
Advanced topics
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Partners

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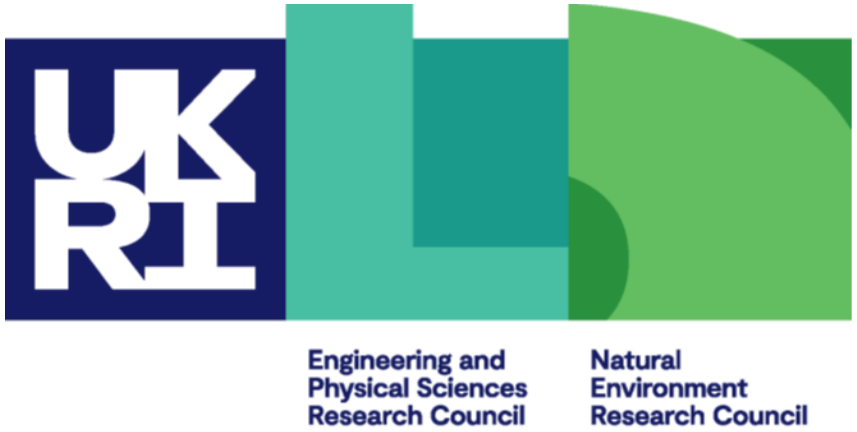

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Outline

- OpenMP/ROCm/CUDA interoperability
- Custom data mapper
- Memory types
- Memory allocation
- Asynchronous tasks

OpenMP/ROCm compatibility

Using ROCm in an OpenMP Program

- Sometimes need to call routines from a library that expects a device pointer, not a mapped variable.
- Might be needed if you want to port a computationally heavy kernel to CUDA/HIP to increase performance
- Might be needed if you want to call vendor libraries (rocFFT/cuFFT, cuBLAS,rocBLAS …)

Using ROCm in an OpenMP Program

- Suppose `var_a` is a variable already mapped to the device with OpenMP
- Want to avoid re-allocating and transferring data with CUDA/HIP
- Need to obtain the address of the variable mapped on the device

Using rocm in an OpenMP Program

- The clause `use_device_addr` makes all references to `var_a` in the code refer to the variable mapped on the GPU.

```C/C++
#pragma omp target data use_device_addr(var_a)
{ . . . . }
```

```Fortran
!$omp target data use_device_addr(var_a)
  . . . .
!$omp end target data
```

Using ROCm with OpenMP

- Example of a matrix multiplication using rocBLAS

```C/C++
#pragma omp target data map(tofrom:A[0:M*K],B[0:K*N],C[0:M*N]){
    #pragma omp target data use_device_addr(A[0:M*K],B[0:K*N],C[0:M*N]){
        rocblas_dgemm( . . . , A, . . . , B, . . . , C, . . .);
  }
}
```

```Fortran
!$omp target data map(to:A(1:M,1:K),B(1:K,1:N)) map(tofrom:C(1:M,1:N))
  !$omp target data use_device_addr(A(1:M,1:K), B(1:K,1:N), C(1:M,1:N))
      call rocblas_dgemm( . . . , A, . . . , B, . . . , C, . . .)
  !$omp end target data
!$omp end target data
```

Using OpenMP in an HIP/CUDA program

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- Memory allocations on HIP/CUDA
- Want to use OpenMP code that uses memory allocated on the device with HIP/CUDA
- Useful when porting from a HIP/CUDA program to a performance portable implementation with OpenMP

Using OpenMP in an HIP/CUDA program

- The clause `is_device_ptr(a,b , . . . )` tells OpenMP `a, b,` … are pointers to data available on the device, not on the host.
- Prevents mapping of the pointer variable, allows using the pointer directly on the device.

Using OpenMP in an HIP/CUDA program

Ex. : Copying an array b to array c

```
double * b_device, c_device;
hipMalloc( &b_device, n*sizeof(double) ) );
hipMalloc( &c_device, n*sizeof(double) ) );

#pragma omp target teams distribute parallel for
is_device_ptr(c_device, b_device)
for (int i=0;i<n;i++) {
  c_device[i] = b_device[i];
}
```

C/C++

Using OpenMP in an HIP/CUDA program

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Ex. : Copying an array b to array c

```fortran
integer, parameter :: fp_kind = kind(0.0)
type(c_ptr) :: cptr_b, cptr_c
real(fp_kind), pointer, dimension(:) :: fptr_b => null(), fptr_c => null()
integer :: n = 5, i, ierr

ierr = hipMalloc(cptr_b, n * sizeof(fp_kind))
ierr = hipMalloc(cptr_c, n * sizeof(fp_kind))
call c_f_pointer(cptr_b, fptr_b, [n])
call c_f_pointer(cptr_c, fptr_c, [n])

!$omp target teams distribute parallel do simd is_device_ptr(fptr_b, fptr_c)
do i = 1, n
  fptr_c(i) = fptr_b(i)
end do
```

Fortran

Custom data mapper

Custom data mappers

- Consider a structure with three arrays: **`c`**, **`d`**, **`e`**.
- Each array is of length **`n`**.
- Mapping a variable of type **`A`** will correctly map scalar variables (like **`n`**) but not the value of the arrays **`c`**, **`d`**, **`e`**.

```c
struct my_struct {
  int n;
  double * c;
  double * d;
  double * e;
};
```
C/C++

```fortran
type my_type
  integer :: n
  real, allocatable :: c(:)
  real, allocatable :: d(:)
  real, allocatable :: e(:)
end type
```
Fortran

Custom data mappers

- All arrays need to be explicitly mapped every time a variable of type **`my_struct`** is used.
- Can be very verbose and error-prone with complex data structures.

```c
my_struct a, b;
#pragma omp target data map(tofrom:a,a.c[0:n],a.d[0:n],a.e[0:n]){
    // Do something with a
}
#pragma omp target data map(tofrom:b,b.c[0:n],b.d[0:n],b.e[0:n]) {
    // Do something with b
}
```

C/C++

```fortran
type(my_type) :: a, b
!$omp target data map(tofrom:a,a%c(1:a%n),a%d(1:a%n),a%e(1:a%n))
    ! Do something with a
!$omp end target data
!$omp target data map(tofrom:b,b%c(1:b%n),b%d(1:b%n),b%e(1:b%n))
    ! Do something with b
!$omp end target data
```

Fortran

Custom data mappers

- Declare all mapping rules for a custom structure only once.

```
#pragma omp declare mapper(my_struct x ) map(x, … )
```
C/C++

```
!$omp declare mapper(my_type :: x) map(x, …)
```
Fortran

- Here **x** is a dummy argument of type **my_struct** or **my_type**.

Custom data mappers

```c
#pragma omp declare mapper(my_struct x) \
  map(x, x.c[0:x.n], x.d[0:x.n], x.e[0:x.n])

my_struct a, b;

#pragma omp target data map(tofrom:a) {
        // Do something with a
}

#pragma omp target data map(tofrom:b) {
        // Do something with b
}

...
```

C/C++

```fortran
type(my_type) :: a, b

!$omp declare mapper(my_type :: x) &
!$omp map(x, x%c(1:x%n), x%d(1:x%n), &
!$omp x.e(1:x%n))

!$omp target data map(tofrom:a)
  ! Do something with a
!$omp end target data

!$omp target data map(tofrom:b)
  ! Do something with b
!$omp end target data

...
```

Fortran

Memory types

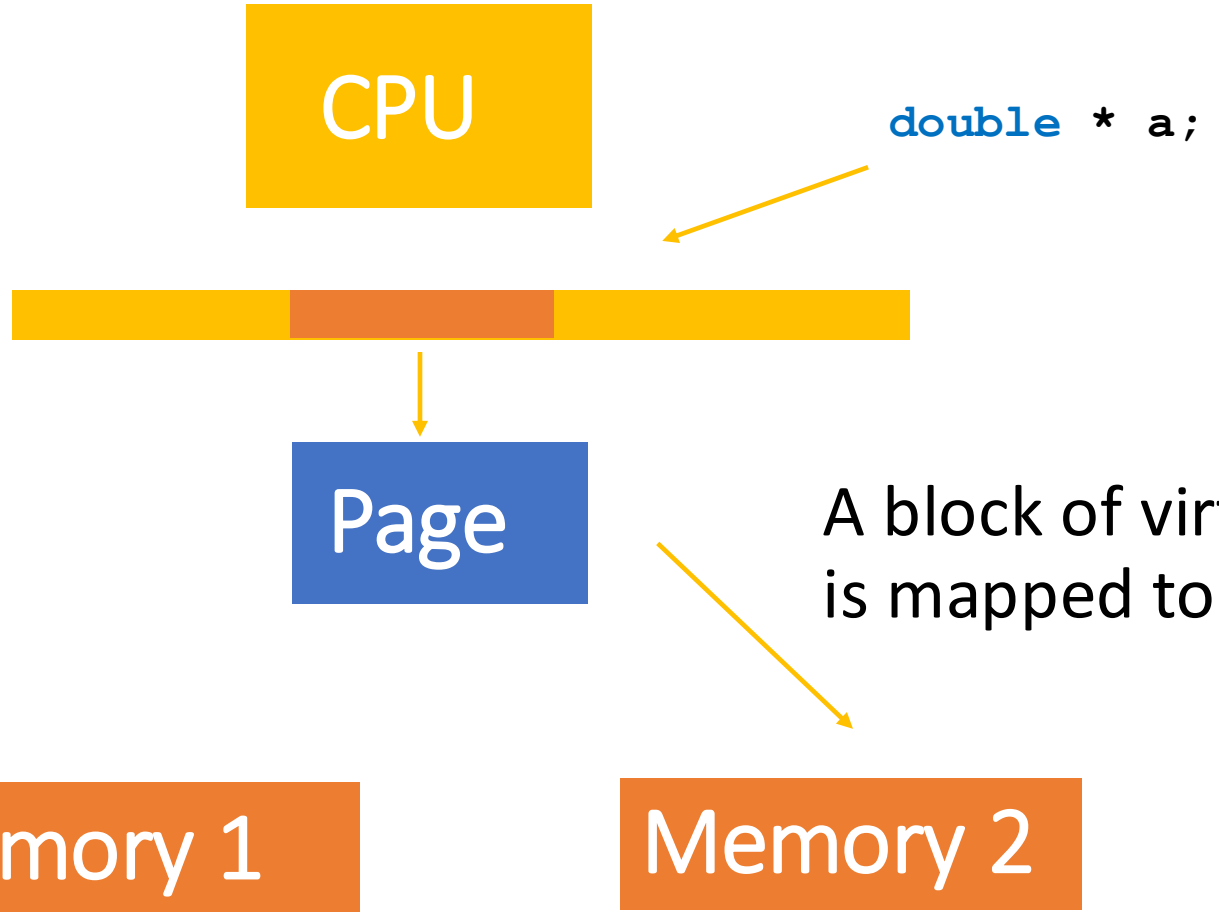
Host memory

- Pageable memory: Memory allocated in the usual way on the (**`malloc`**, **`new`**, **`allocate`**, etc...). Memory is only available on the host.

- Pinned memory: Memory optimized for transfer to the GPU. Custom allocators are used on the host

- Unified memory: Memory is accessible on both the host and the device. Memory allocated in the usual way.

Pageable memory



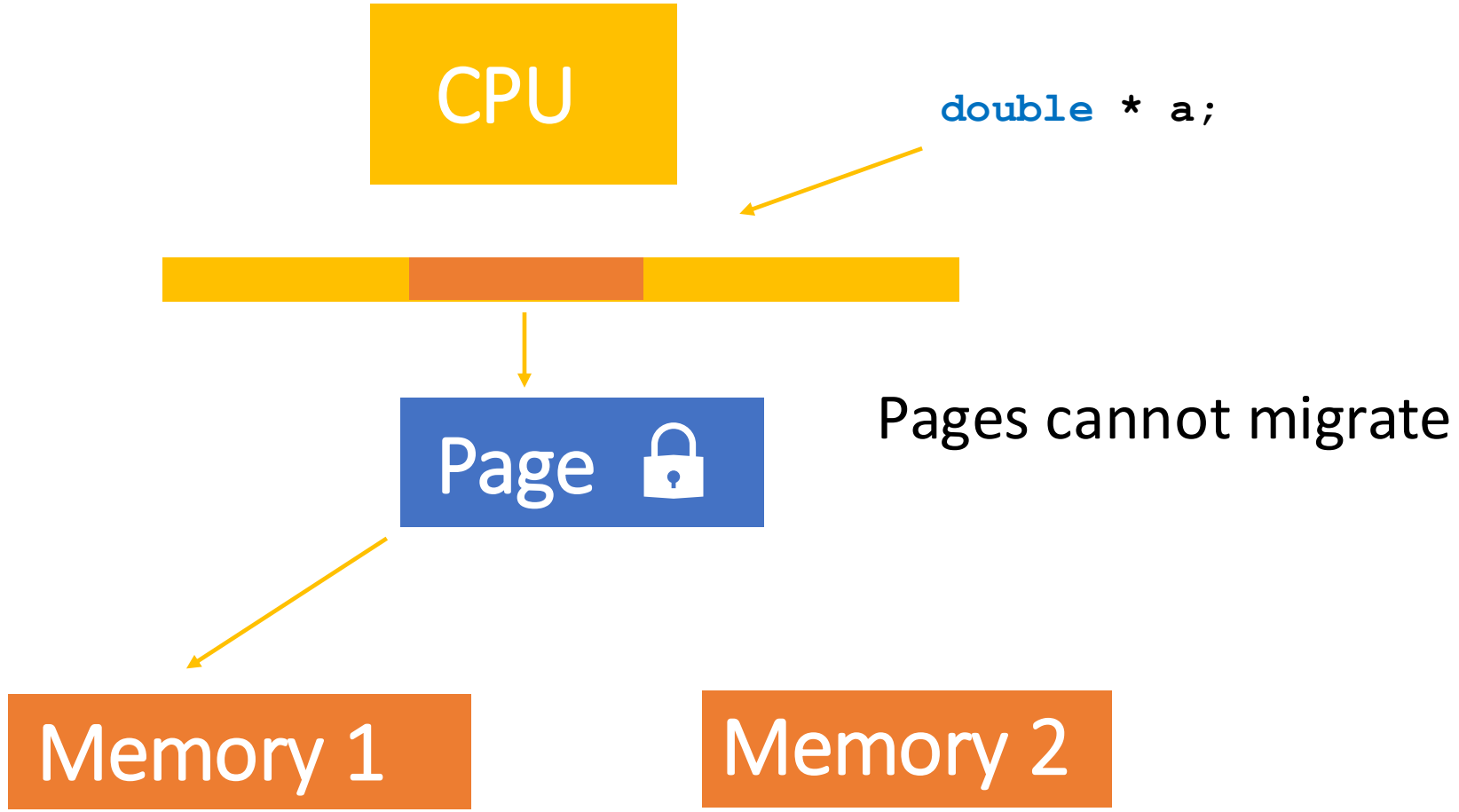
Pointer points to a location in virtual memory.

A block of virtual memory (called a page) is mapped to physical memory.

Pageable memory

- Memory is allocated using the usual allocators.
- Memory address is virtual.
- Virtual memory is mapped to physical memory using a page.
- Pages can migrate between different physical devices.
- Memory is only accessible from the host.

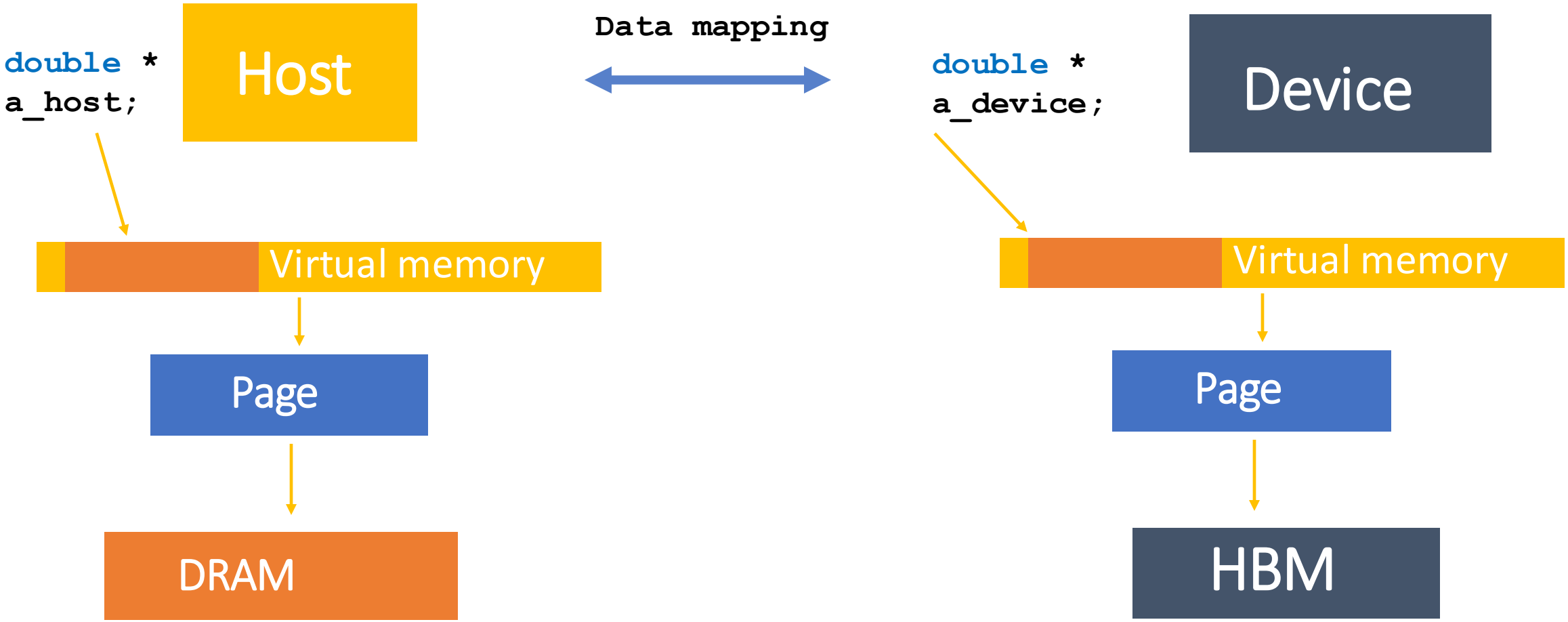
Pinned memory



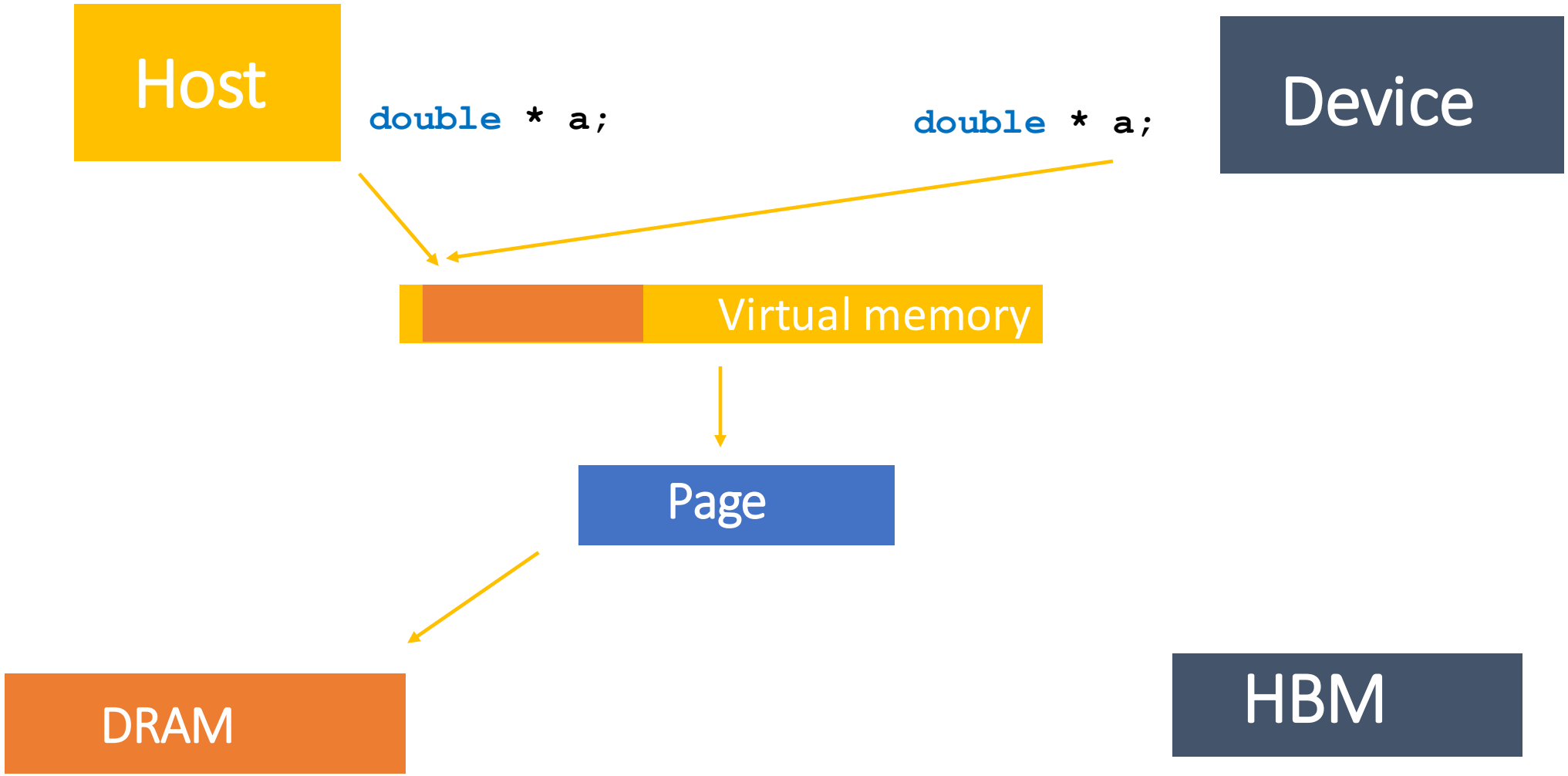
Pinned memory

- Memory is allocated using the usual allocators.
- Memory address is virtual.
- Virtual memory is mapped to physical memory using a page.
- Pages cannot migrate between different physical devices.
- Memory is only accessible from the host.
- Memory transfers are faster than pageable memory.

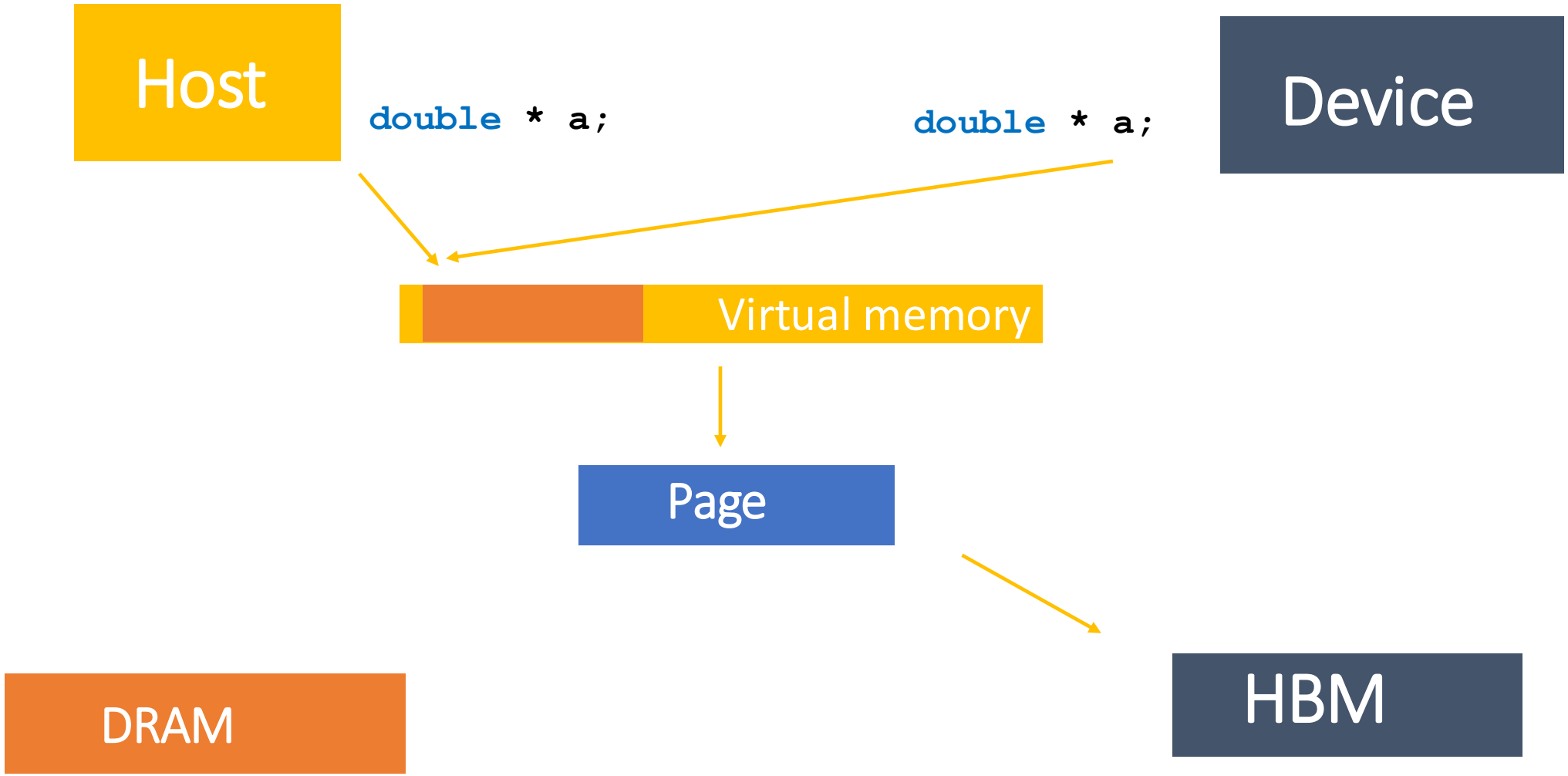
Non-unified memory



Unified memory



Non-unified memory



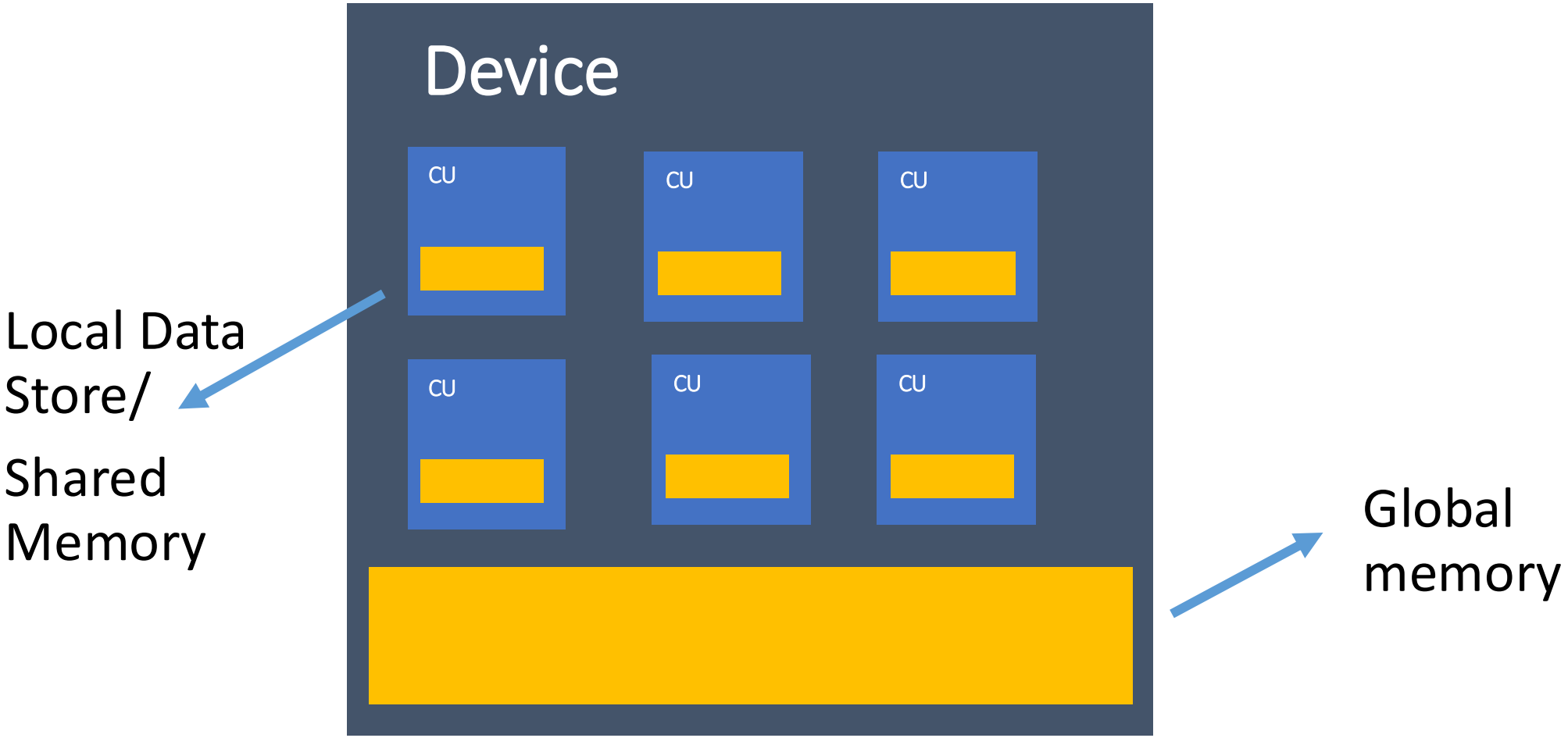
Unified memory

- Standard allocators are used, which are not GPU aware.
- Needs to use **`requires unified_shared_memory`**
- Host can access pages on the device and vice-versa
- Mapping is optional

Unified memory

- Does not work on older devices
- Performance is good only on architectures that have fast interconnect between host and device memory (MI300A, Grace-Hopper etc..).

Memory on the Device



Memory

Device	
Global memory	Shared by all threads on GPU
	Slower than the local data store
Local Data Store	Shared by threads on a CU/team
	Fast but small

Host	
Pageable	Allocated with malloc, new, allocate
	Slow data transfer to GPU
Pinned memory	Fast data transfer
	Requires special allocation calls

OpenMP memory allocators

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OpenMP allocators

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- Define how to allocate memory; is a combination of a memory space and an allocator traits.

- Memory space: hint to the compiler on where to allocate memory. The `omp_default_mem_space` memory space is sufficient for most applications.

- Allocator traits: hints to the compiler on how the memory should be allocated and how the memory will be accessed.
  - *Implementation is undefined*.

OpenMP allocator traits

Allocator trait	Allowed values	Notes
alignment	A positive integer must be a multiple of 2	
access	all	can be accessed from anywhere.
	cgroup	can be accessed by all threads in a contention group.
	pteam	only shared by threads in a team.
	thread	memory private to each thread.
pinned	true , false	

OpenMP allocation on the host

```C/C++
// Use the default memory space.
omp_memspace_handle_t c_memspace = omp_default_mem_space;
// Create an array of 2 traits. The first trait signals that the memory should be pinned.
// The second trait specifies that the memory should be allocated with 128 byte alignment.
omp_alloctrait_t c_traits[2] = { { omp_atk_pinned , true }, {omp_atk_alignment, 128} } ;
// Create a custom allocator.
// Takes as input the memory space, the number of traits and and array of traits.
omp_allocator_handle_t my_allocator = omp_init_allocator(c_memspace, 2, c_traits);
```

C/C++

```Fortran
! Use the default memory space.
integer(omp_memspace_handle_kind) :: c_memspace = omp_default_mem_space
! Create an arry of 2 traits.
type(omp_alloctrait) :: c_traits(2)
! Create a custom allocator.
integer(omp_allocator_handle_kind) :: c_alloc
c_traits(1) = omp_alloctrait(omp_atk_pinned, .TRUE.)
c_traits(2) = omp_alloctrait(omp_atk_alignment, 128)
c_alloc = omp_init_allocator(c_memspace, 2, c_traits)
```

Fortran

OpenMP allocation on the host

- The allocate directive provides a hint to the compiler. It is not guaranteed that the compiler will use the traits you provide.
- You can use the clause `allocate` (`my_allocator`: <item-list>)
- The clause needs to be associated with an allocation statement

OpenMP allocation on the host

```
#pragma omp allocate(my_alloc:b)
b = new double [n];
```
C/C++

```
!$omp allocate(my_alloc:b)
allocate (b(n))
```
Fortran

OpenMP allocation on the device

- On the device you must specify which allocators can be used on the host using the `uses_allocators` clause

C/C++

```
#pragma omp target uses_allocators(my_allocator)
    map(alloc:c[0:BLOCK_SIZE]) allocate(my_allocator:c)
```

Fortran

```
real, allocatable, dimension(:) :: c
!$omp target teams num_teams(4) &
!$omp private(c) &
!$omp uses_allocators(my_allocator) &
!$omp map(alloc:c(1:BLOCK_SIZE)) &
!$omp allocate(my_allocator:c)
```

OpenMP allocation on the LDS

- OpenMP does not (yet) provide a mechanism for allocating on the local store.
- However, you can provide hints to the compiler.
- You can use also compiler extensions, but they are not portable between compilers

OpenMP allocation on the LDS

- Statically allocate memory inside a team.

```c
#pragma omp target teams num_teams(4) {
    double c[BLOCK_SIZE];
    // do something with a team
    #pragma omp parallel for
    for(int i=0; i<BLOCK_SIZE; i++) {
        c[i] = i;
    }
}
```

C/C++

```fortran
program main
  implicit none
  !$omp target teams num_teams(4)
    call loop()
  !$omp end target teams
end program main

subroutine loop
  integer, parameter :: N = 1000
  integer :: i
  real, dimension(N) :: c
  !$omp parallel do
  do i = 1, N
    c(i) = i
  end do
end subroutine loop
```

Fortran

OpenMP allocation on the LDS

- Use the default allocator `omp_pteam_mem_alloc`
- On some compilers you need to use `omp_cgroup_mem_alloc`
- On some compilers neither is implemented

```c
double c[BLOCK_SIZE];

#pragma omp target teams
    num_teams(4) private(c)
    uses_allocators(omp_pteam_mem_alloc)
    map(alloc:c[0:BLOCK_SIZE])
    allocate(omp_pteam_mem_alloc:c)

#pragma omp parallel for shared(c)
for(int i=0;i<BLOCK_SIZE;i++) {
    // do something with c
}
```

C/C++

```fortran
real, allocatable, dimension(:) :: c
!$omp target teams num_teams(4) &
!$omp private(c) &
!$omp uses_allocators(omp_pteam_mem_alloc) &
!$omp map(alloc:c(1:BLOCK_SIZE)) &
!$omp allocate(omp_pteam_mem_alloc:c)

!$omp parallel do shared(c)
do i = 1, BLOCK_SIZE
  ! do something with c
end do
!$omp end target teams
```

Fortran

Asynchronous offloading

Asynchronous offloading

- map directives are blocking : the CPU and all GPU kernel launches will stall until the data is transferred to the GPU.
- kernels offloaded to the device are blocking: the CPU will wait until the kernel finishes executing on the GPU. Only one kernel at a time is executed.
- You can use non blocking calls by adding the `nowait` clause.
- Synchronize tasks launched from a CPU thread using the `taskwait` directive.
- Synchronize tasks and multiple CPU threads using the `barrier` directive.
- Specify dependencies using the `depend` clause.

Asynchronous data transfer

- Add a nowait clause to map directives to overlap memory transfers and computations

```c
#pragma omp target enter data map(to:xsi[0:m],ysi[0:m]) nowait
depend(out:xsi[0:m],ysi[0:m])

my_host_computation()

#pragma omp taskwait
```

C/C++

```fortran
!$omp target enter data map(alloc:xsi(1:m),ysi(1:m)) nowait
depend(out:xsi(1:m),ysi(1:m))

call my_host_computation()

!$omp taskwait
```

Fortran

Asynchronous execution

- Add a **`nowait`** clause to overlap computation on the host and device.

```c
#pragma omp target teams distribute parallel for nowait
for (int j=0; j<m; j++) {
    // computation A on device
}
for (int j=0; j<m; j++) {
    // independent computation B on host
}
#pragma omp taskwait
```

C/C++

```fortran
!$omp target teams distribute parallel do nowait
do j = 1, m
    ! computation A on device
end do
do j = 1, m
    ! independent computation B on host
end do
!$omp taskwait
```

Fortran

Parallel execution on the device

- Add a `nowait` clause to allow running multiple kernels on the device at the same time.
- Compiler might choose to run the kernels serially on the device or in parallel.
- Only advantageous if the offloaded region does not exhaust the resources on the device.

Parallel execution on the device

```c
#pragma omp target teams distribute parallel for nowait
for (int j=0; j<m; j++) {
    // computation A
}
#pragma omp target teams distribute parallel for nowait
for (int j=0; j<m; j++) {
    // independent computation B
}
#pragma omp taskwait
```

C/C++

```fortran
!$omp target teams distribute parallel do nowait
do j = 1, m
    ! computation A on device
end do
!$omp target teams distribute parallel do nowait
do j = 1, m
    ! independent computation B
end do
!$omp taskwait
```

Fortran

Dependencies

- If your kernels depend on data produced by other kernels you can tell that the kernel has a data dependency.
- You use the **depend** clause to mark data dependencies.

`depend(out:x)`	Mark that other tasks depend on the variable **x**, which might be modified by the current task.
`depend(in:x)`	This kernel depend on the variable **x**, modified by other kernels that specify the out modifier.
`depend(inout:x)`	Specify both input and output dependencies.

Dependencies

```
// Initiate data transfer. Mark x as a dependency of a future task.
#pragma omp target enter data map(to:x) nowait depend(out: x[0:m])

// Once x is available on the device start computation on the device.
#pragma omp target teams distribute parallel for nowait depend(inout: x[0:m])
for (int j=0; j<m; j++) {
    // update the array x
}

// Once x is updated from the previous kernel start this kernel.
#pragma omp target teams distribute parallel for nowait depend(in: x[0:m])
for (int j=0; j<m; j++) {
    // use the x array for my computation
}
```

C/C++

Dependencies

```fortran
! Initiate data transfer. Mark x as a dependency of a future task.
!$omp target enter data map(to:x) nowait depend(out: x(1:m))

! Once x is available on the device start computation on the device.
!$omp target teams distribute parallel do nowait depend(inout: x(1:m))
do j = 1, m
    ! update the array x
end do

! Once x is updated from the previous kernel start this kernel.
!$omp target teams distribute parallel do nowait depend(in: x(1:m))
do j = 1, m
    ! use the x array for my computation
end do
```

Fortran

Summary

- OpenMP/ROCm/CUDA interoperability
- Custom data mapper
- Memory types
- Memory allocation
- Asynchronous tasks