PARALLELIZING MPI USING TASKS FOR HYBRID PROGRAMMING MODELS

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Example: Hybrid (MPI+OpenMP*) Application

- Machine supports 4 threads (including hyperthreading)
- 1 MPI rank, 4 threads per rank

* Other names and brands may be claimed as the property of others.
Motivation and Goal

Motivation:

Applications run using hybrid programming models (MPI+X)

- X=OpenMP, TBB, Pthreads
- Application threads run the computation code in parallel
- Usually only one thread calls the MPI library

Goal:

To have an MPI library that runs using multiple threads which do not compete with the application threads (avoid oversubscription)
Approaches (MPI+X, X = OpenMP)

Thread Partitioning
- Partition the threads. Dedicate n threads to MPI and rest to OpenMP

Modify OpenMP library
- OpenMP tells MPI the number of idle threads
- Spawn “number of idle threads” threads in MPI
- MT-MPI: Multithreaded MPI for many-core Environments, ICS’14 by Si et al.

Create tasks in MPI (Our approach)
- Tasks can be executed by idle application threads
- Does not spawn additional threads in MPI, no oversubscription
- No modifications required in OpenMP
- Maps well to any library which supports a tasking model e.g. OpenMP, TBB
Ways to share threads between MPI and OpenMP

Thread partitioning

Our approach (using Tasks)

- Computation
- MPI Call
- Barrier
- Idle
- OpenMP task in MPI library
- Executing OpenMP task
- Executing OpenMP task after creating it
Our approach orthogonal to MPI_THREAD_MULTIPLE

- Parallelism comes from several threads concurrently calling MPI
- Fewer threads are idle to execute MPI tasks
Creating OpenMP tasks in MPI

```c
if(omp_in_parallel()) {
    //Create tasks for what MPI wants to do in parallel
    //which will run on idle pre-existing OpenMP threads
    #pragma omp taskwait
    /* All tasks we created have completed when we get here */
} else {
    /* No pre-existing parallelism so create some */
    #pragma omp parallel
    {
        #pragma omp single nowait
        {
            //Create tasks for what MPI wants to do in parallel
        }
    }
    /* All tasks we created have completed when we get here */
}
```
Where to create tasks inside MPI?

- Shared memory communication
- Packing/unpacking of non-contiguous data
Shared Memory Communication

- **Sender and receiver rank on the same node, use intermediate shared buffer for large messages**
- **Pipelined Double Copy approach** - sender can copy to next cell(s), while receiver is copying from previous cell(s)
- **Find balance between pipeline parallelism and task based parallelism**
Pack/Unpack non-contiguous data

Derived types

- Constructed from existing types (basic and derived). E.g. MPI_Type_indexed, MPI_Type_vector, MPI_Type_struct
- Each task can pack/unpack one or more blocks
Experimental Setup

- Intel® Xeon Phi Processor 7210 (1.3 GHz, 64 cores, 4 threads/core) (Knights Landing)
- 32KB L1 data and instruction cache, 1MB L2 cache
- 96GB DDR, 16GB MCDRAM
- KNL memory mode – Flat, cluster mode – Quadrant, No SNC
- Data placed on MCDRAM (using numactl –m 1)
- Compiler from Intel® Parallel Studio XE Composer Edition for C++ (version 2016.0.109)
- MPICH v3.2b4-98-g4551de1 as the baseline
**Parallel memcpy – OSU latency benchmarks**

<table>
<thead>
<tr>
<th></th>
<th>MPICH (Original)</th>
<th>MPICH (Modified) [Baseline]</th>
<th>MPICH (Modified) with OpenMP tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Size</td>
<td></td>
<td></td>
<td>32KB</td>
</tr>
<tr>
<td>Cell Size</td>
<td>32KB</td>
<td>256KB</td>
<td>#threads * Task Size</td>
</tr>
<tr>
<td>Total Size</td>
<td>256KB</td>
<td>4MB</td>
<td>4MB</td>
</tr>
<tr>
<td>Num Cells</td>
<td>8</td>
<td>16</td>
<td>Total Size/Cell Size</td>
</tr>
</tbody>
</table>
Top Pack Benchmark (from MT-MPI* paper)

- Pack the top surface (XZ plane) of a 3D matrix of doubles
- Matrix volume fixed to 1 GB and Y dimension to 2
- Represented using MPI_Type_vector

*Si et al. MT-MPI: Multithreaded MPI for many-core Environments. ICS’14
Results: Top Pack, MPI_Type_vector

- Packing called from a serial region in application
- 1 MPI rank
- Blk_size(X) decreases as num_blks(Z) increases
Left Pack, Nested MPI_Type_vector

- Tasks at leaf level – Parallelize over Y dimension (vector datatype)
- Tasks at higher level – Parallelize over Z dimension (vector of vectors datatype)
MPI_Pack() called from a parallel region

```c
#pragma omp parallel
{
    thread_id = omp_get_thread_num();
    if (thread_id < 4)
        call MPI_Pack();
    else if (thread_id < 4 + num_idle_threads)
        do_nothing
    else
        do_computation
}
```

- Uses MPI_THREAD_MULTIPLE mode
- Threads are divided into 3 groups -
  - Threads calling MPI_Pack(). Create OpenMP task in MPICH
  - Idle threads. Wait at the barrier and execute tasks
  - Compute threads. Can help in executing tasks when reach the barrier
Results: MPI_Pack() called from a parallel region

- Total threads = 256, Packing threads = 4
- Significant benefits when threads are idle
- No penalty when no idle threads
Transpose from Parallel Research Kernels*

Steps to do the transpose

1. On each rank, local transpose. No data communicated

2. All-to-all communication
   1. Use nested MPI_Type_vector datatype
   2. Parallelize the pack/unpack

* https://github.com/ParRes/Kernels
Results: Transpose Kernel

- Matrix Order 8K doubles
- 2 MPI ranks on 1 KNL node
- Leaf vector – num_blks = 4K, blk_len = 1
Conclusion

- Our task-based approach-
  - Opportunistic
  - No creation of additional threads, so no oversubscription
  - No modification made in the OpenMP library
- Speedup up to 62X on Top Pack, when all the threads are idle
- Speedup up to 6.5X in data packing and up to 1.5X reduction in overall execution time of transpose kernel
- Code is publicly available (link in the paper)
Questions?

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