Solving Linear Systems with OpenMP Target Offloading and oneMKL

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Outline:

• Code Snippet
• How OpenMP Dispatch a MKL Call
• Data Movement
• Kernel Debug Info
• Performance

• The content is from the following paper published in the latest issue of “The Parallel Universe Magazine” by Henry A. Gabb and Nawal Copty


• Full code example available on GitHub.
Code snippet of solving a linear system $aX=b$

```fortran
!$ include "mkl_omp_offload.f90"
program solve_batched_linear_systems
!$ use onemkl_lapack_omp_offload_ilp64 ! 64-bit

... 
real (kind=8), allocatable :: a(:,:,), b(:,:,), a_orig(:,:,), b_orig(:,:,)
(skip other data preparation part)
...
!$omp target data map(to:a) map(tofrom: b) map(from:info_rf, info_rs) map(alloc:ipiv(1:stride_ipiv, 1:batch_size))
  !$omp dispatch
call dgetrf_batch_strided(n, n, a, lda, stride_a, ipiv, stride_ipiv, batch_size, info_rf)
  !$omp dispatch
call dgetrs_batch_strided('N', n, nrhs, a, lda, stride_a, ipiv, stride_ipiv, b, ldb, stride_b, batch_size, info_rs)
!$omp end target data
...
end program solve_batched_linear_systems
```
How to dispatch external function call with OpenMP

```c
!$omp dispatch [clause[ [,] clause] ... ] new-line
call target-call ( [arguments] );  !! or: expression = target-call ( [arguments] );
```

where clause is one of the following:
- device(scalar-integer-expression)
- depend([depend-modifier[,] dependence-type : locator-list)
- nowait
- novariants(scalar-logical-expression)
- nocontext(scalar-logical-expression)
- is_device_ptr(list)
How to move data between host and target

- Create scoped data environment and transfer data from the host to the device and back

### Syntax (C/C++)
```
#pragma omp target data [clause[, clause],...]
structured-block
```

### Syntax (Fortran)
```
!$omp target data [clause[, clause],...]
structured-block
!$omp end target data
```

### Clauses
- `device(scalar-integer-expression)`
- `map([{alloc | to | from | tofrom | release | delete}:] list)`
- `if(scalar-expr)`
• The large matrix a (4 Gb) only moves from host to target once.
• Matrix a resides on device memory within the Offload region, all the dispatch calls on target device “inherits” the data in the OMP target data region.
• 2 MKL dispatch calls compute on it.
real (kind=8), allocatable :: a(:, :) , ! 64 b per element

64 x 8000 x 8000 = 4,096 M, size of a, transfer from host to target memory during setup omp target data region.

```bash
$ ifx -i8 -DMKL_ILP64 -qopenmp -fopenmp-targets=spir64 -fsycl -free lu_solve.F90 -o lu_solve -L${MKLROOT}/lib/intel64 -lmkl_sycl -lmkl_intel_ilp64 -lmkl_intel_thread -lmkl_core -liomp5 -lpthread -ldl

$ OMP_TARGET_OFFLOAD=MANDATORY ZE_AFFINITY_MASK=0.0 LIBOMPTARGET_DEBUG=1 ./lu_solve 8000 8 1 1 >& lu_solve.out
$ grep Moving lu_solve.out
```

```
LiboMptarget --> Moving 88 bytes (hst:0x00007ffe443ba9c8) -> (tgt:0x00000001e55008)
LiboMptarget --> Moving 64 bytes (hst:0x00007ffe443bad68) -> (tgt:0x00000001e55088)
LiboMptarget --> Moving 64 bytes (hst:0x00007ffe443bad18) -> (tgt:0x00000001e55108)
LiboMptarget --> Moving 512000 bytes (hst:0x00007f39ada86240) -> (tgt:0x00007f399a06d000)
LiboMptarget --> Moving 88 bytes (hst:0x00007ffe443bae38) -> (tgt:0x00000001e55188)
LiboMptarget --> Moving 4096000000 bytes (hst:0x00007f3913fff200) -> (tgt:0x00007f3819edd000)
LiboMptarget --> Moving 88 bytes (hst:0x00007ffe443bae98) -> (tgt:0x00000001e55208)
LiboMptarget --> Moving 512000 bytes (tgt:0x00007f399a06d000) -> (hst:0x00007f39ada86240)
LiboMptarget --> Moving 64 bytes (tgt:0x00000001e67040) -> (hst:0x00007f39add5fd80)
LiboMptarget --> Moving 64 bytes (hst:0x00000001e67000) -> (hst:0x00007f39add5fdc0)
```

- real (kind=8) , allocatable :: a(:, :) , ! 64 b per element
- 64 x 8000 x 8000 = 4,096 M, size of a, transfer from host to target memory during setup omp target data region.
Other useful info from LIBOMPTARGET_DEBUG=1
- Get GPU work distribute info: number of teams (grid size in CUDA), team size (block size in CUDA), SIMD width (warp in CUDA), loop bound, device number, kernel identity
## Performance on Intel GPU vs CPU

Timing the solution of 3 batched linear systems of varying matrix sizes on a Linux* (Ubuntu* 20.04 x64, 5.15.47 kernel) system with two 2.0 GHz 4th Gen Intel® Xeon® Platinum 8480+ processors (CPU), an Intel® Data Center GPU Max 1550 (GPU), and 528 GB memory.

<table>
<thead>
<tr>
<th>Matrix Size</th>
<th>CPU Time (in second)</th>
<th>GPU Time (in second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000x1000</td>
<td>0.13</td>
<td>1.70</td>
</tr>
<tr>
<td>4000x4000</td>
<td>3.90</td>
<td>2.10</td>
</tr>
<tr>
<td>1,6000x1,6000</td>
<td>139.45</td>
<td>15.71</td>
</tr>
</tbody>
</table>

All times are in seconds. GPU tests used only one tile. Each linear system had one RHS. Each experiment was run five times. The first run was discarded because it includes the just-in-time compilation overhead for the oneMKL functions. The reported time is the sum of the remaining four runs.
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