OpenMP 4.0

Mark Bull, EPCC

OpenMP 4.0

- Version 4.0 was released in July 2013

- Now available in most production version compilers
  - support for device offloading not in all compilers, and not for all devices!

- Most recent version is 4.5, released in November 2015
  - enhancements to offloading, and a few other new features
  - not in production versions yet – expected sometime this year?

OpenMP 4.0 on ARCHER

- As of 9th March 2016, the default versions of GNU (5.1.0), Intel (15.0.2) and Cray (8.4.1) compilers all support OpenMP 4.0

What's new in 4.0

- User defined reductions
- Construct cancellation
- Portable SIMD directives
- Extensions to tasking
- Thread affinity
- Accelerator offload support

User defined reductions

- As of 3.1 cannot do reductions on objects or structures.
- UDR extensions in 4.0 add support for this.

- Use **`declare reduction`** directive to define new reduction operators
- New operators can then be used in reduction clause.

```
#pragma omp declare reduction (reduction-identifier :
typename-list : combiner) [identity(identity-expr)]
```

- `reduction-identifier` gives a name to the operator
  - Can be overloaded for different types
  - Can be redefined in inner scopes
- `typename-list` is a list of types to which it applies
- `combiner` expression specifies how to combine values
- `identity` can specify the identity value of the operator

  Can be an expression or a brace initializer

Example

```
#pragma omp declare reduction (merge : std::vector<int>
: omp_out.insert(omp_out.end(), omp_in.begin(), omp_in.end()))
```

- Private copies created for a reduction are initialized to the identity that was specified for the operator and type
  - Default identity defined if identity clause not present
- Compiler uses combiner to combine private copies
- `omp_out` refers to private copy that holds combined values
- `omp_in` refers to the other private copy
- Can now use `merge` as a reduction operator.

Construct cancellation

- Clean way to signal early termination of an OpenMP construct.
  - one thread signals
  - other threads jump to the end of the construct

!$omp cancel *construct* **[if (expr)]**

where *construct* is **parallel**, **sections**, **do** or **taskgroup** cancels the construct

!$omp cancellation point *construct*

checks for cancellation (also happens implicitly at cancel directive, barriers etc.)

Example

```
!$omp parallel do private(eureka)
do i=1,n
   eureka = testing(i,...)
!$omp cancel parallel if(eureka)
end do
```

- First thread for which **`eureka`** is true will cancel the parallel region and exit.
- Other threads exit next time they hit the **`cancel`** directive
- Could add more cancellation points inside **`testing()`**

Portable SIMD directives

- Many compilers support SIMD directives to aid vectorisation of loops.
  - compiler can struggle to generate SIMD code without these
- OpenMP 4.0 provides a standardised set
- Use **`simd`** directive to indicate a loop should be SIMDized

```
#pragma omp simd [clauses]
```

- Executes iterations of following loop in SIMD chunks
- Loop is not divided across threads
- SIMD chunk is set of iterations executed concurrently by SIMD lanes

- Clauses control data environment, how loop is partitioned
- `safelen(length)` limits the number of iterations in a SIMD chunk.
- `linear` lists variables with a linear relationship to the iteration space (induction variables)
- `aligned` specifies byte alignments of a list of variables
- `private`, `lastprivate`, `reduction` and `collapse` have usual meanings.
- Also `declare simd` directive to generate SIMDised versions of functions.
- Can be combined with loop constructs (parallelise and SIMDise), e.g.: `#pragma omp parallel for simd`

Extensions to tasking

- **taskgroup** directive allows a task to wait for all descendant tasks to complete
- Compare **taskwait**, which only waits for children
- Unlike **taskwait**, it has an associated structured block

```
#pragma omp taskgroup
{
  create_a_group_of_tasks(could_create_nested_tasks);
} // all created tasks complete by here
```

Task dependencies

- **depend** clause on task construct

```
!$omp task depend(type:list)
```

where *type* is **in**, **out** and *list* is a list of variables.

  - list may contain subarrays: OpenMP 4.0 includes a syntax for C/C++
- **in**: the generated task will be a dependent task of all previously generated sibling tasks that reference at least one of the list items in an **out** clause.
- **out**: the generated task will be a dependent task of all previously generated sibling tasks that reference at least one of the list items in **in** or **out** clause.
  - can also use **inout** for clarity, but semantics are same as **out**

Example

```
#pragma omp task depend (out:a)
   { ... }
#pragma omp task depend (out:b)
   { ... }
#pragma omp task depend (in:a,b)
   { ... }
```

- The first two tasks can execute in parallel
- The third task cannot start until both the first two are complete

Asynchronous Many Tasks

- This example is quite simple, but the concept is quite powerful
- Portable way of doing Asynchronous Many Task style programming (as in OmpSs, PLASMA/DPLASMA).
- Programmer just specifies computational tasks and their data dependencies – actual execution order is determined by the OpenMP runtime (respecting the dependencies).
- Can help to avoid scalability problems with “bulk synchronous” approaches

Thread affinity

- Since many systems are now NUMA and SMT, placement of threads on the hardware can have a big effect on performance.
- Up until now, control of this in OpenMP is very limited.
- Some compilers have their own extensions.
- OpenMP 4.0 gives much more control
- Don't expect this to be necessary for most ARCHER applications
    - only really helpful if there are nested OpenMP parallel regions
    - most ARCHER applications use MPI + one level of OpenMP

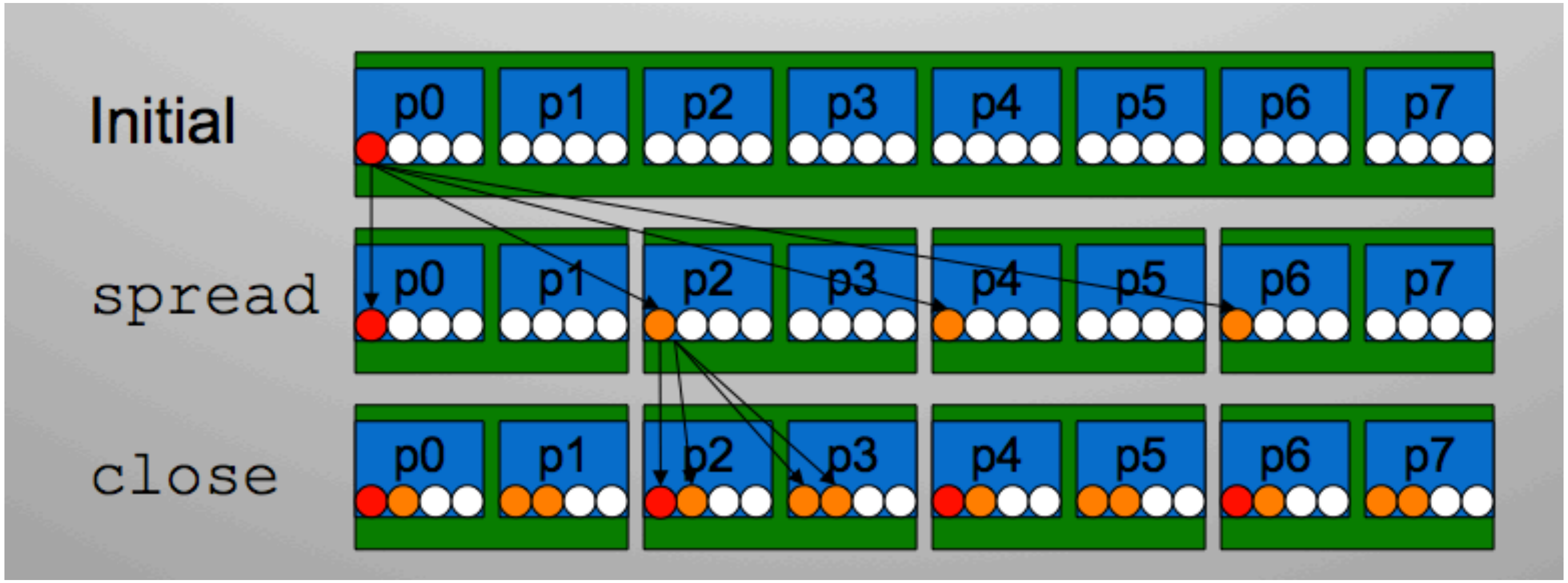
Affinity environment

- Increased choices for **OMP_PROC_BIND**
- Can still specify **true** or **false**
- Can now provide a list (possible item values: **master**, **close** or **spread**) to specify how to bind parallel regions at different nesting levels.
- Added **OMP_PLACES** environment variable
- Can specify abstract names including threads, cores and sockets
- Can specify an explicit ordered list of places
- Place numbering is implementation defined

Example

- Processor with 8 cores, 4 hardware threads per core.

```
export OMP_PLACES=threads
export OMP_PROC_BIND="spread,close"
```



Accelerator support

- Similar to, but not the same as, OpenACC directives.
- Support for more than just loops
- Less reliance on compiler to parallelise and map code to threads
- Not GPU specific
- Fully integrated into OpenMP
- Not relevant for ARCHER (no accelerators!)

- 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.

- Code inside target region is executed on the device.
- Executes sequentially by default.
- Can include other OpenMP directives to run in parallel
- Clauses to control data movement.

```
#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];
}
```

- **`target data`** construct just moves data and does not execute code (c.f. **`#pragma acc data`** in OpenACC).
- **`target update`** construct updates data during a target data region.
- **`declare target`** compiles a version of function/subroutine that can be called on the device.
- Target regions are blocking: the encountering thread waits for them to complete.
  - Asynchronous behaviour can be achieved by using target regions inside tasks (with dependencies if required).
  - N.B. This has changed in OpenMP 4.5: can use **`nowait`** clause on target

What about GPUs?

- Executing a target region on a GPU can only use one multiprocessor
  - synchronisation required for OpenMP not possible between multiprocessors
  - not much use!
- `teams` construct creates multiple master threads which can execute in parallel, spawn parallel regions, but cannot synchronise or communicate with each other.
- `distribute` construct spreads the iterations of a parallel loop across teams.
  - Only schedule option is static (with 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.

OpenMP target vs. OpenACC

- Latest versions of OpenMP (4.5) and OpenACC (2.5) support pretty much the same functionality with different syntax.
- Exception is OpenACC kernels directive which relies on compiler auto-parallelisation capabilities – goes against the prescriptive philosophy of OpenMP.
- OpenACC is not likely to evolve any further, but will not die off quickly
- Maybe worth considering using OpenMP 4.5 for portability and sustainability.