Introduction to OpenMP Offload: Part II

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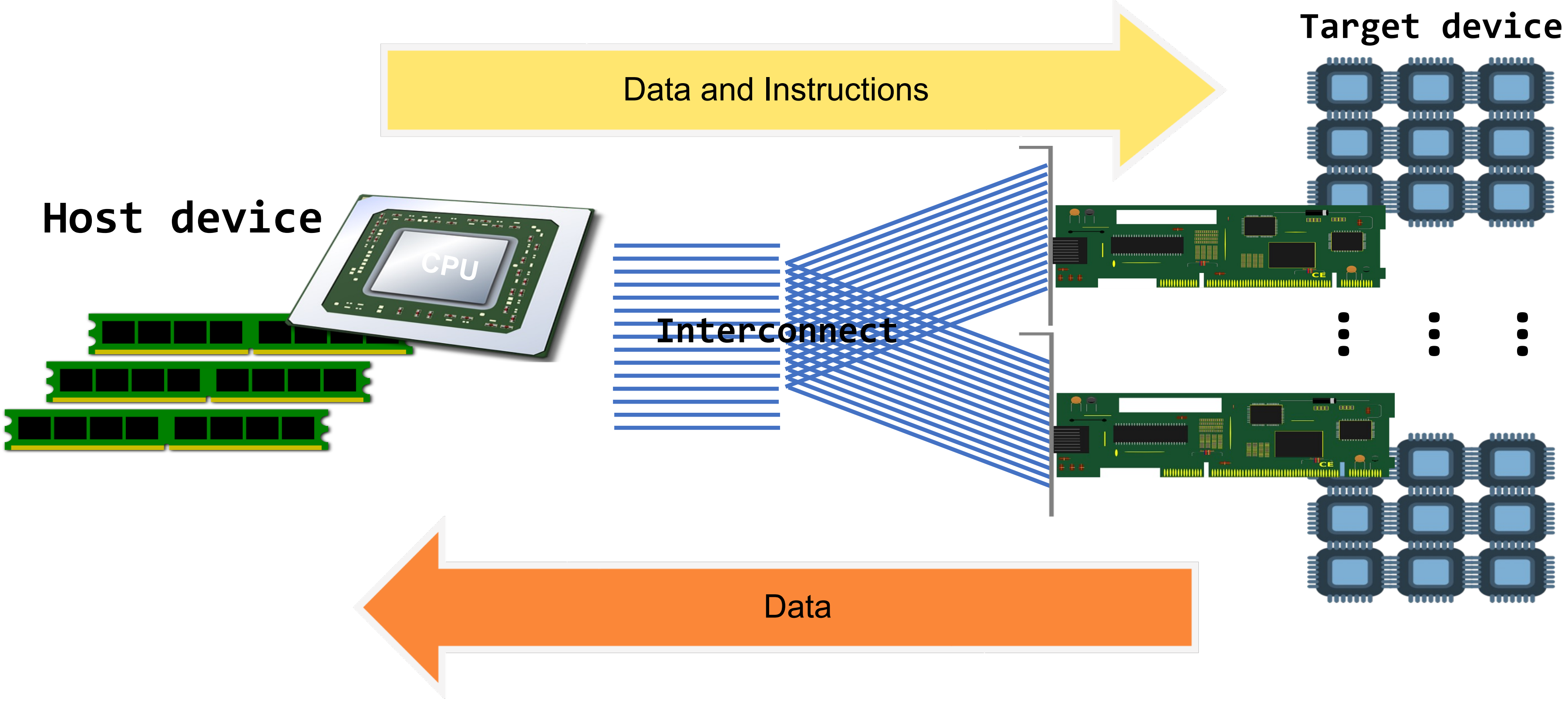
Recap: OpenMP Offload

- OpenMP offload constructs are a set of directives for C, C++, and Fortran that were introduced in OpenMP 4.0 and further enhanced in later versions. Accelerators



Recap: `target` directive

C/C++	Fortran	Description
#pragma omp target *[clause[[,] clause] ...] new-line structured-block*	**!$omp target** *[clause[[,] clause] ...] loosely/tightly-structured-block* **!$omp end target**	The **target** construct offloads the enclosed code to the accelerator.

– A device data environment is created for the structured block
– The code region is mapped to the device and executed.

Recap: Clauses on `target` directive

- Clauses allowed on the target directive:
  - device([device-modifier :] integer-expression)
  - if([target :] scalar-expression)
  - thread_limit(integer-expression)
  - private(list)
  - firstprivate(list)
  - in_reduction(reduction-identifier : list)
  - map([[map-type-modifier[,] [map-type-modifier[,] ...]] map-type:] locator-list)
  - is_device_ptr(list)
  - has_device_addr(list)
  - defaultmap(implicit-behavior[:variable-category])
  - nowait
  - depend([depend-modifier,] dependence-type : locator-list)
  - allocate([allocator :] list)
  - uses_allocators(allocator[(allocator-traits-array)] [,allocator[(allocator-traits-array)] ...])

`map` clause on `target` directive

Syntax: **`map`**(*[[map-type-modifier[,] [map-type-modifier[,] ...] map-type :] locator-list*)

"The map clause specifies how an original list item is mapped from the current task's data environment to a corresponding list item in the device data environment of the device identified by the construct."

`map` clause: `map-type-modifiers`

- `always`
  - value of list item is always copied to (for **to** and **tofrom**) and from device (for **from** and **tofrom)**
- `close`
  - **hint** to the runtime to allocate memory close to the target device
- `present`
  - sets a requirement that the corresponding list item already exists in the device data environment
  - If the list item is not present it causes a runtime error

`map` clause: other modifiers

- `mapper`
  - Provides a mechanism to override implicit mapping and provide custom mapping
  - A `declare mapper` directive must be used to create a unique mapper
  - Use case: Nested structure elements or nested structures (deep copy)

```
/*C code to show use of mappers*/
```

```
  …
typedef struct S{
  size_t len;
  double *data;
} S_t;

#pragma omp declare mapper(X: S_t s)  map(s,
s.data[0:s.len])
…
int main(){
  S_t A;
  //allocate and initialize elements of A
#pragma omp target map(mapper(X))
{
      //work using array elements of A
} // end target
…
```

`map` clause: other modifiers (cont.)

- `iterator`
  - Defines a set of iterators, each of which is an iterator-identifier and an associated set of values
  - Expands based on the values assigned
  - Example:
    - `map(int iterator(i=0:n), tofrom: p[i])`

`map` clause: `map-types`

- `to`
  - allocates data and moves data to the device
- `from`
  - allocates data and moves data from the device
- `tofrom`
  - allocates data and moves data to and from the device
- `alloc`
  - allocates data on the device
- `release`
  - decrements the reference count of a variable by 1
- `delete`
  - reference count of a variable is set to 0
  - deletes the data from the device

If a map-type is not specified, the map-type defaults to `tofrom`

Mapping Rules: Reference Count

Atomic Operation

- On entry to device environment:
  - If a corresponding storage block is not present in the device data environment, then:
    - A new storage block corresponding to original list item (on host) is created in the device data environment;
    - Reference count of this storage block is initialized to zero; and
  - The ref count is then incremented by 1
  - For every list item in the storage block
    - If ref count of the storage block is `1` - new list item is created in the storage block
    - If ref count of the list item is 1 or `always map-type-modifier` is present, and `map-type` is `to` or `tofrom` the list item value on the target device is updated to the value on the host device

Mapping Rules: Reference Count (cont.)

- On exit from device environment:
  - If ref count is 1 or `always map-type-modifier` is specified, and `map-type` is `from` or `tofrom` original list item (on the host device) is updated
  - if ref count is finite and:
    - map-type is `delete` → ref count is set to 0
    - if map-type is not `delete` → ref count is decremented by 1 (min 0)
  - If the reference count is zero then the corresponding list item is removed from the device data environment.

Atomic Operation

Implicit Mapping Rules on `target` directive

- C/C++: Pointer is treated as if it is the base pointer of a zero-length array section mapped using the `map` clause.
- Fortran: If a scalar variable has the TARGET, ALLOCATABLE or POINTER attribute treated → `map( tofrom: )`
- All:
  - Scalars variables are implicitly `firstprivate` (not mapped)
  - **If a variable is not a scalar then it is treated as if it was mapped with a map-type of `tofrom`.**

Implicit Mapping Rules on `target` directive (cont.)

- A base variable 'X' of a list item 'a' is in a reduction, lastprivate or linear clause on a combined target construct → treated as if `map(tofrom: X )`
- A base variable 'X' of a list item 'a' is in an in_reduction clause on a target construct → treated as if `map(always, tofrom:a)`

Allocating Memory on the Target Device

C/C++	Fortran	Description
void* omp_target_alloc(size_t size, int device_num);	type(c_ptr) function omp_target_alloc(size, device_num) bind(c) use, intrinsic :: iso_c_binding, only : c_ptr, c_size_t, c_int integer(c_size_t), value :: size integer(c_int), value :: device_num	routine allocates memory in a device data environment and returns a device pointer to that memory
void omp_target_free(void *device_ptr, int device_num);	subroutine omp_target_free(device_ptr, device_num) bind(c) use, intrinsic :: iso_c_binding, only : c_ptr, c_int ..	routine frees the device memory allocated by the omp_target_alloc routine.

- The omp_target_alloc routine returns a device pointer that references the device address of a storage location of size bytes.
- The storage location is dynamically allocated in the device data environment of the device specified by device_num.

`is_device_ptr` clause on `target` directive

- The `is_device_ptr` clause indicates that its list items are device pointers
- For C++ the list item must be:
  - type of pointer or array,
  - reference to pointer or reference to array
- For C it must have a type of pointer or array.
- For Fortran the list item must be of type C_PTR
- Support for device pointers created outside of OpenMP is implementation defined
- `is_device_ptr` clause is not necessary when using **requires unified_address**

Using is_device_ptr

/*C code for example of is_device_ptr*/

```
int *array_device = NULL;
int *array_host = NULL;

array_device = (int *) omp_target_alloc(N*sizeof(int), omp_get_default_device());

array_host = (int *) malloc(N*sizeof(int));
/* initialize array_host */

#pragma omp target is_device_ptr(array_device) map(tofrom: array_host[0:N])
{
    for (int i = 0; i < N; ++i) {
      array_device[i] = i;
      array_host[i] += array_device[i];
    }
}
…
…
```

has_device_addr and defaultmap clause on target directive

- has_device_addr clause indicates that the list items already have device addresses
  - list item must have a valid device address for the device data environment
  - if not, leads to unspecified behavior
- defaultmap clause is used to change implicitly determined data-mapping and data-sharing attribute rules of variables referenced in the target region
  - Example: defaultmap(tofrom: scalar)

OpenMP Offload: Example using omp `target`

/*C code to offload Matrix Addition Code to Device with map clause using static arrays*/

```
…
int A[N][N], B[N][N], C[N][N];
/*
  initialize arrays
*/
#pragma omp target map(to: A, B) map(from: C)
{
  for (int i = 0; i < N; ++i) {
    for (int j = 0; j < N; ++j) {
      C[i][j] = A[i][j] + B[i][j];
    }
  }
} // end target
```

/*C code to offload Matrix Addition Code to Device with map clause using dynamic arrays*/

```
…
int *A, *B, *C;
/*
  allocate arrays of size N and initialize
*/
#pragma omp target map(to: A[0:N], B[0:N])
map(from: C[0:N])
{
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }
    }
} // end target
```

Array Sections

Array Sections in OpenMP

- An array section designates a subset of the elements in an array.

[[lower-bound] : length [: stride]]

- Must be a subset of the original array.
- Array sections are allowed on multidimensional arrays.
- Must be integers or integer expressions
  – The **length** must evaluate to a non-negative integer and must be explicitly specified
- when the size of the array dimension is not known
  – The **stride** must evaluate to a positive integer, default 1 – lower-bound when absent it defaults to 0.

Target Device Data Persistence

/*C code for multiple offload kernels */

```
  …
#pragma omp target map(to: A, B) map(from: C)
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }
    }
  }

/*
Some computation using C (no changes to A, B or C)
*/

#pragma omp target map(to: A, B, C) map(from: D)
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        D[i][j] = A[i][j] + B[i][j] C[i][j];
      }
    }
  }
…
…
```

Is this optimal ?

NO

A and B are unchanged between the two target regions.

OpenMP Device Data Directives

C/C++ API	Fortran API	Description
#pragma omp target data *clause[[[,] clause] ...] new-line structured-block*	**!$omp target data** *clause[[[,] clause] ...] Loosely/tightly-structured-block* **!$omp end target data**	The target data construct maps variables to a device data environment for the extent of the region using the **map** clause.
#pragma omp target enter data [*clause[[,] clause] ...] new-line*]	**!$omp target enter data** [*clause[[,] clause]*]	A **standalone directive** that specifies that variables are mapped to a device data environment. It does so via a **map** clause
#pragma omp target exit data [*clause[[,] clause] ...] new-line*]	**!$omp target exit data** [*clause[[,] clause]*]	A **standalone directive** that specifies that variables are unmapped from a device data environment via a **map** clause

target data map directive usage

/*C code for multiple offload kernels with structured data mapping using target data map*/

```
  …
#pragma omp target data map(to: A, B)
{
#pragma omp target map(from: C) //kernel 1
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }end-for
    }end-for
  } end target

/*
Some computation on host using C (no changes to A, B or C)
*/

#pragma omp target map(to: C) map(from: D) //kernel 2
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        D[i][j] = A[i][j] + B[i][j] C[i][j];
      }
    }
  }
}//end target-data
…
…
```

Multiple offload kernels using target enter/exit data

/*C code for multiple offload kernels using target enter/exit data map*/

```
void foo(){
#pragma omp target enter data map(to: A, B)
}

void bar(){
…
#pragma omp target map(to: C)   {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        D[i][j] = A[i][j] + B[i][j] C[i][j];
      }
    }
  }

#pragma omp target exit data map(release: C)
map(from: D)

}
```

```
int main(){
..
  foo();

#pragma omp target map(from: C)
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }end-for
    } //end-for
  } //end target
  …
  bar();
…
}


…
```

target update construct

- Syntax

```
C/C++ : #pragma omp target update clause[ [ [,] clause] ... ] new-line
        Fortran: !$omp target update clause[ [ [,] clause] ... ]
```

- The target update directive makes list items consistent according to the specified data-motion-clauses.
  - `update to` makes makes the corresponding list items in the target device data environment consistent with their original list items
  - `udate from` makes makes the original list item in the host device data environment consistent with their corresponding list items on the target device data environment

`target update` directive usage

/*C code for multiple offload kernels using target data map and target update*/

```
 …
#pragma omp target data map(to: A, B) map(alloc: C, D)
{

#pragma omp target
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }
    }
  }
#pragma omp target update from(C)                  //Updates C device → host
/*
Some changes to A (no changes to B or C)
*/
#pragma omp target update to(A)                    //Updates A host → device

#pragma omp target map(from: D)
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        D[i][j] = A[i][j] + B[i][j] C[i][j];
      }
    }
  }
}//end target-data
```

Declare Target directives

- Applied to procedures and/or variables to ensure that they can be executed or accessed on a device.
- A variable declared in the directive must:
  - have a mappable type
  - have static storage duration
- Two variations:
  - `declare target` directive (clauses: `enter`, `link`, `device_type`, `indirect`)
  - `begin declare target` directive (clauses: `device_type`, `indirect`)
    - Must be paired with end `declare target` directive

begin/end declare target example

```
/*C code for demonstrating use of declare target*/

#pragma omp begin declare target
int a[N], b[N], c[N];
int i = 0;
#pragma omp end declare target

void update() {
  for (i = 0; i < N; i++) {
    /*update a, b, and c*/
  }
}

#pragma omp declare target to(update)

int main() {
  update();
  #pragma omp target update to(a,b,c)
  #pragma omp target
  {
    update();
  }
  #pragma omp target update from( a, b, c)
```

Device Memory Query Routines

C/C++	Fortran	Description
int omp_target_is_present(const void *ptr, int device_num);	integer(c_int) function omp_target_is_present(ptr, device_num) & bind(c) use, intrinsic :: iso_c_binding, only : c_ptr, c_int ..	routine tests whether a host pointer refers to storage that is mapped to a given device.
int omp_target_is_accessible(const void *ptr, size_t size, int device_num);	integer(c_int) function omp_target_is_accessible(& ptr, size, device_num) bind(c) use, intrinsic :: iso_c_binding, only : c_ptr, c_int ..	routine tests whether host memory is accessible from a given device.
void * omp_get_mapped_ptr (…);	type(c_ptr) function omp_get_mapped_ptr(…	routine returns the device pointer that is associated with a host pointer for a given device.

Device Memory Copy Routines

C/C++	Fortran	Description
int omp_target_memcpy_rect(..);	integer(c_int) function omp_target_memcpy_rect(dst,src,element_size, & .	copies a rectangular subvolume from a multi-dimensional array to another multi-dimensional array.
int omp_target_memcpy_async(…);	integer(c_int) function omp_target_memcpy_async(..	routine asynchronously performs a copy between host and device pointers.
int omp_target_memcpy_rect_async(…);	integer(c_int) function omp_target_memcpy_rect_async(…	routine asynchronously performs a copy between host and device pointers.
int omp_target_memcpy(void *dst,..);	integer(c_int) function omp_target_memcpy(dst, src, length, & dst_offset, src_offset, dst_device_num, src_device_num) bind(c) use, intrinsic :: iso_c_binding, only : c_ptr, c_int, c_size_t ..	routine copies memory between host and device pointers.

Other Device Memory Routines

C/C++	Fortran	Description
int omp_target_associate_ptr(…);	integer(c_int) function omp_target_associate_ptr(…	routine maps a device pointer to a host pointer
int omp_target_disassociate_ptr(…);	integer(c_int) function omp_target_disassociate_ptr(..	routine removes the associated pointer for a given device from a host pointer.