( /* extract the set of states supported         */
  ompt_state_t current_state,   /* current state in the enumeration               */
  ompt_state_t *next_state,     /* next state in the enumeration                  */
  const char **next_state_name  /* string description of next state               */
);

/* thread inquiry */
OMPT_API ompt_thread_id_t ompt_get_thread_id( /* identify the current thread      */
  void
);

OMPT_API ompt_state_t ompt_get_state( /* get the state for a thread               */
  ompt_wait_id_t *wait_id       /* for wait states: identify what awaited         */
);

/* parallel region inquiry */
OMPT_API ompt_parallel_id_t ompt_get_parallel_id( /* identify a parallel region       */
  int ancestor_level /*  how many levels the ancestor is removed from the current region */
);

OMPT_API int ompt_get_parallel_team_size( /* query # threads in a parallel region        */
  int ancestor_level /*  how many levels the ancestor is removed from the current region */
);

/* task inquiry */
OMPT_API ompt_task_id_t ompt_get_task_info(  /* identify a task                   */
  int depth,                    /*  how many levels removed from the current task      */
  ompt_task_type_t *type /* return the type of the task */
);

OMPT_API ompt_frame_t *ompt_get_task_frame(
  int depth                     /*  how many levels removed from the current task      */
);

/* target device inquiry */
OMPT_API ompt_target_device_id_t ompt_get_target_device_id( /* return active target
                                                  device ID               */
```

```
  void
);

OMPT_API ompt_target_device_time_t ompt_get_target_device_time( /* return current time
                                                                   stamp of a device    */
  omp_target_device_id_t id       /* the target device of interest                      */
);
```

A.6   Record Types and Buffer Management

TODO: add target records, as they are allowed on a target device

```
/* OMPT record type */
typedef enum {
  ompt_record_ompt,
  ompt_record_native,
  ompt_record_notype
} ompt_record_type_t;


/* native record abstract */
typedef struct ompt_record_native_abstract_s {
  ompt_record_native_kind_t kind,
  const char *type;
  uint64_t start_time;
  unit65_t end_time;
  uint32_t hwid;
  ompt_task_id_t target_task_id;
} ompt_record_native_abstract_t;


/* OMPT record */
typedef struct ompt_record_s {
  ompt_event_t type;                          /* event type */
  uint64_t time;                              /* time, when the record occurred */
  ompt_thread_id_t thread_id;                 /* thread identifier for this record */
  ompt_task_id_t target_task_id    /* link back to its associated target task */
  union
  {
    ompt_record_thread_t;                     /* for thread         */
    ompt_record_thread_type_t;                /* for thread type    */
    ompt_record_wait_t;                       /* for wait           */
    ompt_record_parallel_t parallel;          /* for inside parallel */
    ompt_record_new_workshare_t new_workshare; /* for workshares    */
    ompt_record_new_parallel_t new_parallel;  /* for new parallel   */
    ompt_record_task_t task;                  /* for tasks          */
    ompt_record_task_switch_t task_switch;    /* for task switch    */
    ompt_record_new_task_t new_task;          /* for new tasks      */
    /* there might be additional implementation-specific types listed here */
  } record;
} ompt_record_t;


/* target record types */
typedef struct
{
  ompt_thread_id_t thread_id       /* ID of thread                    */
} ompt_record_thread_t;


typedef struct
{
  ompt_thread_type_t thread_type,  /* type of thread                  */
  ompt_thread_id_t thread_id       /* ID of thread                */
} ompt_record_thread_type_t;


typedef struct {
```

```
  ompt_wait_id_t wait_id          /* wait ID                      */
} ompt_record_wait_callback_t;

typedef struct
{
  ompt_parallel_id_t parallel_id;  /* ID of parallel region */
  ompt_task_id_t task_id;          /* ID of task */
} ompt_record_parallel_t;

typedef struct
{
  ompt_parallel_id_t parallel_id;  /* ID of parallel region */
  ompt_task_id_t task_id;          /* ID of task */
  void *workshare_function;        /* pointer to outlined function */
} ompt_record_new_workshare_t;

typedef struct
{
  ompt_task_id_t parent_task_id;   /* ID of parent task */
  ompt_frame_t *parent_task_frame; /* frame data of parent task */
  ompt_parallel_id_t parallel_id;  /* ID of parallel region */
  uint32_t requested_team_size;    /* requested number of threads */
  void *parallel_function;         /* pointer to outlined function */
} ompt_record_new_parallel_t;

typedef struct
{
  ompt_task_id_t task_id; /* ID of task */
} ompt_record_task_t;

typedef struct
{
  ompt_task_id_t suspended_task_id; /* ID of suspended task */
  ompt_task_id_t resumed_task_id;   /* ID of resumed task */
} ompt_record_task_switch_t;

typedef struct
{
  ompt_task_id_t parent_task_id;   /* ID of parent task */
  ompt_frame_t *parent_task_frame; /* frame data of parent task */
  ompt_task_id_t new_task_id;      /* ID of created task */
  void *new_task_function;         /* pointer to outlined function */
} ompt_record_new_task_t;

/* buffer management routines */
typedef void (*ompt_target_buffer_request_callback_t) (
  ompt_target_event_t** buffer,   /* pointer to host memory to store target records */
  size_t* bytes                   /* buffer size in bytes */
);

typedef void (*ompt_target_buffer_complete_callback_t) (
  ompt_target_event_t* buffer,   /* pointer to buffer with target event records */
  omp_target_device_id_t device, /* target device */
  size_t valid_bytes             /* number of valid bytes in the buffer */
```

```
);

/* register target buffer callbacks */
OMPT_API void ompt_target_register_buffer_callbacks(
  /* pointer to buffer request callback */
  ompt_target_buffer_request_callback_t request_callback,
  /* pointer to buffer complete callback */
  ompt_target_buffer_complete_callback_t complete_callback
);
```

A.7   Registration and Initialization

Function `ompt_tool` is the only global symbol associated with OMPT. To use OMPT, a tool overlays an implementation of `ompt_tool` in place of the default one provided by an OpenMP runtime system. Use of this interface is described in Section 7.1.

```
extern "C" {
  ompt_initialize_fn_t ompt_tool(void);
};
```

Function `ompt_tool` returns a pointer to a tool initializer, whose type signature is described below. Use of this interface is described in Section 7.2.

```
typedef void (*ompt_initialize_fn_t) (
  const char *runtime_version,
  unsigned int ompt_version,
  ompt_function_lookup_t lookup
);
```
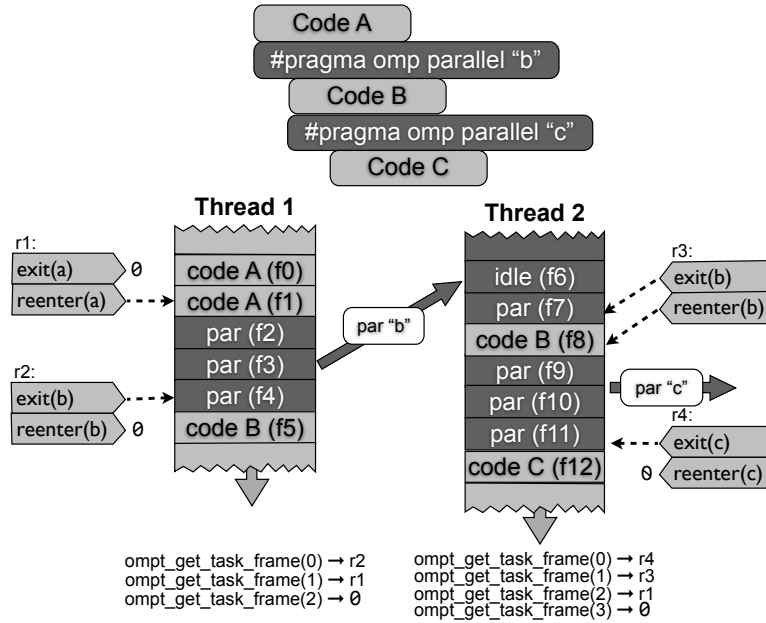
B   Task Frame Management and Inspection

Figure 1: Frame information.

Figure 1 illustrates a program executing a nested parallel region, where code A, B, and C represent, respectively, code associated with an initial task, outer-parallel, and inner-parallel regions. Figure 1 also depicts the stacks of two threads, where each new function call instantiates a new stack frame below the previous frames. When thread 1 encounters the outer-parallel region (parallel "b"), it calls a routine in the OpenMP runtime system to create a new parallel region. The OpenMP runtime sets the `reenter_runtime_frame` field in the `ompt_frame_t` for the initial task executing code A to frame f1—the user frame in the initial task that calls the runtime. The `ompt_frame_t` for the initial task is labeled `r1` in Figure 1. In this figure, three consecutive runtime system frames (labeled "par" with frame identifiers f2–f4) are on the stack. Before starting the implicit task for parallel region "b" in thread 1, the runtime sets the `exit_runtime_frame` in the implicit task's `ompt_frame_t` (labeled `r2`) to f4. Execution of application code for parallel region "b" begins on thread 1 when the runtime system invokes application code B (frame f5) from frame f4.

Let us focus now on thread 2, an OpenMP thread. Figure 1 shows this worker executing work for the outer-parallel region "b." On the OpenMP thread's stack is a runtime frame labeled "idle," where the OpenMP thread waits for work. When work becomes available, the runtime system invokes a function to dispatch it. While dispatching parallel work might involve a chain of several calls, here we assume that the length of this chain is 1 (frame f7). Before thread 2 exits the runtime to execute an implicit task for parallel region "b," the runtime sets the `exit_runtime_frame` field of the implicit task's `ompt_frame_t` (labeled `r3`) to frame f7. When thread 2 later encounters the inner-parallel region "c," as execution returns to the runtime, the runtime fills in the `reenter_runtime_frame` field of the current task's `ompt_frame_t` (labeled `r3`) to frame f8—the frame that invoked the runtime. Before the task for parallel region "c" is invoked on thread 2, the runtime system sets the `exit_runtime_frame` field of the `ompt_frame_t` (labeled `r4`) for the implicit task for "c" to frame f11. Execution of application code for parallel region "c" begins on thread 2 when the runtime system invokes application code C (frame f12) from frame f11.

Below the stack for each thread in Figure 1 is set of `ompt_get_task_frame` inquiries that are assumed to be made on each thread for the stack state shown. Each call indicates an ancestor level with an argument and shows the ID of the `ompt_frame_t` record returned. Note that thread 2 has task frame information for three levels of tasks, whereas thread 1 has only two.

C   Implementation Considerations for Tool Registration

Whether a tool-supplied implementation of `ompt_tool` defined as a strong global symbol is visible to an OpenMP runtime system when present in the address space of a process is non-obvious. There are several scenarios to consider. A tool-supplied version of `ompt_tool` is visible to an OpenMP runtime system if:

- The tool implementation of `ompt_tool` is statically-linked into an executable. Such an implementation of `ompt_tool` will be visible to an OpenMP runtime system regardless of whether the runtime is statically linked into the executable or dynamically-linked into a shared library.

- An implementation of `ompt_tool` is in a tool's shared library, which we denote $\mathcal{L}_T$. Such an implementation of `ompt_tool` will be visible to an OpenMP runtime system in a library $\mathcal{L}_O$ as long as (a) $\mathcal{L}_O$ is a shared library itself, and (b) $\mathcal{L}_T$ is in the dynamic library search path for $\mathcal{L}_O$ ahead of $\mathcal{L}_O$ itself. $\mathcal{L}_T$ is guaranteed to be on $\mathcal{L}_O$'s dynamic library search path ahead of $\mathcal{L}_O$ *iff*

  - $\mathcal{L}_T$ is pre-loaded by the dynamic linker into the address space of a process before execution begins.[4]
  - $\mathcal{L}_T$ and $\mathcal{L}_O$ are both direct shared library dependences of a load module[5] and $\mathcal{L}_T$ appeared ahead of $\mathcal{L}_O$ when linking the load module.
  - A load module dynamically loads $\mathcal{L}_T$ ahead of a shared library $\mathcal{L}_X$ (because $\mathcal{L}_T$ preceded $\mathcal{L}_X$ when the load module was linked), and $\mathcal{L}_X$ directly or indirectly loads $\mathcal{L}_O$.

The recommended approach for handling registration in the OpenMP runtime system for a particular target platform depends on the features supported by compiler, linker, and operating system.

Compiler and linker support weak symbols.   On systems where the compiler and linker support weak symbols, it is convenient for the OpenMP runtime system to define `ompt_tool` as a weak global symbol that returns 0. Definition of `ompt_tool` as a weak global symbol is suitable for use in either a static or dynamic library. If a shared-library implementation of an OpenMP library $\mathcal{L}_O$ defines `ompt_tool` as a weak global symbol, then a tool library $\mathcal{L}_T$ must be appear on the dynamic library search path ahead of $\mathcal{L}_O$ for the tool version of `ompt_tool` to be invoked.

Compiler and linker don't support weak symbols.   On systems that don't support weak symbols, different implementation strategies are needed for static and dynamic linking.

For a static library implementation of an OpenMP runtime library, the library can provide a stub version of `ompt_tool` in a separate object file. In this case, the linker will include the OpenMP library's stub implementation of `ompt_tool` only if no tool supplied version is already present when the OpenMP runtime library is used to resolve undefined symbols.

An OpenMP implementation used as a dynamic library can define `ompt_tool` as a global symbol. The version in the OpenMP library would be invoked only if no tool-supplied implementation of `ompt_tool` is statically linked in the executable or a tool library that appears before the OpenMP runtime library in the dynamic library search path during execution.

A Binary rewriter alters a load module that provides an OpenMP runtime system.   Regardless of whether a system supports weak symbols or not, one can use a static or dynamic binary rewriting tool to modify an OpenMP runtime system present in an executable or a shared library to invoke a tool-supplied version of a version of `ompt_tool` rather than the default implementation of `ompt_tool` present in the OpenMP runtime.

---

[4]While Linux and some other operating systems support library pre-loading, library pre-loading is not universally available.
[5]A load module is an application binary or a shared library.