
Advanced topics
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Reusing this material

Partners

Engineering and Physical Sciences Research Council

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Outline

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

OpenMP/ROCm compatibility

Using ROCm with OpenMP

- Sometimes need to call routines from a library that expects a device pointer, not a mapped variable.
- Common applications: matrix multiplication (rocBLAS/cuBLAS), Fourier transforms (rocFFT, cuFFT), …

Using ROCm with OpenMP

- Sometimes need to call routines from a library that expects a device pointer, not a mapped variable.
- For instance, when doing matrix multiplication (rocBLAS/cuBLAS), Fourier transforms (rocFFT, cuFFT).

Using ROCm with OpenMP

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

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

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

Using ROCm with OpenMP

- If `var_a_ptr` is a pointer to an array, need to refer to the contents of the array, not the variable containing the address.
- This can be be done by using `use_device_ptr`.

```
auto var_a = new double[N];
double *var_a_ptr = var_a;
#pragma omp target data map(tofrom : var_a_ptr[0 : N]) use_device_ptr(var_a_ptr)
{ … }
```
C/C++

```
real, target, dimension(N) :: var_a
real, pointer, dimension(:) :: var_a_fptr => null()
type(c_ptr) :: var_a_cptr
var_a_cptr = c_loc(var_a)
!$omp target data map(tofrom: var_a_fptr(1:N)) use_device_ptr(var_a_fptr)
call c_f_pointer(var_a_cptr, var_a_fptr, [N])
...
!$omp end target data
```
Fortran

Using ROCm with OpenMP

- Example of a matrix multiplication using rocBLAS

```
#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, . . .);
  }
}
```

C/C++

```
!$omp target data map(to:A(1:M,1:K),B(1:K,1:N)) map(tofrom:C(1:M,1:N))
  !$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
```

Fortran

Using OpenMP with HIP

- Useful when an application uses both optimized HIP kernels and OpenMP kernels.
- Memory allocated on the device with HIP might need to be used by HIP kernels.

Using OpenMP with HIP

- 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 with HIP

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 simd
is_device_ptr(c_device, b_device)
for (int i=0;i<n;i++) {
  c_device[i] = b_device[i];
}
```
C/C++

Using OpenMP with HIP cond

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.

```
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++

```
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

```
#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++

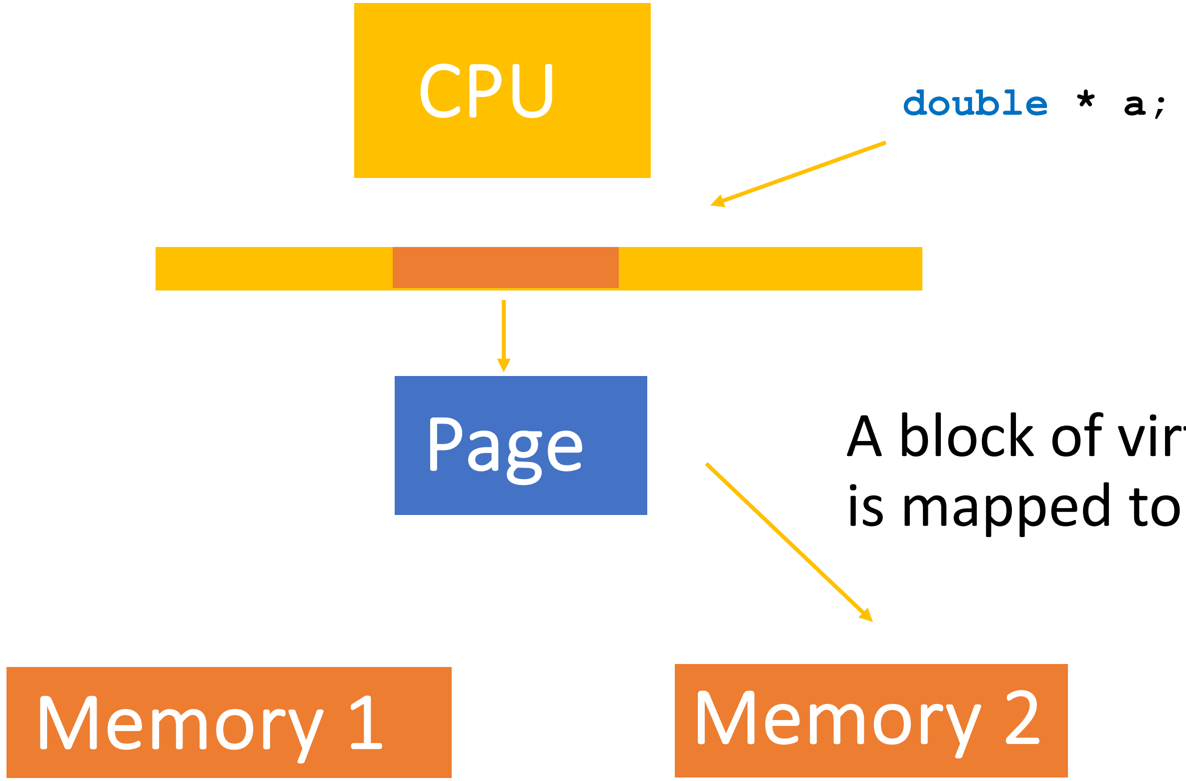
```
type(my_type) :: a, b

!$omp declare mapper(my_type :: x) &
!$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 CPU (**`malloc`**, **`new`**, **`allocate`**, etc…).
- Pinned memory: Memory optimized for transfer to the GPU.
- Managed memory: Memory is accessible from the device as well.
  - Custom allocators are used.
- Unified memory: Memory is accessible on both the host and the device.

Pageable memory



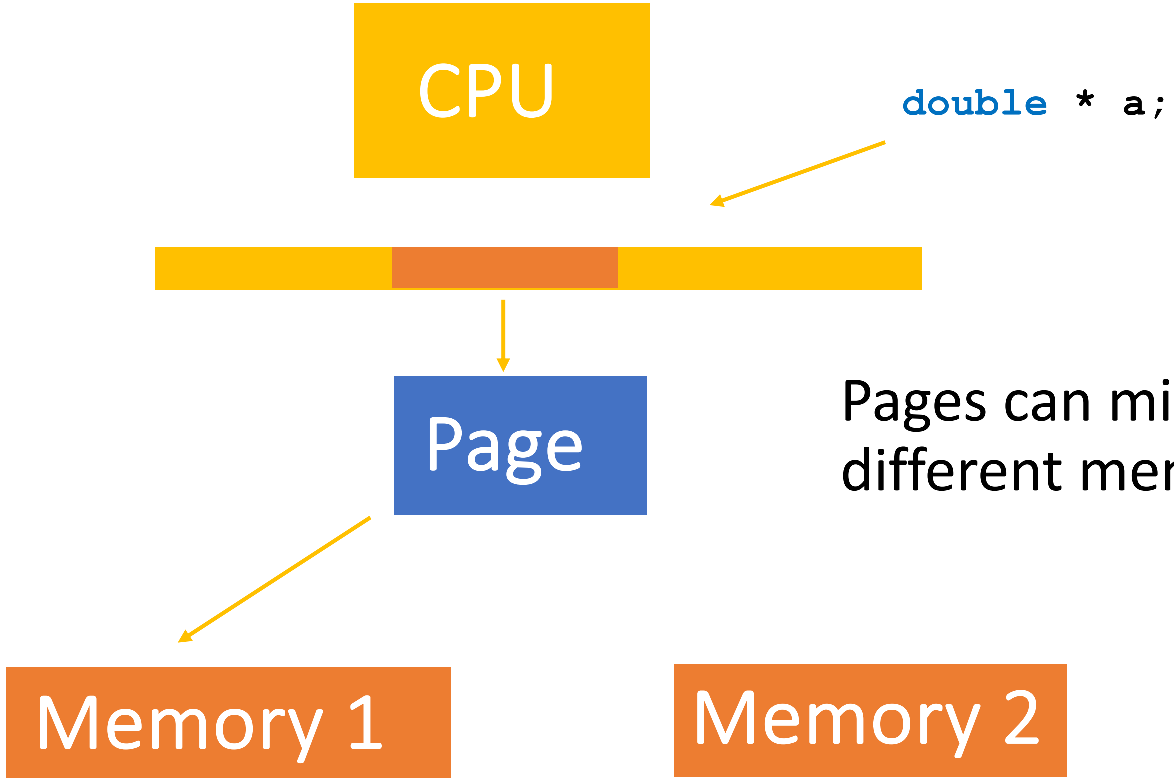
Pointer points to a location in virtual memory.

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.

Pageable memory

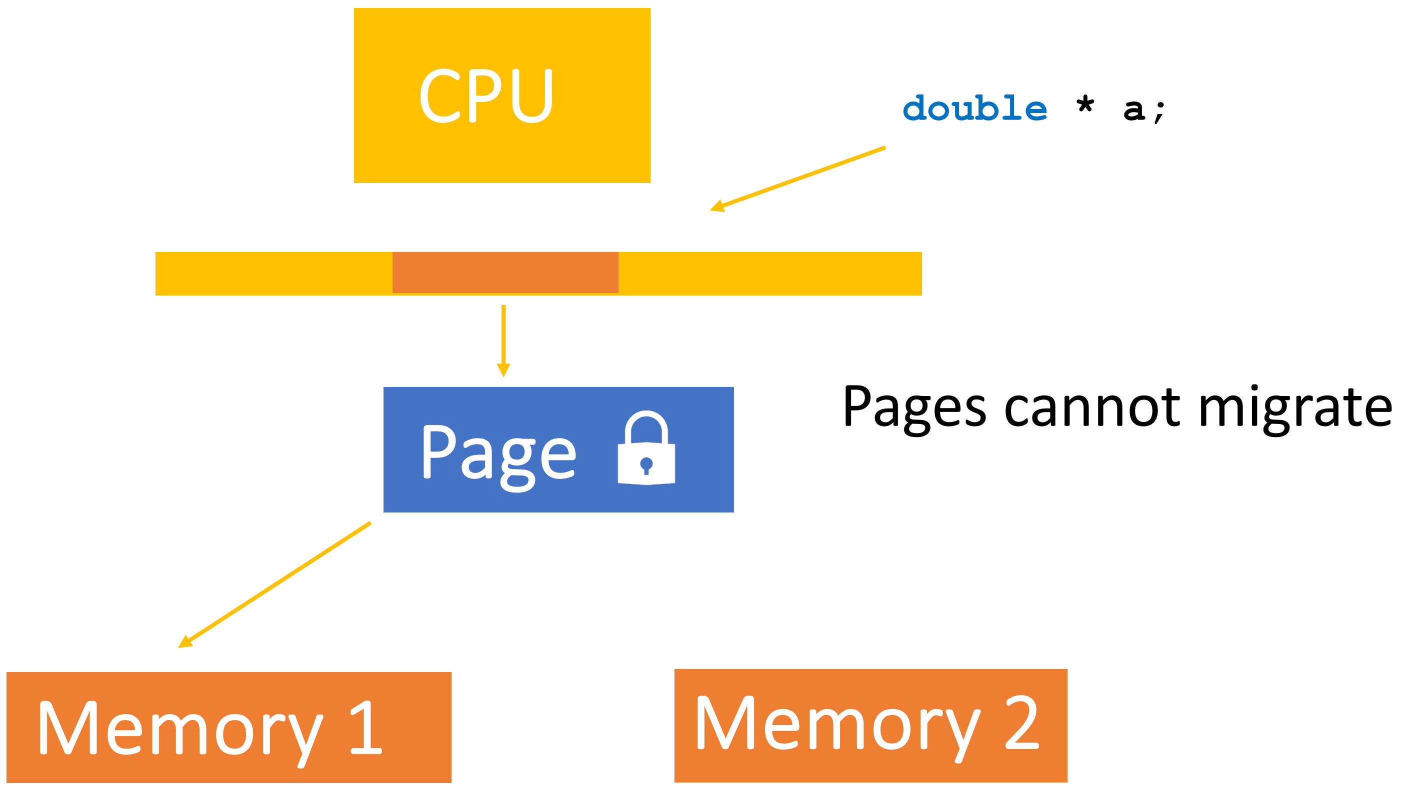


Pages can migrate between different memory location.

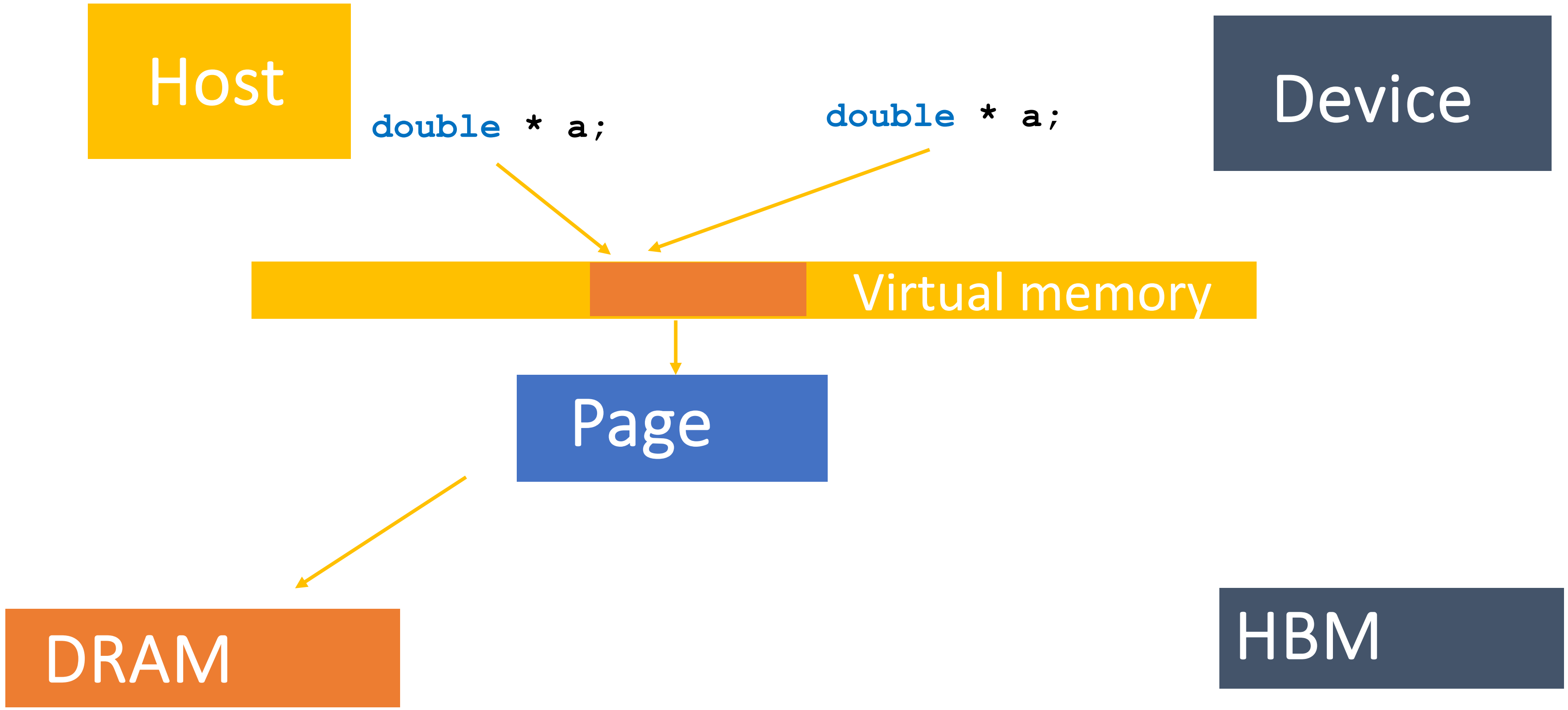
Pinned memory

- 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.

Pinned memory



Unified memory



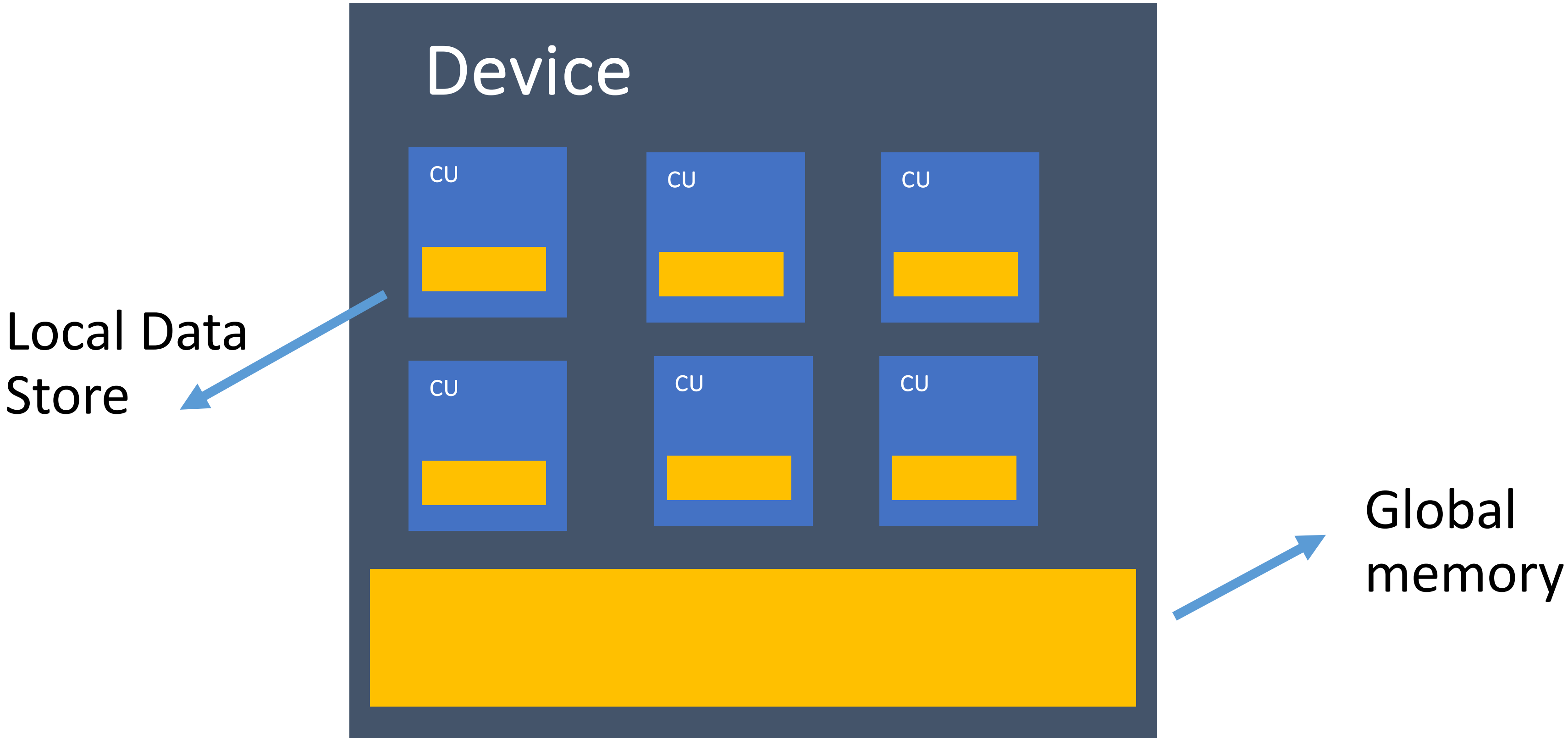
Unified memory

- Standard allocators are used, which are not GPU aware.
- Host can access pages on the device and vice-versa.
- Pages might or might not migrate between device and host.
- Performance can be very poor on architectures that do not have fast interconnect between host and device memory.

Managed memory

- Similar to unified memory.
- Memory is allocated using a special allocator.
- Pages are accessible either from the device or the host.
- Pages can migrate between the host and the device.
- Performance can be very poor on architectures that do not have fast interconnect between host and device memory.

Device memory



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

OpenMP allocators

- 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

```
// 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++

```
! 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.

```
#pragma omp allocate(b) allocator(c_alloc)
b = new double [n];
```

C/C++

```
!$omp allocate(b) allocator(c_alloc)
allocate (b(n))
```

Fortran

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.

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`
- One needs to specify which allocators to use on the target.
- The allocate clause specifies which variable to use for the variable **c**.

```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 using the **`taskwait`** directive.
- Specify dependencies using the **`depend`** clause.

Asynchronous data transfer

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

```
#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++

```
!$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 data transfer

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

```
#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++

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

Fortran

Asynchronous data transfer

- 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 a single kernel is too small to exhaust the resources on the device.

Asynchronous data transfer

```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 contd.

```
! 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