Advanced OpenMP

Accelerator Offloading

Accelerator support in OpenMP

- Not GPU specific
  - Not many other interesting devices at the moment, however
- Fully integrated into OpenMP for the CPU
- Introduced in OpenMP 4.0, with significant revisions/extensions in 4.5 and 5.0
- Similar to, but not the same as, OpenACC directives.
  - OpenACC is an alternative standard for offloading to GPUs
  - Developed before OpenMP 4.0
- Current, usable implementations of OpenMP for GPUs are: Cray, NVIDIA, IBM, LLVM/clang, gcc

OpenMP device model

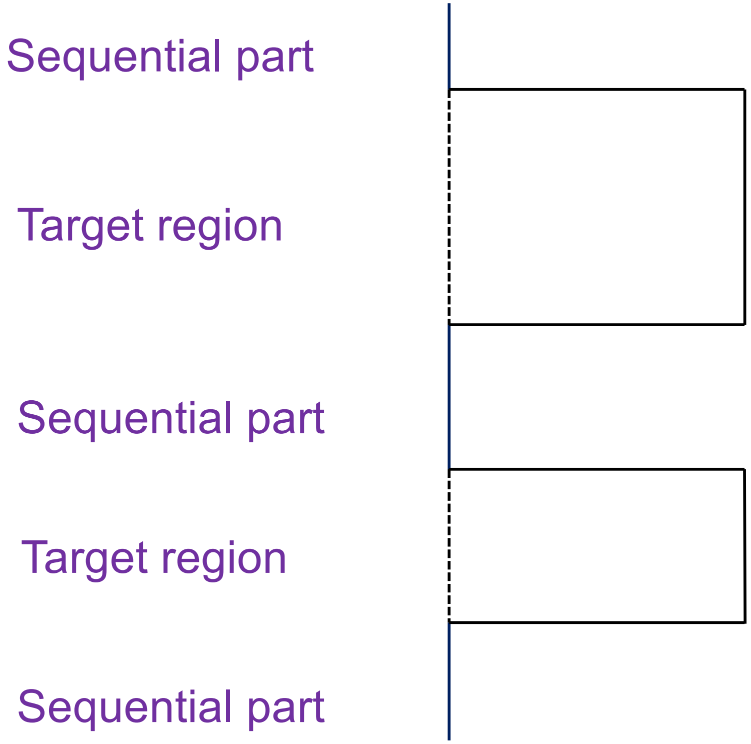
- Host-centric model with one host device and multiple target devices of the same type.
- *device*: a logical execution engine with local storage.
- *device data environment*: a data environment associated with a target data or target region.
- **`target`** constructs control how data and code is offloaded to a device.
- Data is mapped from a host data environment to a device data environment.

Target region

- The *target region* is the basic offloading construct in OpenMP.
- A target region defines a section of a program.
- The OpenMP program starts executing on the host
- When a target region is encountered, the code it contains is executed on a device
- By default, the code inside the target region executes sequentially
- At the end of the target region, the host thread waits for the target region code to finish, and continues executing the next statements

```
#pragma omp target
    structured block
```

Target region



```
int main(){
.
.
#pragma omp target
{
.
.
.
.
.
.
.
}
.
.
.
.
#pragma omp target
{
.
.
.
}
.
.
.
```

Host and device data

- Host and device have separate memory spaces
- In order to access data inside the target region, it must be mapped to the device.
- Mapped data must not be accessed by the host until the target region has completed
- Default behaviour (in 4.5):
  - scalars referenced in the target construct are treated as *firstprivate* (new copy on device, initialised with value on host)
  - Static arrays are copied to the device on entry and back to the host on exit

Map clause

- More control is available via the map clause on the target construct

```
#pragma omp target map(map-type:list)
```

where list is a list of variables and map-type is one of:

`to`	copy the data to the device on entry
`from`	copy the data to the host on exit
`tofrom`	copy the data to the device on entry and back on exit
`alloc`	allocate an uninitialised copy on the device (don’t copy values)

Example

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

- Sequential execution of the loop on the device – not very useful!

Dynamically allocated data

- Need to specify the number of elements to be copied:

```
int* B = (int*)malloc(sizeof(int)*N);
#pragma omp target map(to:B[0:N])
```

Can specify part of an array:

```
#pragma omp target map(to:B[10:3])
```

Note: syntax in C/C++ `[start:length]` is different from Fortran subarrays `[start:end]`!

Keeping data on the device

- Moving data between the host and device is expensive on a lot of current hardware
- Would like to avoid mapping data in every target region if it can be kept on the device between target regions
- **`target data`** constructs just map data and do not offload any code
- **`target update`** construct copies values between host and device between target constructs

Target data constructs

```
#pragma omp target enter data map(to: A[0:N],B[0:N])

for (r=0; r<reps; r++){
#pragma omp target
  {
    // do stuff with A and B
  }
  // do something on the host
}

#pragma omp target exit data map(from: B[0:N])
```

Target update construct

```
#pragma omp target enter data map(to: A[0:N],B[0:N])

#pragma omp target
  {
    // do stuff with A and B
  }
#pragma omp target update from(A[0])
   // modify A[0] on the host
#pragma omp target update to(A[0])
#pragma omp target
  {
    // do more stuff with A and B
  }
#pragma omp target exit data map(from: B[0:N])
```

Parallelism on the device

- In principle we can use all the ”normal” OpenMP constructs inside a target region to create and use threads on the device
  - Parallel regions, worksharing, synchronization, tasks, etc.
- However, GPUs are not able to support a full threading model outside of a single stream multiprocessor (SM)
  - no synchronization or memory fences possible between SMs
  - no coherency between L1 caches
  - a parallel region inside a target region will only execute on one SM
  - compare with CUDA – can only synchronise threads inside a thread block, not between thread blocks

Example

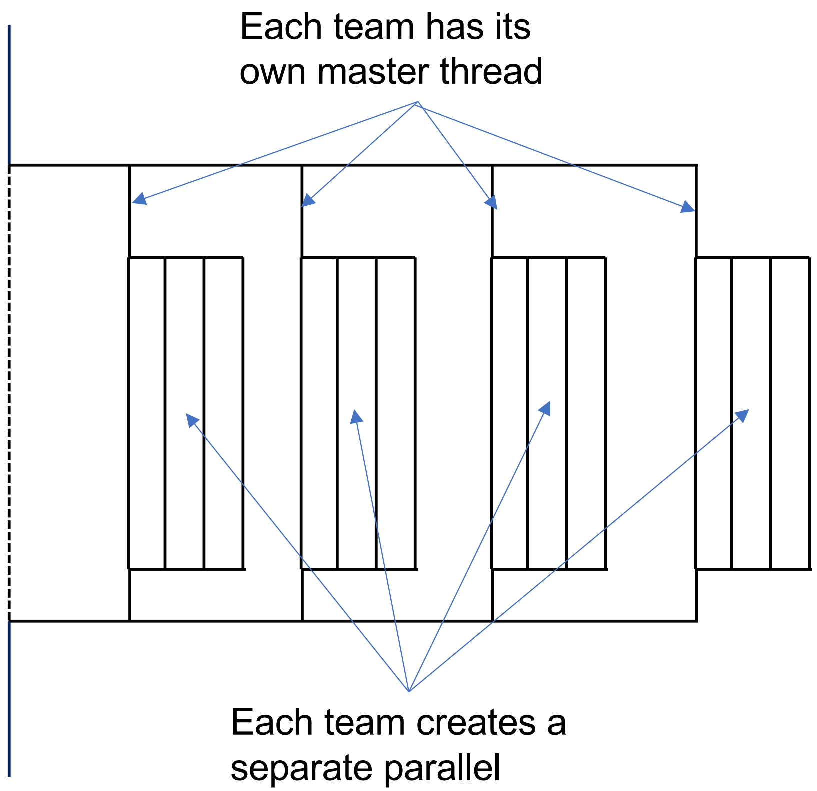
```
#pragma omp target map(to:B,C),
map(tofrom:sum)
#pragma omp parallel for reduction(+:sum)
for (int i=0; i<N; i++){
     sum += B[i] + C[i];
}
```

- On some devices, this might work fine
- On a GPU, this will only utilise one SM

Teams construct

- Creates multiple master threads inside a target region
- Each master thread can spawn its own team of threads with a parallel region
- Threads in different teams cannot synchronise with each other
  - Barriers, critical regions, locks, atomics only apply to the threads within a team
- Can set the number of teams, query the current team ID and query the number of teams

Teams and parallel regions



Each team has its own master thread

Each team creates a separate parallel region

```
int main(){
.
.
#pragma omp target
#pragma omp teams
#pragma omp parallel
{
.
.
.
.
.
.
.
}
.
```

Distribute construct

- As ever, loops are the main source of parallelism in most applications
    - and especially so for GPUs
- If we offload a parallel loop to the device, we would like to distribute the iterations of the loop across the teams as well as across the threads within the teams
- `distribute` construct can be used to do this
- Like the `for` construct but, assigns iterations of the following loop to different teams
- Has a schedule clause `dist_schedule`, but the only schedule kind allowed is static, with a (optional) chunksize

Example

```
#pragma omp target teams distribute parallel for\
map(to:B,C), map(tofrom:sum) reduction(+:sum)
for (int i=0; i<N; i++){
      sum += B[i] + C[i];
}
```

- Distributes iterations across multiprocessors *and* across threads within each multiprocessor.
- Note the (long!) combined construct here

Calling functions inside target regions

- **declare target** compiles a version of function/subroutine that can be called on the device

```
#pragma omp declare target
int myfunc(int index);
#pragma omp end declare target

#pragma omp target teams distribute parallel for\
map(tofrom:sum) reduction(+:sum)
for (int i=0; i<N; i++){
        sum += myfunc(i);
}
```

Target directive clauses

- **`device`** clause allows the programmer to specify which device to offload to (if there is more than one).
  - Takes an integer parameter – device numbering is implementation dependent
- By default, the host thread blocks until target region is completed. Can change this behaviour with a **`nowait`** clause.
  - Target region is actually a task, so task synchronisation constructs (e.g. taskwait) can be used to wait for completion.
  - Need to make sure the host does not access mapped data until the target region completes

Performance issues

- Transferring data between host and device is expensive
- Need to minimize this as much as possible
    - Don’t transfer anything that’s not required
    - Keep data on the device as far as possible (using `target data` regions)

- GPUs need lots of threads to work efficiently
- Need to expose a lot of parallelism – much more than for the CPU
    - For nested loops can use the `collapse` clause to parallelise two or more loops in the nest

Memory layout

- For CPUs having different threads accessing neighbouring words in memory can be bad
  - risk of false sharing
  - OK if its just reads
- For GPUs having different threads accessing neighbouring words in memory can be good
  - allows coalesced loads/stores
- If data structures are being used on both CPU and GPU, it may be best to explicitly change the layout (e.g. transpose multidimensional arrays) before mapping to the GPU.
  - Might also be possible to interchange loops, and/or use a `static,1` schedule (some implementations do this by default)

Reusing this material