Introduction to OpenMP Device Offload

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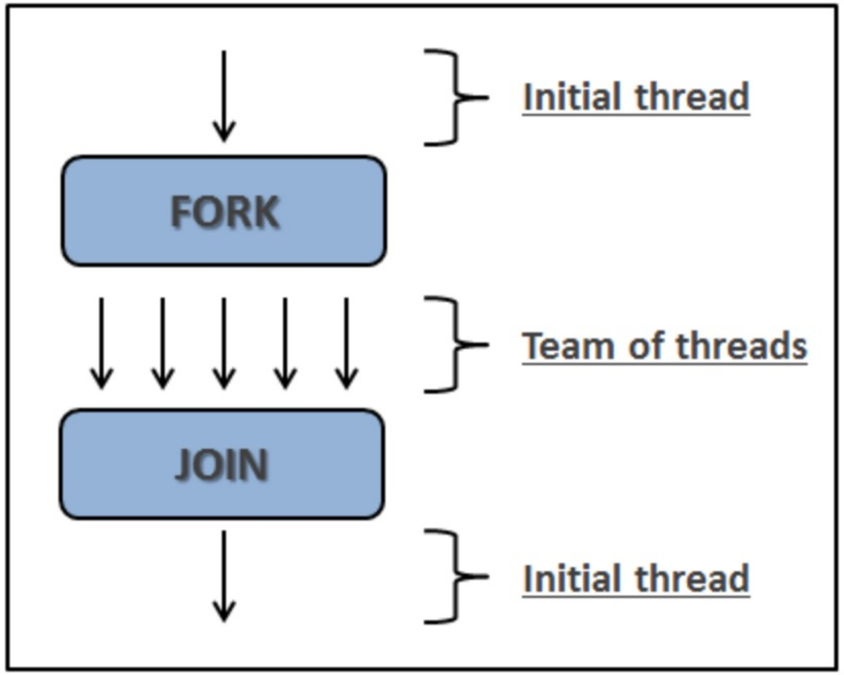
Outline

- Introduction to OpenMP
- History of OpenMP
- Recap of OpenMP Worksharing
- Introduction to OpenMP Offload
- Offload Steps
- Expressing parallelism
- Useful Runtime Routines
- Hands On

Introduction to OpenMP

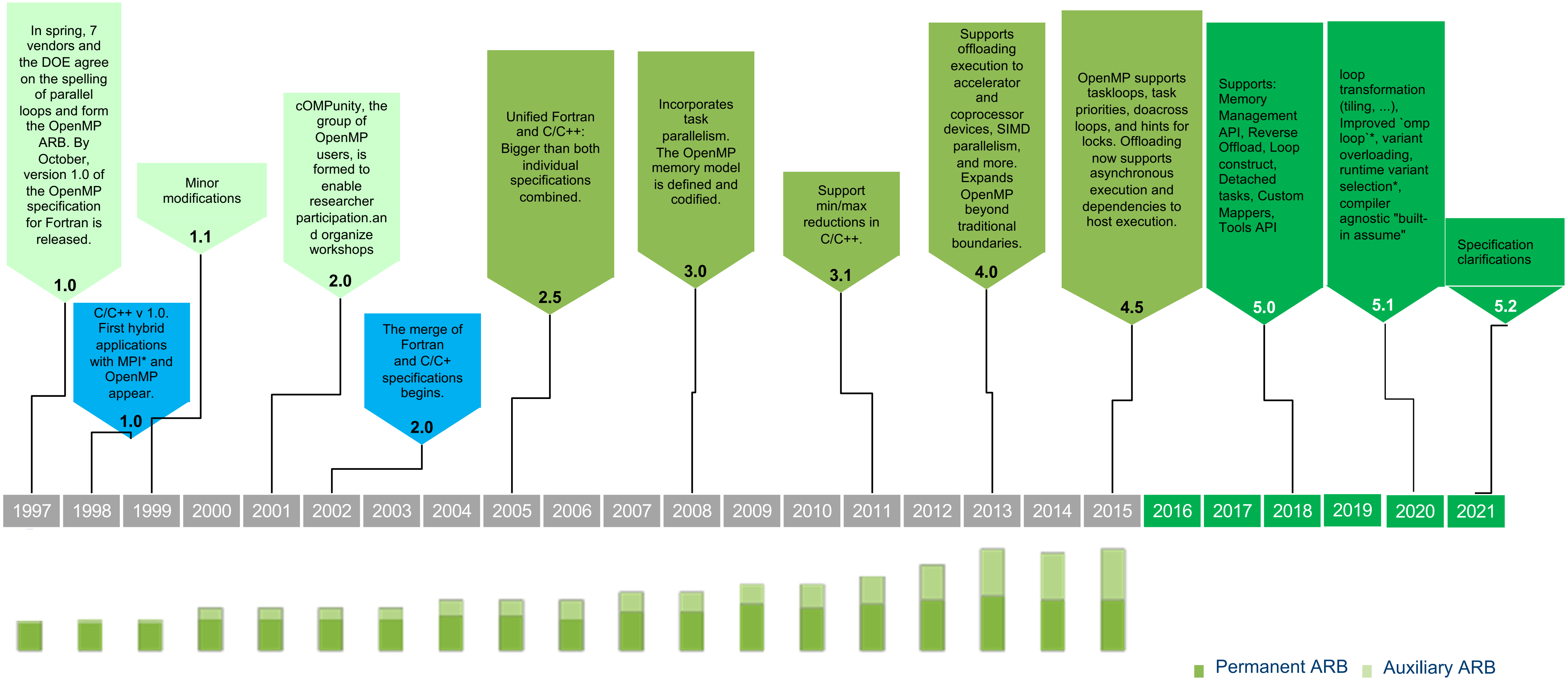
It is a An Application Program Interface (API) to allow programmers to develop threaded parallel codes on shared memory computational units.

- Directives are understood by OpenMP aware compilers (others are free to ignore)
- Generates parallel threaded code
  - Original thread becomes thread "0"
  - Share resources of the original thread (or rank)
  - Data-sharing attributes of variables can be specified based on usage patterns



Reference: Somewhere from the web

History of OpenMP: 1997 - 2021



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Reference: 2021 Exascale Computing Project Virtual Annual Meeting April 12 – 16, 2021

Recap: OpenMP Worksharing

#pragma omp parallel → All threads will execute the region

#pragma omp parallel for → All threads will execute a part of the iterations

- Creates a team of OpenMP threads that execute the structured-block that follows
- Number of threads property is generally specified by OMP_NUM_THREADS env variable or num_threads clause (num_threads has precedence)

Recap: OpenMP Worksharing

Serial

```
for (int i = 0; i < N; ++i)
{
    C[i] = A[i] + B[i];
}
```

- 1 thread/process will execute each iteration sequentially
- Total time = time_for_single_iteration * N

Parallel

```
#pragma omp parallel
for (int i = 0; i < N; ++i)
{
    C[i] = A[i] + B[i];
}
```

- Say, OMP_NUM_THREADS = 4
- 4 threads will execute each iteration sequentially (overwriting values of C)
- Total time = time_for_single_iteration * N

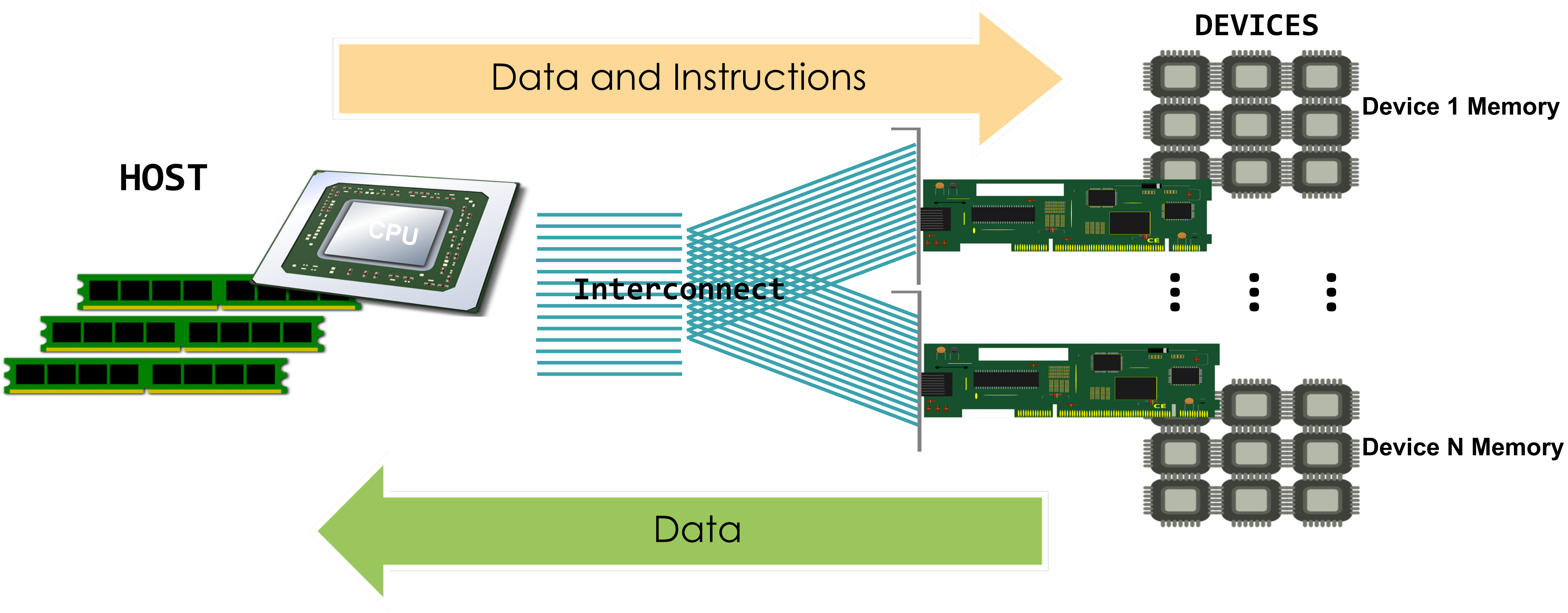
Parallel Worksharing

```
#pragma omp parallel for
for (int i = 0; i < N; ++i)
{
    C[i] = A[i] + B[i];
}
```

- Say, OMP_NUM_THREADS = 4
- 4 threads will distribute iteration space (roughly N/4 per thread)
- Total time = time_for_single_iteration * N/4

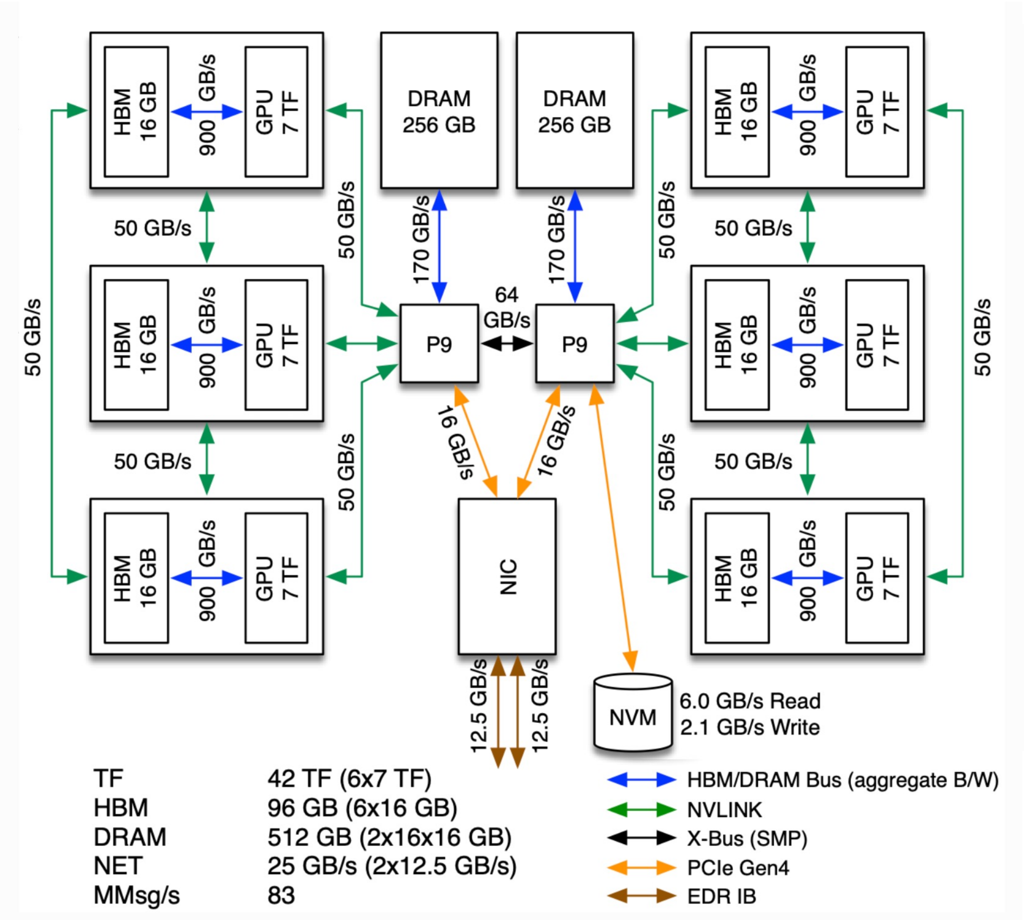
Introduction: OpenMP Offload

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

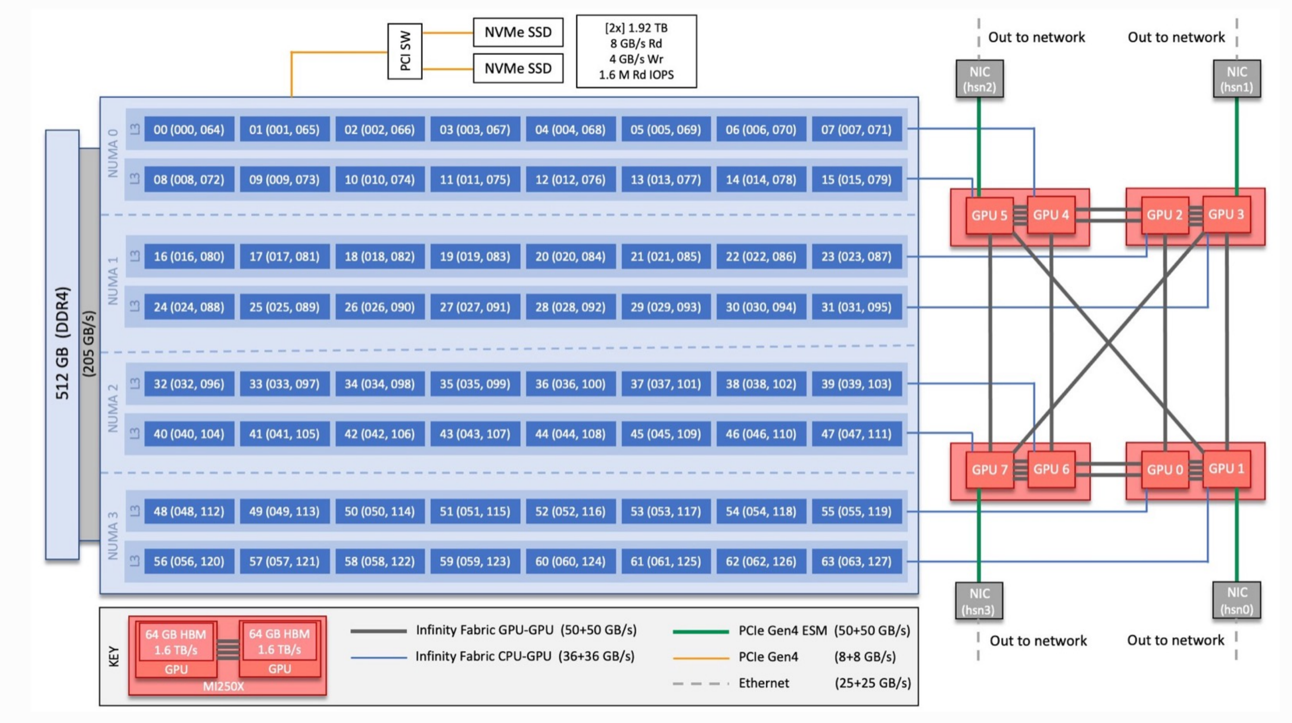


Summit vs. Frontier

Summit Node



Frontier Node



OpenMP Offload: Steps

- **Identification** of compute kernels
  - CPU initiates kernel for execution on the device

- Expressing **parallelism** within the kernel

- Manage **data transfer** between CPU and Device
  - relevant data needs to be moved from host to device memory
  - kernel executes using device memory
  - relevant data needs to be moved from device to main memory

Step 1: Identification of Kernels to Offload

- Look for compute intensive code and that can benefit from parallel execution
  - Use performance analysis tools to find bottlenecks
- Track independent work units with well defined data accesses
- Keep an eye on platform specs
  - GPU memory is a precious resource
- Confirm via Profiling
  - Tools like rocprof and HPCToolkit

- More information regarding rocprof can be found at: https://docs.olcf.ornl.gov/systems/frontier_user_guide.html#optimization-and-profiling
- More information on HPCToolkit can be found at: http://hpctoolkit.org

How to Offload ?

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.

OpenMP Offload: Target Directive

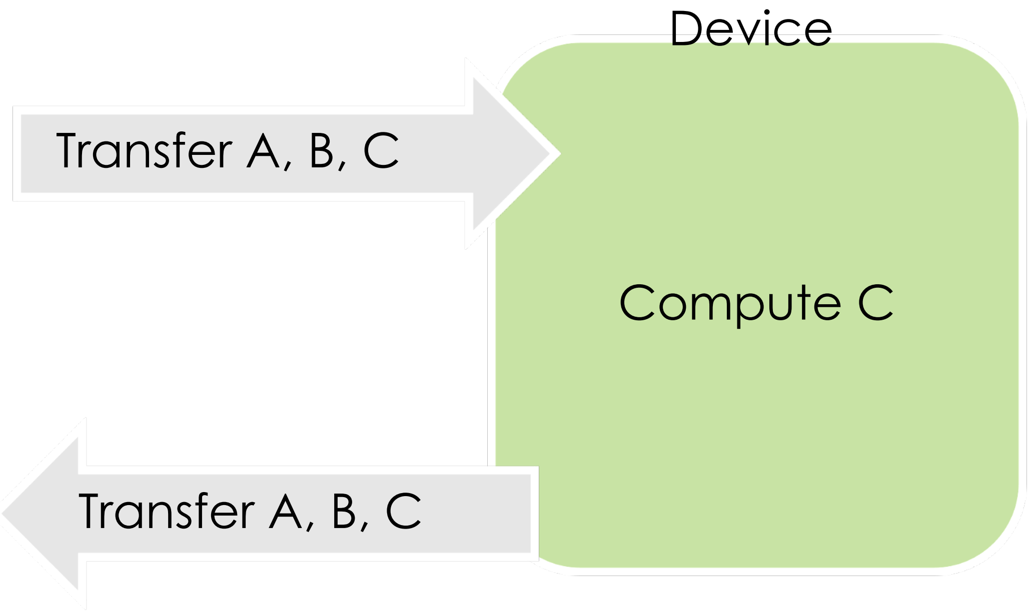
- Clauses allowed on the target directive:
  - if([target :] scalar-expression)
  - device([device-modifier :] integer-expression)
  - thread_limit(integer-expression)
  - private(list)
  - firstprivate(list)
  - in_reduction(reduction-identifier : list)
  - map([[map-type-modifier[,] [map-type-modifier[,] ...]] 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)] ...])

OpenMP Offload: Example using omp `target`

/*C code to offload Matrix Addition Code to Device*/

```c
…
int A[N][N], B[N][N], C[N][N];
/*
  initialize arrays
*/
#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];
    }
  }
} // end target
```

Kernel

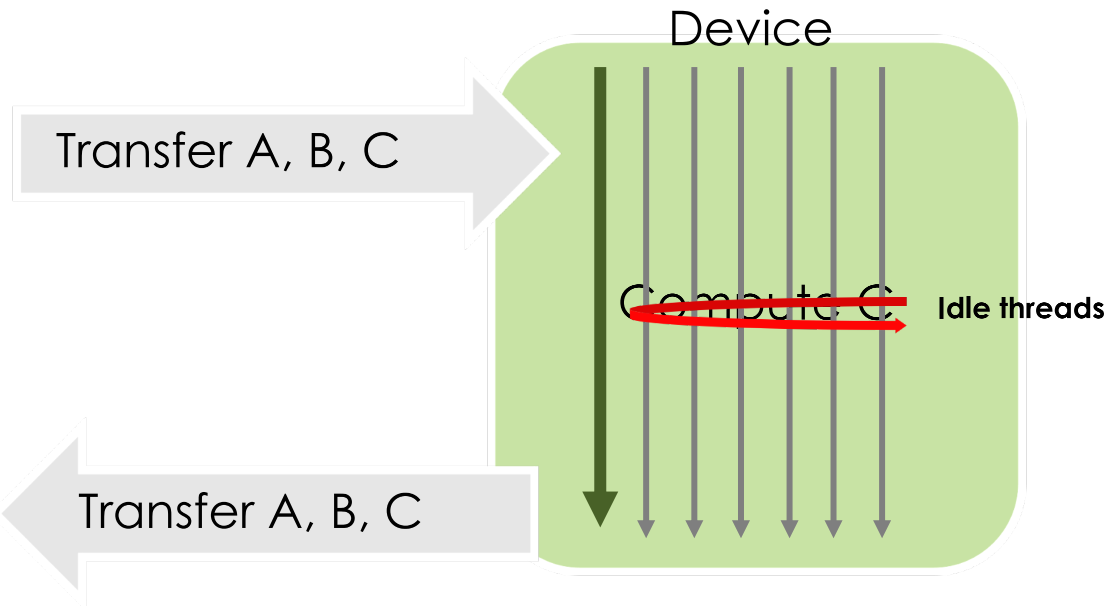


The target construct is a task generating construct

Step 2: Expressing Parallelism

/*C code to offload Matrix Addition Code to Device*/

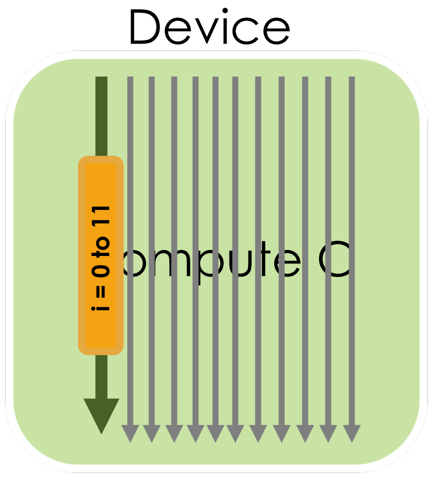
```
  …
  int A[N][N], B[N][N], C[N][N];
  /*
    initialize arrays
  */
#pragma omp target
  {
    for (int i = 0; i < N; ++i) {
      for (int j = 0; j < N; ++j) {
        C[i][j] = A[i][j] + B[i][j];
      }
    }
  } // end target
```



Expressing Parallelism: Increasing device utilization

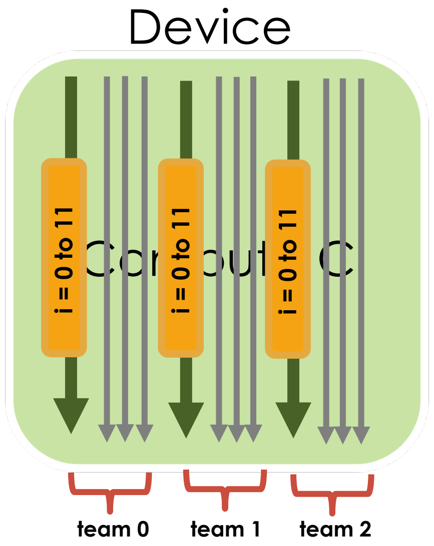
target

```
#pragma omp target
for (int i = 0; i < 12; ++i)
{
    C[i] = A[i] + B[i];
}
```



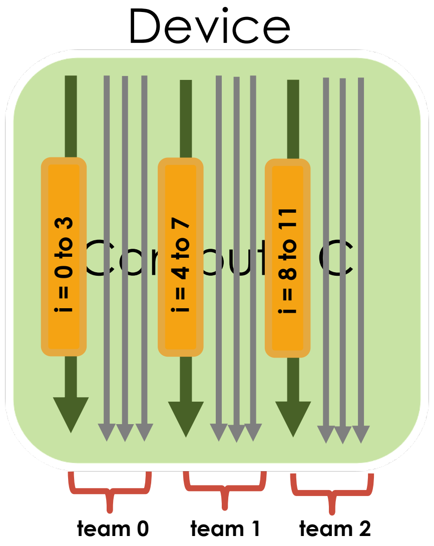
target teams

```
#pragma omp target teams
num_teams(3)
for (int i = 0; i < 12; ++i)
{
    C[i] = A[i] + B[i];
}
```



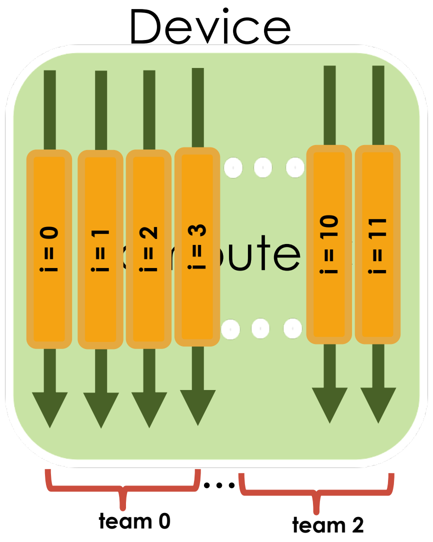
target teams distribute

```
#pragma omp target teams
distribute num_teams(3)
for (int i = 0; i < 12; ++i)
{
    C[i] = A[i] + B[i];
}
```



target teams distribute parallel

```
#pragma omp target teams
distribute parallel for
num_teams(3)
for (int i = 0; i < 12; ++i)
{
    C[i] = A[i] + B[i];
}
```



Expressing Parallelism: Device Execution Directives

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.
#pragma omp target teams *[clause[[,] clause] …] new-line structured-block*	**!$omp target teams** *[clause[[,] clause] …] loosely/tightly-structured-block* **!$omp end target teams**	The **target** construct offloads the enclosed code to the accelerator. The **teams** construct creates a league of teams. The **initial** thread of each team executes the code region.
#pragma omp target teams distribute *[clause[[,] clause] …] new-line loop-nest*	**!$omp target teams distribute** *[clause[[,] clause] …] loop-nest [***!$omp end target teams distribute***]*	The **target** construct offloads the enclosed code to the accelerator. A **league** of thread teams is created, and loop iterations are **distributed** and executed by the initial teams.
#pragma omp target teams distribute parallel for *[clause[[,] clause] …] new-line loop-nest*	**!$omp target teams distribute parallel do** [clause[[,] clause] …] loop-nest *[***!$omp end target teams distribute parallel do***]* ***need simd to map to threads**	The **target** construct offloads the enclosed code to the accelerator. A **league** of thread teams are created, and loop iterations are **distributed** and **executed in parallel** by all threads of the teams.

Expressing Parallelism: Other combinations

C/C++	Fortran	Description
#**pragma omp target parallel** *[clause[[,] clause] ...]* new-line structured-block	**!$omp target parallel** *[clause[[,] clause] ...]* *loosely-structured-block* **!$omp end target parallel**	The **target** construct offloads the enclosed code to the accelerator. The **parallel** construct creates a team of OpenMP threads that execute the region.
#pragma omp target parallel for *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target parallel do** *[clause[[,] clause] ...]* *loop-nest* [**!$omp end target parallel do**]	The **target** construct offloads the enclosed code to the accelerator. The **parallel for/do** combined construct creates a thread team and distributes the inner loop iterations over threads.
#pragma omp target parallel loop *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target parallel loop** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target parallel loop***]*	The **target** construct offloads the enclosed code to the accelerator. The **parallel** construct creates a team of OpenMP threads that execute the region. The **loop** construct allows concurrent execution of the associated loops.
#**pragma omp target teams loop** *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target teams loop** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target teams loop***]*	The **target** construct offloads the enclosed code to the accelerator. The **teams** construct creates a league of teams. The **loop** construct allows concurrent execution of the associated loops.

Expressing Parallelism : SIMD

* We will revisit this when we discuss Frontier specifics *

C/C++	Fortran	Description
#pragma omp target simd *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target simd** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target simd***]*	Semantics are identical to explicitly specifying a target directive immediately followed by SIMD directive.
#pragma omp target parallel for simd \ *clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target parallel do simd** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target parallel do simd***]*	Semantics are identical to explicitly specifying a target directive immediately followed by a parallel worksharing-loop SIMD directive.
#pragma omp target teams distribute simd \ *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target teams distribute simd** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target teams distribute simd***]*	Semantics are identical to explicitly specifying a target directive immediately followed by a teams distribute simd directive
#pragma omp target teams distribute parallel for simd \ *[clause[[,] clause] ...] new-line* *loop-nest*	**!$omp target teams distribute parallel do simd** *[clause[[,] clause] ...]* *loop-nest* *[***!$omp end target teams distribute parallel do simd***]*	Semantics are identical to explicitly specifying a target directive immediately followed by a teams distribute parallel worksharing-loop SIMD directive.

Useful RT Routines: Device Environment

C/C++	Fortran	Where to call ?		Description
		Host	Target region	
int omp_get_num_procs(void);	integer function omp_get_num_procs()	✓	✓	returns the number of processors available to the device
void omp_set_default_device(int device_num);	subroutine omp_set_default_device(device_num) integer device_num	✓	✗	sets the value of the default-device-var ICV of the current task to device_num
int omp_get_default_device(void);	integer function omp_get_default_device()	✓	✗	returns the default target device
✓ int omp_get_num_devices(void);	integer function omp_get_num_devices()	✓	✗	returns the number of non-host devices available for offloading code or data.
✓ int omp_get_device_num(void);	integer function omp_get_device_num()	✓	✓	returns the device number of the device on which the calling thread is executing
✓ int omp_is_initial_device(void);	logical function omp_is_initial_device()	✓	✓	returns true if the current task is executing on the host otherwise, it returns false.
int omp_get_initial_device(void);	integer function omp_get_initial_device()	✓	✗	return the device number of the host device

Teams Region: Useful RT Routines

C/C++	Fortran	Where to call ? Host	Where to call ? Target region	Description
int omp_get_num_teams(void);	integer function omp_get_num_teams()	✔	✔	returns the number of initial teams in the current teams region.
int omp_get_team_num(void);	integer function omp_get_team_num()	✔	✔	returns the initial team number of the calling thread
void omp_set_num_teams(int num_teams);	subroutine omp_set_num_teams(num_teams) integer num_teams	✔	✔	the number of threads to be used for subsequent teams regions that do not specify a num_teams clause
int omp_get_max_teams(void);	integer function omp_get_max_teams()	✔	✔	returns an upper bound on the number of teams that could be created by a teams construct
void omp_set_teams_thread_limit(int thread_limit);	subroutine omp_set_teams_thread_limit(thread_limit) integer thread_limit	✔	✔	defines the maximum number of OpenMP threads per team

References

- Examples were adapted from: https://github.com/SOLLVE/sollve_vv
- OpenMP Specification (5.x)
  - https://www.openmp.org/specifications/
- https://www.nas.nasa.gov/hecc/assets/pdf/training/OpenMP4.5_3-20-19.pdf
- OpenMP Disussion @ 2021 Exascale Computing Project Virtual Annual Meeting (April 12 – 16, 2021)