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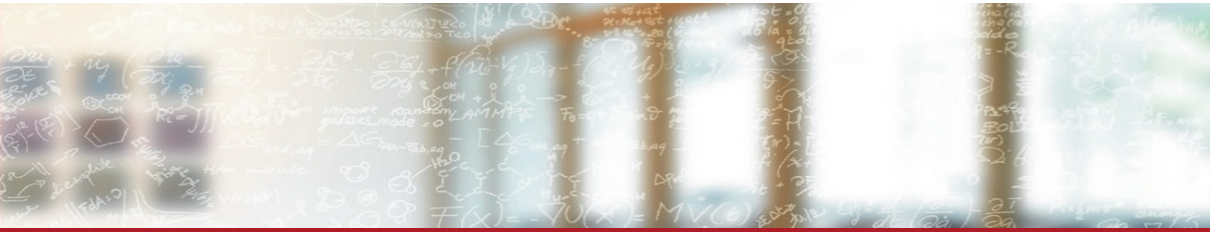

# GPU programming using OpenACC

CSCS-USI Summer School 2021

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# Goals of the course

- Part I
  - Basic concepts
    - Execution and memory model
    - Basic directives
    - Hands-on sessions
  - Advanced topics
    - Asynchronous execution and wait queues
    - Interoperability with CUDA and MPI
    - Deep copy
    - Hands-on sessions
- Part II
  - Port the miniapp to GPU using OpenACC
  - Walk away ready to start hacking your own code

# Introduction to OpenACC

# What is OpenACC?

- Collection of compiler directives for specifying loops and regions to be offloaded from a host CPU to an attached accelerator device
- Host + Accelerator programming model
- High-level representation
- Current specification version: 3.1
- Similarities to classic OpenMP for multicores

# Why to use OpenACC?

Because . . .

- I don't care about all the little hardware details, I want my science done.
- I want to run on accelerators, but I still need a fast and readable code.
- I need portability across different accelerator vendors, but also to be able to run on the multicore.
- I inhereted a large legacy monolithic codebase, which I don't dare to refactor completely, but I need to get my results faster.
- My code is in Fortran.

# OpenACC is not a silver bullet

- A high-level representation is not a panacea.
  - You still need to understand and adapt to the programming model.
- Does not substitute hand-tuning, but can serve as a very good starting point.
  - Some low-level CUDA constructs are not exposed (shared memory, groups etc.)
- User base not yet as large as of classic OpenMP for multicores, but it is expanding.
  - You may run into compiler bugs or specification ambiguities.

# Format of directives

- C/C++
  - `#pragma acc` *directive-name [clause-list] new-line*
  - Scope is the following *block of code*
- Fortran
  - `!$acc` *directive-name [clause-list] new-line*
  - Scope is until `!$acc end` *directive-name*

# Programming model

- Host-directed execution
- Compute intensive regions are offloaded to attached accelerator devices
- Host orchestrates the execution on the device
  - Allocations on the device
  - Data transfers
  - Kernel launches
  - Wait for events
  - Etc. . .

# Execution model

- The device executes *parallel* or *kernel regions*
- Parallel region
  - Work-sharing loops
- Kernel region
  - Multiple loops to be executed as multiple kernels
- Levels of parallelism
  1. *Gang*
  2. *Worker*
  3. *Vector*
  - Parallelism levels are decided by the compiler but can be fine-tuned by the user

# Execution model

- The device executes *parallel* or *kernel regions*
- Parallel region
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- Kernel region
  - Multiple loops to be executed as multiple kernels
- Levels of parallelism
  1. *Gang* → *CUDA block*
  2. *Worker* → *CUDA warp*
  3. *Vector* → *CUDA threads*
  - Parallelism levels are decided by the compiler but can be fine-tuned by the user
  - Mapping to CUDA blocks/warps/threads is implementation defined

# Execution model

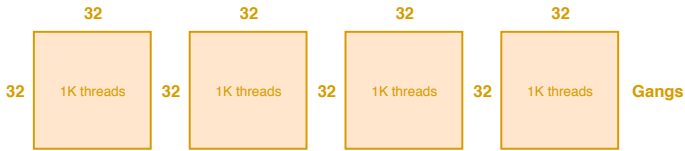
Modes of execution

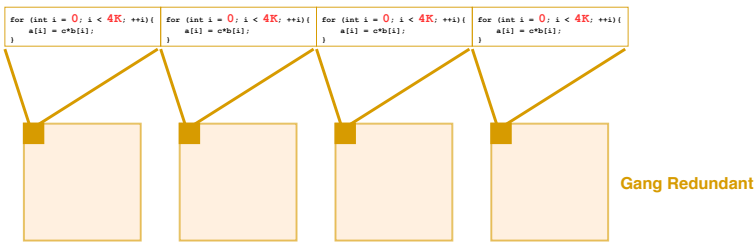
- Gang
  - Gang-redundant (GR)
  - Gang-partioned (GP)
- Worker
  - Worker-single (WS)
  - Worker-partitioned (WP)
- Vector
  - Vector-single (VS)
  - Vector-partitioned (VP)

# Execution model

## Modes of execution

```
for (int i = 0; i < 4096; ++i) {
    a[i] = c*b[i];
}
```



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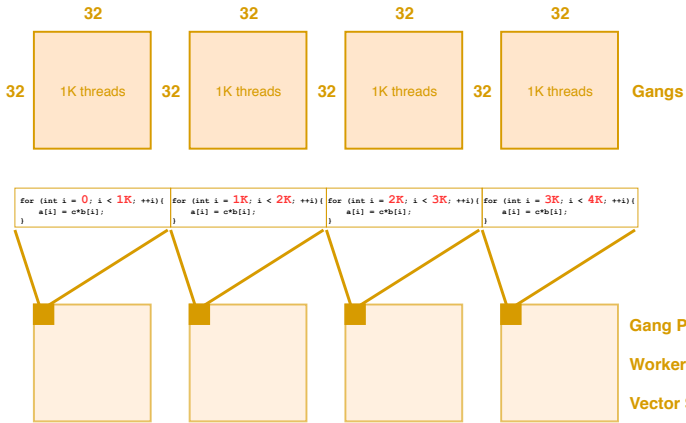

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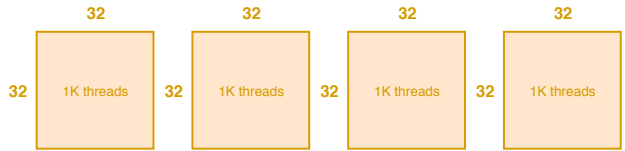

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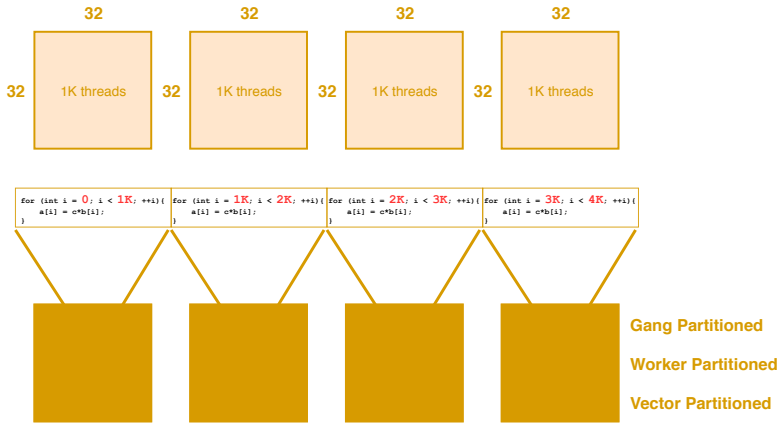

# Execution model

The `kernels` construct

**Multiple loops inside kernels construct**

```
!$acc kernels
    !GR model
    y(1) = y(1) + x(1)
    do i = 1, N
        !compiler decides on the partitioning (GP/WP/VP modes)
        y(i) = y(i) + a*x(i)
    enddo
    do i = 1, N
        !compiler decides on the partitioning (GP/WP/VP modes)
        y(i) = b*y(i) + a*x(i)
    enddo
!$acc end kernels
```

- Compiler will try to deduce parallelism
- Loops are launched as different GPU kernels

# Execution model

The `parallel` construct

## Parallel construct

```
!$acc parallel
    y(1) = y(1) + x(1)   !GR model
!$acc end parallel
!$acc parallel
    do i = 1, N   !loop executed in GR mode
        y(i) = y(i) + a*x(i)
    enddo
!$acc end parallel
!$acc parallel
    !$acc loop
    do i = 1, N   !compiler decides on the partitioning (GP/WP/VP modes)
        y(i) = b*y(i) + a*x(i)
    enddo
!$acc end parallel
```

- No automatic parallelism deduction → parallel loops must be specified explicitly
- Implicit gang barrier at the end of `parallel`

# Execution model

## Work-sharing loops

- C/C++: `#pragma acc loop`
  - Applies to the immediately following `for` loop
- Fortran: `!$acc loop`
  - Applies to the immediately following `do` loop
- Loop will be automatically striped and assigned to different threads
  - Use the `independent` clause to force striping
- Convenience syntax combines `parallel`/`kernels` and `loop` constructs
  - `#pragma acc parallel loop`
  - `#pragma acc kernels loop`
  - `!$acc parallel loop`
  - `!$acc kernels loop`

# Execution model

Work-sharing loops – the `collapse` clause

## Collapse loops

```
!$acc loop collapse(2)
do i = 1,N
    do j = 1,N
        A(i,j) = coeff*B(i,j)
    enddo
enddo
```

- OpenACC vs. OpenMP
  - OpenACC: apply the `loop` directive to the following $N$ loops and possibly collapse their iteration spaces if independent
  - OpenMP: Collapse the iteration spaces of the following $N$ loops

# Execution model

Controlling parallelism

- Amount of parallelism at the `kernels` and `parallel` level
  - `num_gangs(...)`, `num_workers(...)`, `vector_length(...)`
- At the `loop` level
  - `gang`, `worker`, `vector`

**100 thread blocks with 128 threads each**

```
!$acc parallel num_gangs(100), vector_length(128)
    !$acc loop gang, worker, vector
    do i = 1, n
        y(i) = y(i) + a*x(i)
    enddo
!$acc end parallel
```

# Execution model

## Variable scoping

- Allowed in the `parallel` directive only
- `private`: A copy of the variable is placed in each *gang* (CUDA block)
- `firstprivate`: Same as `private` but initialized from the host value

# Execution model

## Variable scoping

- Allowed in the `parallel` directive only
- `private`: A copy of the variable is placed in each *gang* (CUDA block)
- `firstprivate`: Same as `private` but initialized from the host value

Implicit scoping:

- (C/C++/Fortran) Scalar variables are firstprivate to the *thread* that executes the loop, array variables are shared in global memory (different to OpenMP!)
- (C/C++ only) Scope of variables declared inside a parallel block depends on the current execution mode:
  - *Vector-partitioned* mode → private to the thread
  - *Worker-partitioned, Vector-single* mode → private to the worker
  - *Worker-single* mode → private to the gang

# Execution model

Reduction operations

- `#pragma acc parallel reduction(<op>:<var>)`
  - e.g., `#pragma acc parallel reduction(+:sum)`
- `#pragma acc loop reduction(<op>:<var>)`
- `var` must be scalar
- `var` is copied and default initialized within each gang
- Intermediate results from each gang are combined and made available outside the parallel region
- Complex numbers are also supported
- Operators: `+`, `*`, `max`, `min`, `&`, `|`, `%`, `&&`, `||`

# Execution model

Calling functions from parallel regions

- `#pragma acc routine {gang | worker | vector | seq}`
  - Just before the function declaration or definition
- `!$acc routine {gang | worker | vector | seq}`
  - In the specification part of the subroutine
- Parallelism level of the routine
  - `gang`: must be called from GR context
  - `worker`: must be called from WS context
  - `vector`: must be called from VS context
  - `seq`: must be called from sequential context

# Memory model

Where is my data?

- The host and the device have separate address spaces
  - Data management between the host and the device is the programmer's responsibility
  - You must make sure that all the necessary data for a computation is available on the accelerator before entering the compute region
  - You must make sure to transfer the processed data back to the host if needed
  - Internally the address spaces are linked with a so-called present table

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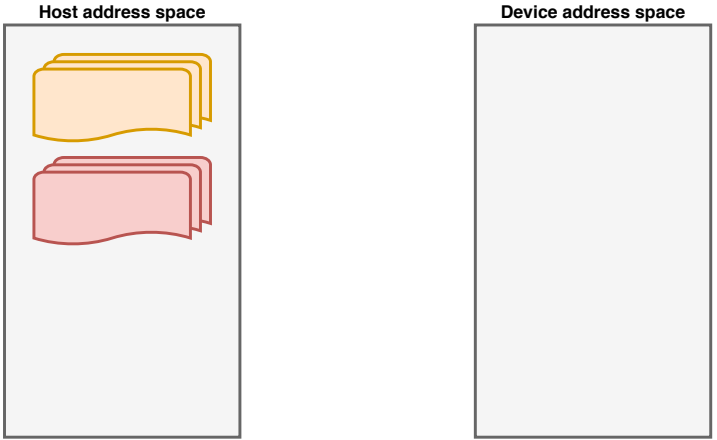
- But there can be some exceptions:
  - The "device" might be the multicore → no need for data management
  - Some compilers may infer automatically the necessary data transfers
  - Nvidia Pascal GPUs provide efficient support for a unified memory view between the host and the accelerator

# Memory model

Separate address spaces



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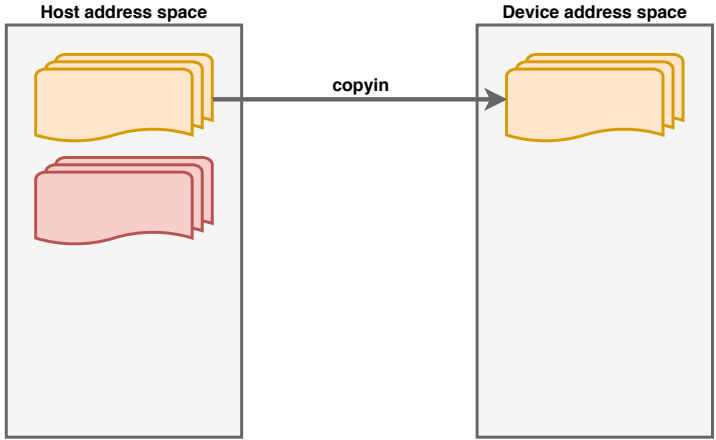

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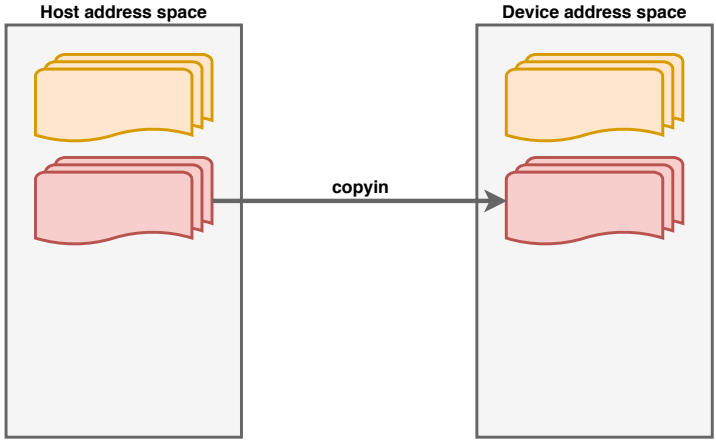

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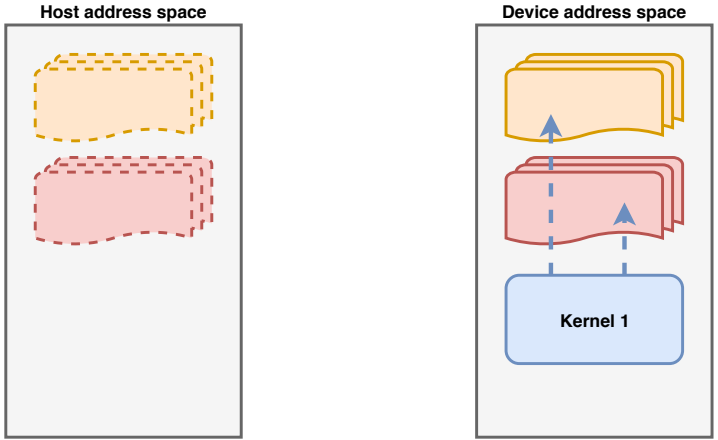

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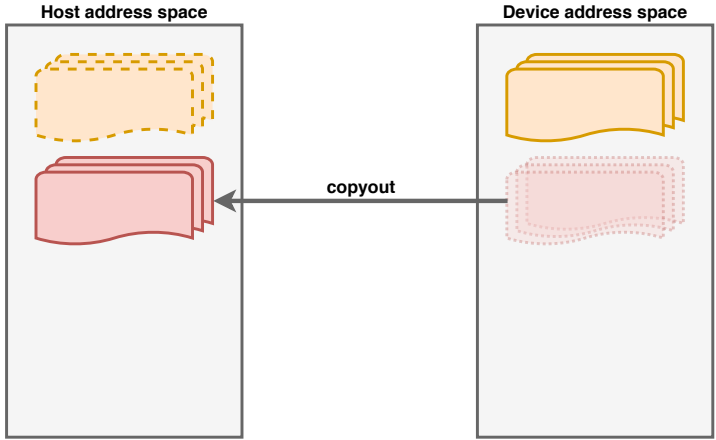

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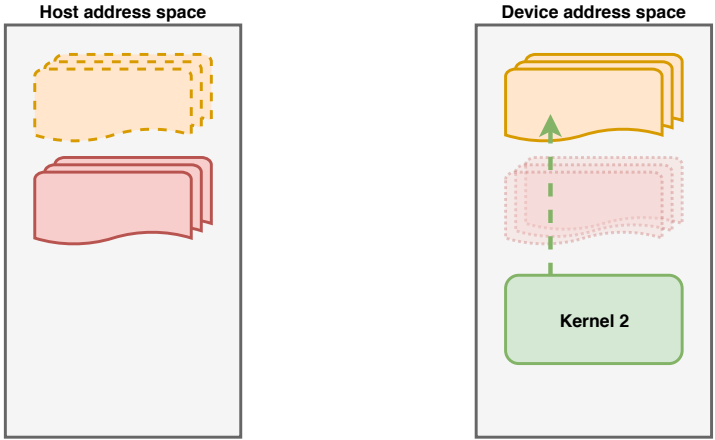

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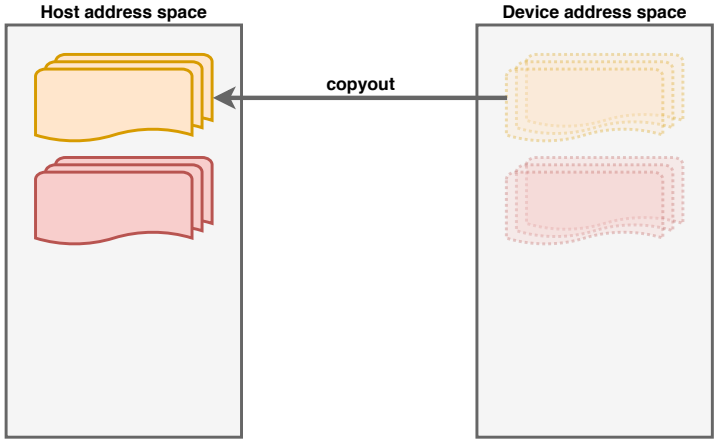
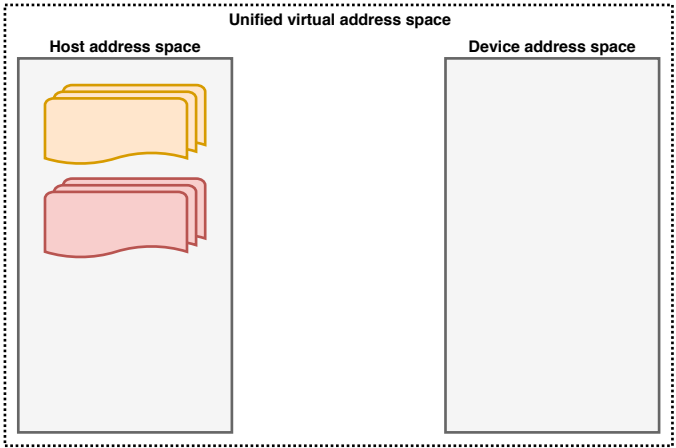


# Memory model

Unified memory address space



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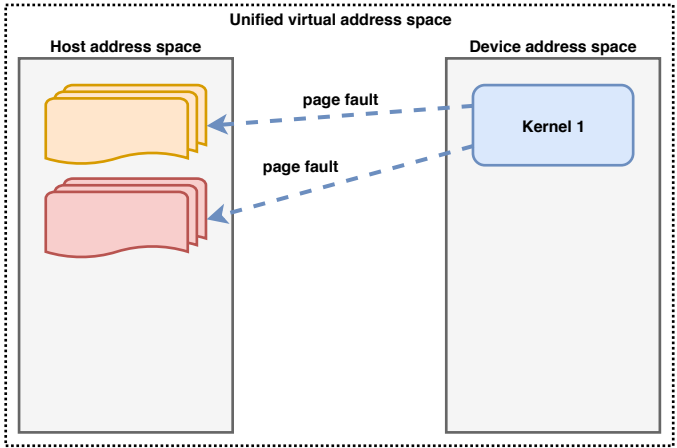

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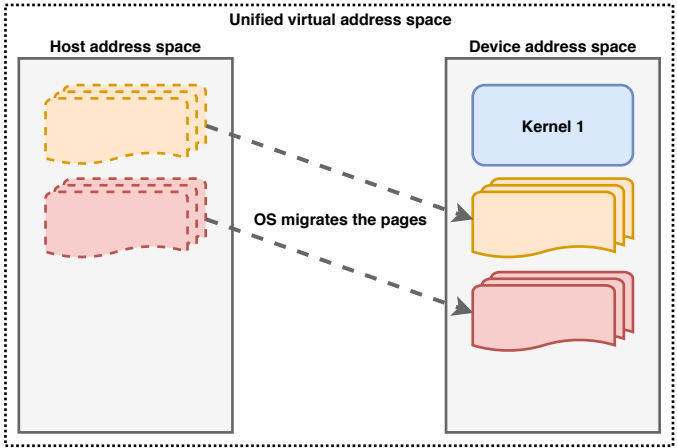

# Memory model

## Directives accepting data clauses

Data clauses may appear in the following directives:

- Compute directives:
  - `#pragma acc kernels`
  - `#pragma acc parallel`
- Data directives:
  - `#pragma acc data`
  - `#pragma acc enter data`
  - `#pragma acc exit data`
  - `#pragma acc declare`
  - `#pragma acc update`

# Memory model

## Data clauses

- `create(a[0:n])`: Allocate array `a` on device
- `copyin(a[0:n])`: Copy array `a` to device
- `copyout(a[0:n])`: Copy array `a` from device
- `copy(a[0:n])`: Copy array `a` to and from device
- `present(a)`: Inform OpenACC runtime that array `a` is on device
- `delete(a)`: Deallocate array `a` from device (`exit data` only)

Not for the `acc update` directive

# Memory model

## The `acc data` directive

- Defines a scoped data region
  - Data will be copied in at entry of the region and copied out at exit
  - A *structural reference count* is associated with each memory region that appears in the data clauses

- C/C++: `#pragma acc data` *`[data clauses]`*
  - The next block of code is a data region

- Fortran: `!$acc data` *`[data clauses]`*
  - Defines a data region until `!$acc end data` is encountered

# Memory model

The `acc enter/exit data` directives

- Defines an unscoped data region
  - Data will be resident on the device until a corresponding `exit data` directive is found
  - Useful for managing data on the device across compilation units
  - A *dynamic reference count* is associated with each memory region that appears in the data clauses
- C/C++:
  - `#pragma acc enter data [data clauses]`
  - `#pragma acc exit data [data clauses]`
- Fortran:
  - `!$acc enter data [data clauses]`
  - `!$acc exit data [data clauses]`

# Memory model

## The `acc declare` directive

- Functions, subroutines and programs define *implicit data regions*
- The `acc declare` directive is used in variable declarations for making them available on the device during the lifetime of the implicit data region
- Useful for copying global variables to the device

- C/C++: `#pragma acc declare` *`[data clauses]`*
- Fortran: `!$acc declare` *`[data clauses]`*

- The variables are not initalized

# Memory model

## The `acc update` directive

- May be used during the lifetime of device data for updating the copies on either host or the device

- `#pragma acc update host(<var-list>)`
  - Update host copy with corresponding data from the device

- `#pragma acc update device(<var-list>)`
  - Update device copy with corresponding data from the host

# Memory model

## Array ranges

Data clauses may accept as arguments:

- Whole arrays
  - C/C++: You *must* specify bounds for dynamically allocated arrays
    - `#pragma acc data copyin(a[0:n])`
    - But `#pragma acc data present(a)` is acceptable: `a`'s bounds can be inferred by the runtime
  - Fortran: array shape information is already embedded in the data type
    - `!$acc data copyin(a)`
- Array subranges
  - C/C++: start and length
    - `#pragma acc data copyin(a[2:n-2])`
  - Fortran: first index and last index
    - `!$acc data copyin(a[3:n])`

# Synchronization directives

- Atomic operations
  - `#pragma acc atomic` [atomic-clause]
  - `!$acc atomic` [atomic-clause]
  - Atomic clauses: `read`, `write`, `update` and `capture`
  - Example of “capturing” a value:
    - `v = x++;`
- No global barriers → cannot be implemented due to hardware restrictions
- No equivalent of `__syncthreads()`

# Leverage the unified memory

- Virtual address space shared between CPU and GPU
- The CUDA driver and the hardware take care of the page migration
- Introduced with the Kepler architecture and CUDA 6, but is significantly improved with Pascal

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- Virtual address space shared between CPU and GPU
- The CUDA driver and the hardware take care of the page migration
- Introduced with the Kepler architecture and CUDA 6, but is significantly improved with Pascal

- You could completely omit the data management in OpenACC !
- Supported by the PGI compiler using the `-ta=tesla:managed` option

# Hands-on exercises

General information

- Base directory for the OpenACC exercises is `topics/openacc`:
- `practicals/`: The hands-on exercises
- `solutions/`: Where the solutions will appear
- `ci/`: Continuous integration tests for the exercises (ask me offline if interested)

# Hands-on exercises

General information

- `grep TODO *.{cpp,f90,f03}`
- PGI compiler is recommended, GNU and Cray compiler are present in `make` files
- `module load craype-accel-nvidia60` for loading CUDA and set the target architecture to the GPU
- `make`

# Hands-on

Exercise 1 – AXPY

- `practicals/axpy/axpy_openacc.{cpp,f90}`
- Run as:
  `srun --reserv=summer_school -Cgpu ./axpy.openacc [ARRAY_SIZE]`
  - `ARRAY_SIZE` is power of 2, default is 16
- Try with different sizes. Does the GPU outperform the CPU version?

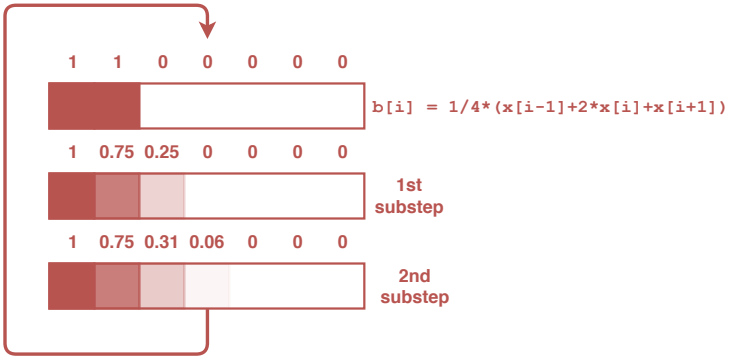
# Hands-on

Exercise 2 – Dot product

- `practicals/basics/dot_openacc.{cpp,f90}`
- Run as:
  `srun --reserv=summer_school -Cgpu ./dot.openacc [ARRAY_SIZE]`
  - `ARRAY_SIZE` is power of 2, default is 2
- Try with different sizes. Does the GPU outperform the CPU version?

# Hands-on

Exercise 3 – 1D blur kernel



# Hands-on

Exercise 3 – 1D blur kernel

- `practicals/basics/blur_openacc.{cpp,f90}`
- Run as:
  `srun --reserv=summer_school -Cgpu ./blur.openacc [ARRAY_SIZE]`
  - `ARRAY_SIZE` is multiple of 2, default is 20
- Offload to GPU the loops of the naive kernel; why is it so slow?

# Hands-on

Exercise 3 – 1D blur kernel

- `practicals/basics/blur_openacc.{cpp,f90}`
- Run as:
  `srun --reserv=summer_school -Cgpu ./blur.openacc [ARRAY_SIZE]`
  - `ARRAY_SIZE` is multiple of 2, default is 20
- Offload to GPU the loops of the naive kernel; why is it so slow?
- Moving data to and from the device is slow (≈7–8 GB/s per direction)
- Avoid unnecessary data movement in the `nocopies` kernel
  - Move the necessary data to GPU early enough and keep it there as long as possible
  - Update host copies using `#pragma acc update` directive if needed

# Hands-on

Exercise 4 – Experiment with the unified memory

- Remove all the data directives and data clauses
- Compile the `blur_twice_naive` kernel with `-ta=tesla:managed`
- How does it compare to the manual data management in terms of performance?
- Can you explain the performance difference?

# Asynchronous execution and wait queues

By default, all OpenACC directives are blocking.

- The calling CPU thread must wait for the OpenACC operation (data transfer, kernel etc.) to complete
- All OpenACC operations are enqueued in a single *activity queue* (CUDA stream)
- All items in an activity queue are executed synchronously, but activity queues are independent from each other

# Asynchronous execution and wait queues

OpenACC allows you to enqueue operations on different activity queues using the `async` clause and wait for them using the `wait` directive/clause.

- `async(<qno>)`: push operations to activity queue `qno` and continue execution on the host
- `wait(<qno>)`: wait for pending operations in activity queue `qno` to finish before launching next operation on the device
- `#pragma acc wait(<qno>)`: Wait for all events in activity queue `qno` to finish before continuing execution on the host
  - Wait for all queues to finish if used without an argument

# Asynchronous execution and wait queues

Example of operations pipelining

## Operations are executed sequentially

```
#pragma acc data ...
for (auto p = 0; p < n; ++p) {
    #pragma acc update device(A[p][0:m])
    #pragma acc parallel loop
    for (auto i = 0; i < m; ++i) {
        // work on A[p] array
    }

    #pragma acc update host(A[p][0:m])
}
```

# Asynchronous execution and wait queues

Example of operations pipelining

## Operations are pipelined

```
#pragma acc data ...
for (auto p = 0; p < n; ++p) {
    #pragma acc update device(A[p][0:m]) async(p)
    #pragma acc parallel loop async(p)
    for (auto i = 0; i < m; ++i) {
        // work on A[p] array
    }

    #pragma acc update host(A[p][0:m]) async(p)
}
#pragma acc wait
```

This concept is useful for overlapping computation and data transfers to the device.

# Interoperability with CUDA

- Can I use a CUDA pointer inside OpenACC device context?
- Can I call a CUDA function from OpenACC host context?

Short answer is *yes*.

# Interoperability with CUDA

Use CUDA pointers inside OpenACC device context

A scenario:

- Have a CUDA code that needs to call a function that uses OpenACC.
- This function may accept an array that has been allocated already on the GPU by CUDA.

The problem?

- OpenACC only knows of pointers that it is managing itself; the `present` clause won't work. No idea what this pointer is; never seen it before!

# Interoperability with CUDA

Use CUDA pointers inside OpenACC device context

Solution:

- We need to instruct the OpenACC runtime to trust this pointer and that it is a valid device pointer.
- OpenACC runtime will just treat that pointer as known, but it won't check its shape.
- Use the `deviceptr(<ptrlist>)` clause with `parallel`, `kernels` and `data` directives

# Interoperability with CUDA

Use CUDA pointers inside OpenACC device context – Example

```
void copy(double *dst, const double *src, size_t n) {
  #pragma acc parallel loop deviceptr(dst, src)
  for (size_t i = 0; i < n; ++i) {
    dst[i] = src[i];
  }
}

int main() {
  double *a, *b;
  cudaMalloc(&a, 1024);
  cudaMalloc(&b, 1024);
  ...
  copy(b, a, 1024);
  return 0;
}
```

# Interoperability with CUDA

Register CUDA pointers in the present table with runtime library routine

Another scenario:

- You want to call OpenACC code without `deviceptr(<ptrlist>)` clause, e.g., from OpenACC and CUDA.

The Solution:

- You register the CUDA pointer with `acc_map_data` in the present table.

```
int main() {
  double *a_host, *a_device;
  a_host = new double[1024];
  cudaMalloc(&a_device, 1024);
  acc_map_data(a_host, a_device, sizeof(double)*1024);
  ...
  acc_unmap_data(a_host);
  ...
  return 0;
}
```

# Interoperability with CUDA

Call a CUDA function from OpenACC host context

Scenario:

- My code is in OpenACC, but I need to call an optimized library written in CUDA, which accepts device pointers, e.g., cuBLAS.

# Interoperability with CUDA

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- I only “see” device pointers while in a parallel region, but I want to get a device pointer, while executing on the host.

# Interoperability with CUDA

Call a CUDA function from OpenACC host context

Scenario:

- My code is in OpenACC, but I need to call an optimized library written in CUDA, which accepts device pointers, e.g., cuBLAS.

Problem:

- I only “see” device pointers while in a parallel region, but I want to get a device pointer, while executing on the host.

Solution:

- Use a `host_data` region
  - `#pragma acc host_data use_device(<varlist>)`

# Interoperability with CUDA

The `host_data` directive

- C/C++: `#pragma acc host_data use_device(<varlist>)`
  - In the next block of code the compiler will make available the device address of any variable in `<varlist>`.
- Fortran: `!$acc host_data use_device(<varlist>)`
  - The compiler will make available the device address of any variable in `<varlist>` until a matching `!$acc end host_data` is found.
- Optional clauses:
  - `if(`*`condition`*`)`: Use the device pointer if *condition* is true.
  - `if_present`: Use the device pointer if variables in `<varlist>` are present on the device.

*Heads-up: Remember this directive if you want to combine OpenACC and MPI.*

# Hands-on

Exercise 5 – Calling cuBLAS methods

Source code:

- `practicals/gemm/gemm.cpp`
- Run as:
  `srun --reserv=summer_school -Cgpu ./axpy.openacc [ARRAY_SIZE]`
  - `ARRAY_SIZE` is power of 2, default is 8

Steps:

1. Compile with '`make CPPFLAGS=`' to get also the naive implementation → too slow!
2. Offload the GEMM method to the GPU using OpenACC
3. Make use of cuBLAS GEMM through OpenACC
4. Compare the performance of the different versions

# Hands-on

Exercise 6.1 – 2D diffusion example

Source code:

- `diffusion2d_omp.{cpp,f90}`: our baseline code
  - Single node OpenMP version for the CPU
- `diffusion2d_openacc.{cpp,f90}`
  - Single node OpenACC version
  - Run as:
    ```
    srun --reserv=summer_school -Cgpu ./diffusion2d.openacc [ARRAY_SIZ
    ```
    - `ARRAY_SIZE` is power of 2, default is 16
  - Fill in the parts where `OPENACC_DATA` is defined.

# Hands-on

Exercise 6.2 – 2D diffusion example using CUDA data management

Source code:

- `diffusion2d_openacc.{cpp,f90}`
  - Single node OpenACC version
  - Run as:
    `srun --reserv=summer_school -Cgpu ./diffusion2d.openacc.cuda [ARRA`
    - `ARRAY_SIZE` is power of 2, default is 16
  - Fill in the parts where `OPENACC_DATA` is undefined.

# Deep Copy

The concept

## True deep copy (ideal)

```
struct foo {
    int *arr;
    size_t len;
};
// ...
for (auto i = 0; i < 3; ++i) {
    f[i].len = 10;
    f[i].arr = new int[f[i].len];
}

#pragma acc enter data copyin(f[0:3])
```

- Where will `f[i].arr` refer to?

# Deep Copy

The concept

## True deep copy (ideal)

```
struct foo {
    int *arr;
    size_t len;
};
// ...
for (auto i = 0; i < 3; ++i) {
    f[i].len = 10;
    f[i].arr = new int[f[i].len];
}

#pragma acc enter data copyin(f[0:3])
```

- Where will `f[i].arr` refer to? → They will be host pointers!
- Ideally, we would like everything to be magically copied.
  - Not so easy, especially for C/C++.

# Deep Copy

The manual solution – OpenACC 2.6

## Manual deep copy (top-down approach)

```
#pragma acc enter data copyin(f[0:3])
for (auto i = 0; i < 3; ++i) {
    #pragma acc enter data copyin(f[i].arr[0:f[i].len])
}
// do stuff on the device
for (auto i = 0; i < 3; ++i) {
    #pragma acc exit data copyout(f[i].arr[0:f[i].len])
}
#pragma acc exit data copyout(f[0:3])
```

- The runtime will attach the `f[i].arr` pointer to the device copy of the data.
- This happens implicitly if the `f[i].arr` pointer is present on the device.

# Deep Copy

The manual solution – OpenACC 2.6

## Manual deep copy (bottom-up approach)

```
for (auto i = 0; i < 3; ++i) {
    #pragma acc enter data copyin(f[i].arr[0:f[i].len])
}

#pragma acc enter data copyin(f[0:3])
for (auto i = 0; i < 3; ++i) {
    acc_attach((void **) &f[i].arr);
}
// do stuff on the device
```

- At the time when `f[i].arr` is copied to the device, the pointer is not already present on the device.
- If we copy the `struct` later, we need to manually attach the pointer to the device copy of the data.

# OpenACC vs. OpenMP

- OpenMP 4.0 introduced directives for offloading computation to accelerators
- Similar concepts to OpenACC but OpenMP is a more prescriptive standard
- There is no OpenMP-OpenACC merger envisioned right now
- Compiler support for GPU targets
  - Cray
  - IBM XL
  - GCC (needs to be compiled specially)
  - Clang (under development)

# OpenACC and compiler support

- PGI
  - Latest spec support; drives the OpenACC development
  - Twice per year a community release
- Cray
  - Support up to OpenACC 2.0; no new features or later spec support
  - Bug fixes and support for the current implementation only
  - From CCE 9.0 onward support will be dropped
- GCC
  - Support of OpenACC 2.0a from GCC 5.1 onward
  - Support of OpenACC 2.5 in development branch

# More information and events

- `http://www.openacc.org`
  - Specification and related documents
  - Tutorials
  - Events

- GPU Hackathons
  - One week+ of intensive development for porting your code to the GPUs
  - 3 developers + 2 mentors per team
  - Several virtual events scheduled for 2021
  - Find the one that fits you and apply!

# Porting the miniapp to GPUs using OpenACC

# General information

- C++ only
- OpenACC version resides in `miniapp/openacc`
- MPI+OpenACC version resides in `miniapp/mpi/openacc`
- Plotting script inside the `scripts/` folder
  - Use `plot.sh` in order not to mess with your environment.
- Interesting files
  - `main.cpp`: the solver
  - `data.h`: domain types
  - `linalg.cpp`: linear algebra kernels
  - `operators.cpp`: the diffusion kernel + communication routines

# Hints

Differences to CUDA version

- No need for a separate `kernels` namespace
- No need for keeping a a copy of the device pointer
  - OpenACC runtime does just that for you
- No need for grid and block dimensions calculations
- The calculations for the interior points and the boundaries are based on the serial version

# Hints

- There are two C++ abstractions that complicate things:

  1. Domain data is encapsulated inside the `Field` class
     - Allocated and initialized inside the constructor
     - Deallocated inside the destructor

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Hint: *OpenACC provides the* `enter data` *and* `exit data` *directives for unscoped data management*

2. Operators for accessing the domain data

Hint: *Operators are just another kind of functions;* `acc routine` *directive is just for that*

# Performance tips

- All OpenACC operations are synchronous. Do we really want that?
  - You may just push your operations to an activity queue (note: cuBLAS is pushing to queue 0), but ...
  - ... you will need to synchronize sometimes!
- Fine tune your parallelism
- Try dropping the C++ operator abstractions
  - Code will become ugly (and error-prone), but you may get some bits of performance; judge if it's worth it.