



Software

# PARALLELIZING MPI USING TASKS FOR HYBRID PROGRAMMING MODELS

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May 25, 2018

ROME workshop (in conjunction with IPDPS 2018), Vancouver, Canada

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**Acknowledgment:** This material is based upon work supported by the U.S. Department of Energy and Argonne National Laboratory and its Leadership Computing Facility under Award Number(s) DE-AC02-06CH11357.

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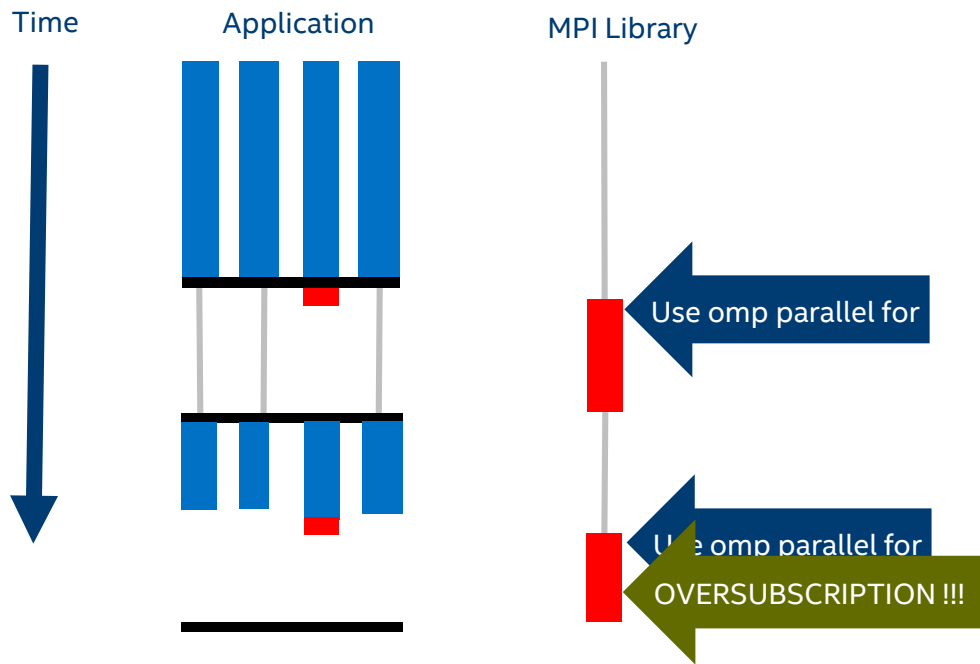
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# Example: Hybrid (MPI+OpenMP\*) Application



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

	Computation
	MPI Call
	Barrier
	Idle

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

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# 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)

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# Approaches (MPI+X, X = OpenMP)

## Thread Partitioning

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

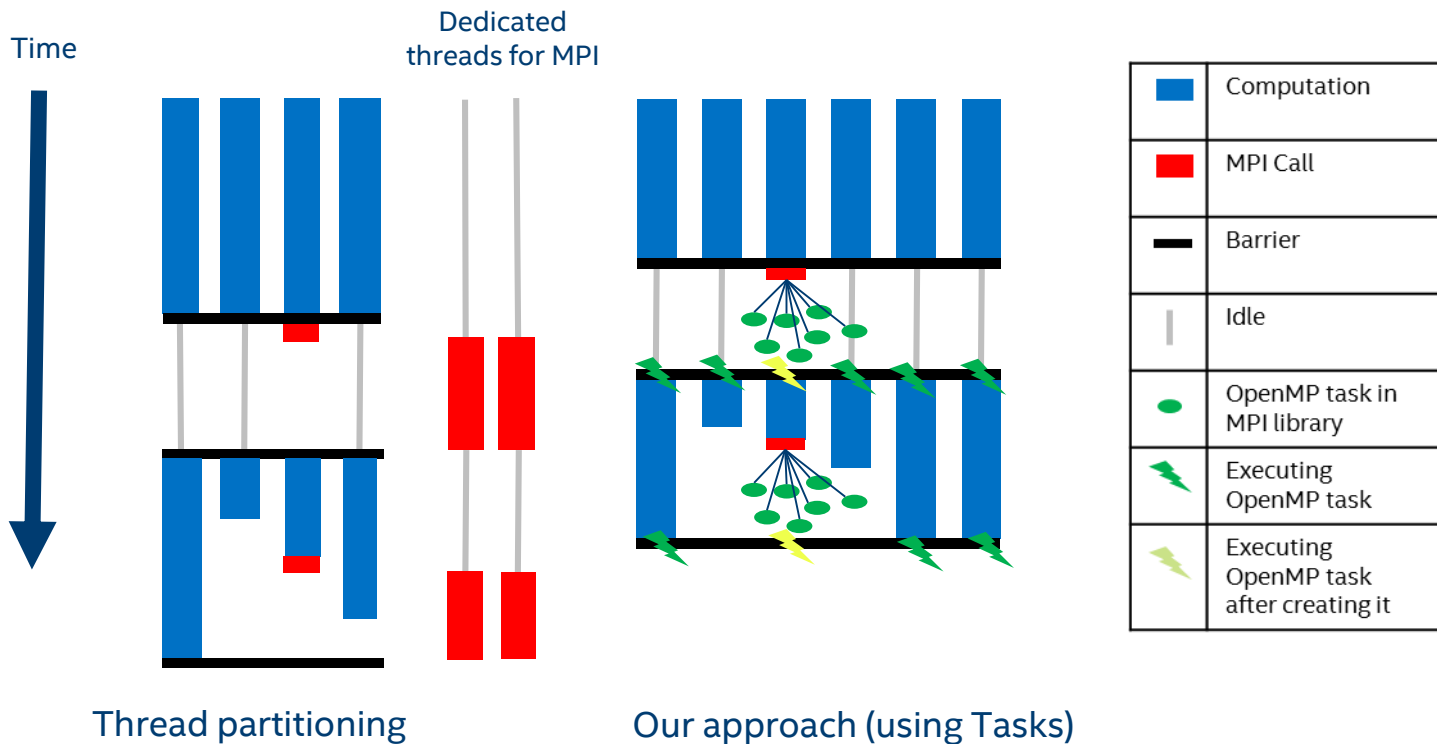
## Modify OpenMP library

- 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



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# Our approach orthogonal to MPI\_THREAD\_MULTIPLE



Do not expect much benefit with MPI\_THREAD\_MULTIPLE

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

# Creating OpenMP tasks in MPI

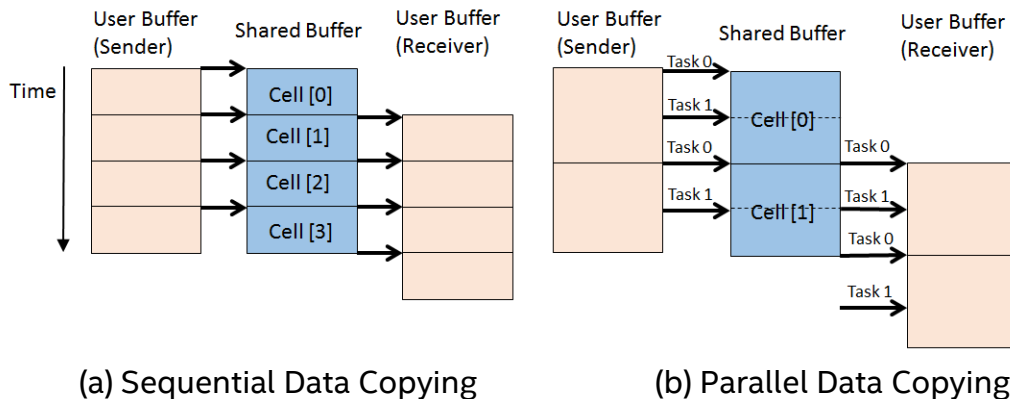
```
if(omp_in_parallel()) {
    //Create tasks for what MPI wants to do in parallel
    //which will run on idle pre-existing OpenMP threads
    #pragma omp taskwait
    /* All tasks we created have completed when we get here */
} else {
    /* No pre-existing parallelism so create some */
    #pragma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

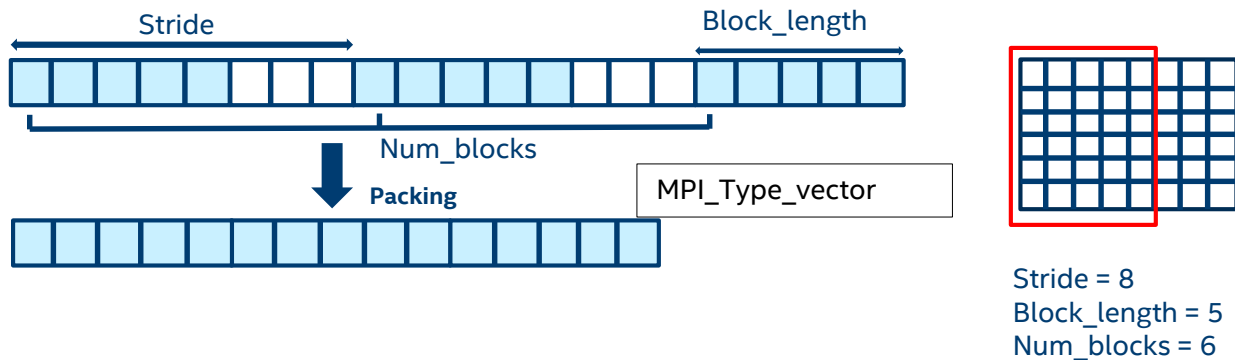
- Shared memory communication
- Packing/unpacking of non-contiguous data

# 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



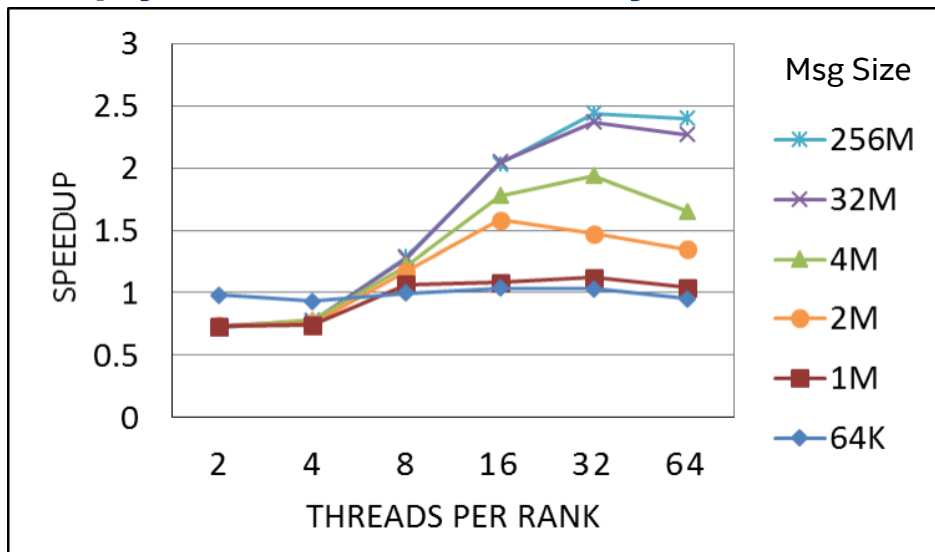
## Derived types

- 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

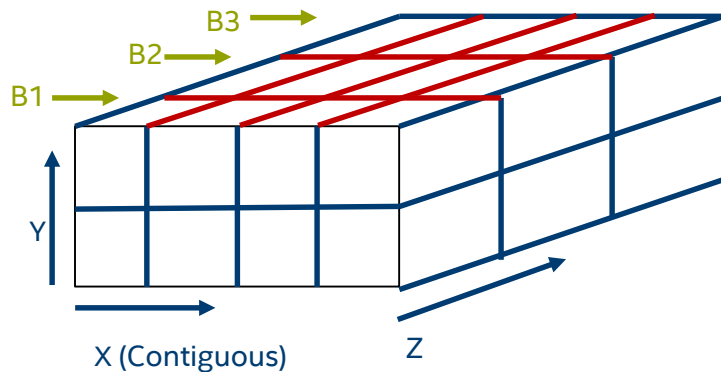
- Intel® Xeon Phi Processor 7210 (1.3 GHz, 64 cores, 4 threads/core) (Knights Landing)
- 32KB L1 data and instruction cache, 1MB L2 cache
- 96GB DDR, 16GB MCDRAM
- KNL memory mode – Flat, cluster mode – Quadrant, No SNC
- Data placed on MCDRAM (using numactl –m 1)
- Compiler from Intel® Parallel Studio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

# Parallel memcpy – OSU latency benchmarks



	MPICH (Original)	MPICH (Modified) [Baseline]	MPICH (Modified) with OpenMP tasks
Task Size			32KB
Cell Size	32KB	256KB	#threads * Task Size
Total Size	256KB	4MB	4MB
Num Cells	8	16	Total Size/Cell Size

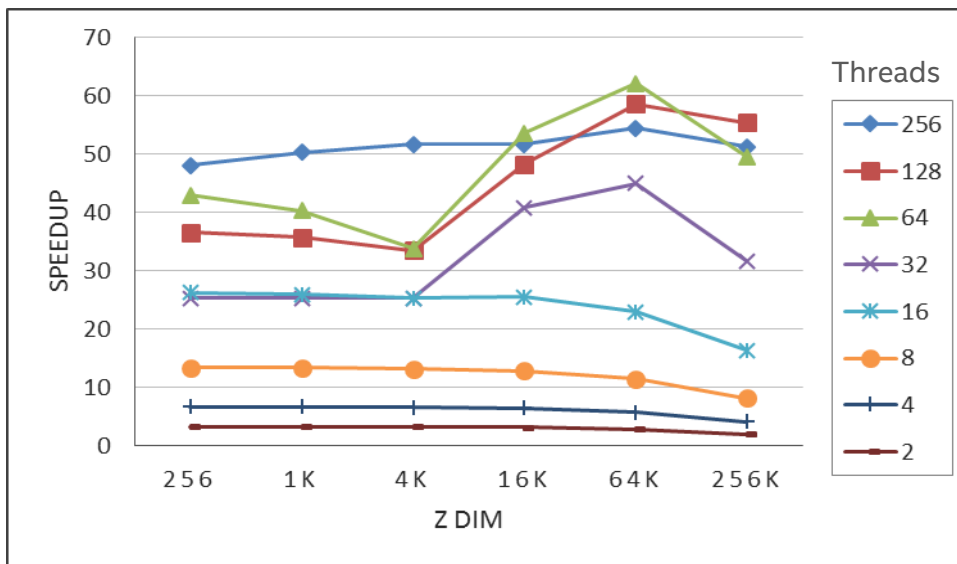
# Top Pack Benchmark (from MT-MPI\* paper)



- 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`

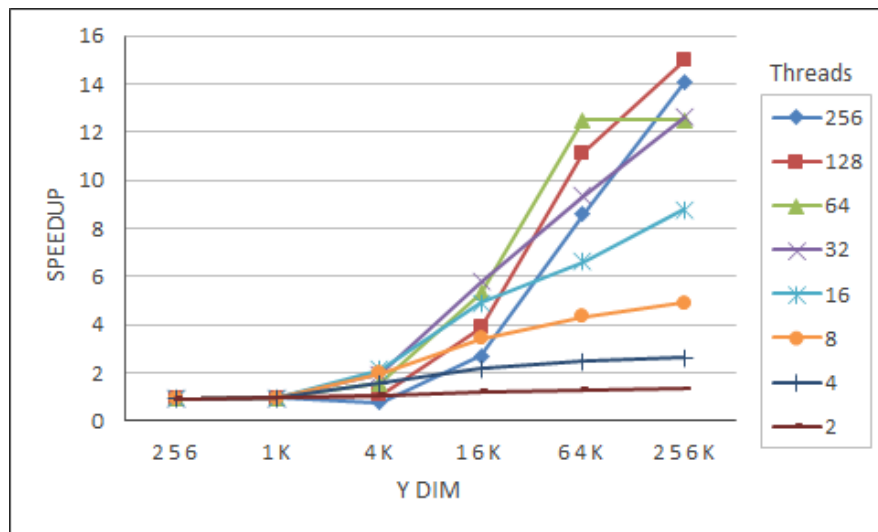
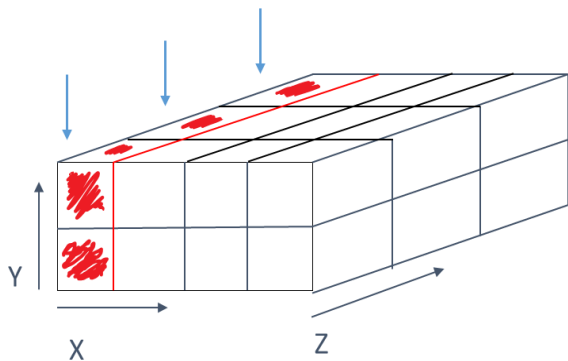
\*Si et al . MT-MPI: Multithreaded MPI for many-core Environments . ICS'14

# 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)

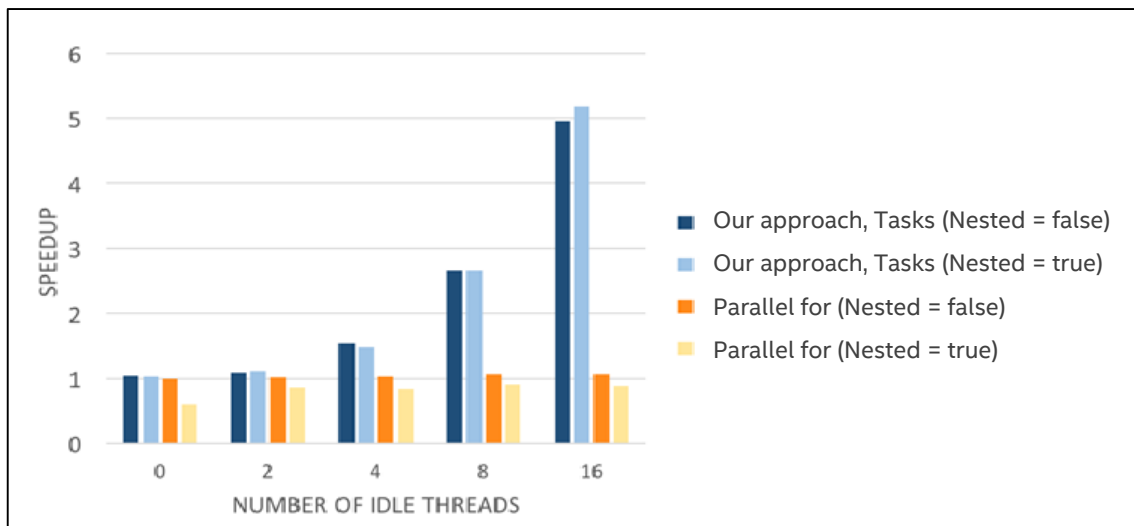


# MPI\_Pack() called from a parallel region

```
#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
}
```

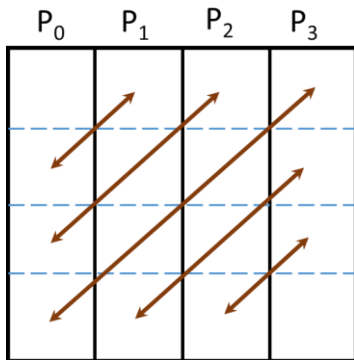
- Uses MPI\_THREAD\_MULTIPLE mode
- Threads are divided into 3 groups -
  - **Threads calling MPI\_Pack().** Create OpenMP task in MPICH
  - **Idle threads.** Wait at the barrier and execute tasks
  - **Compute threads.** Can help in executing tasks when reach the barrier

# 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\*

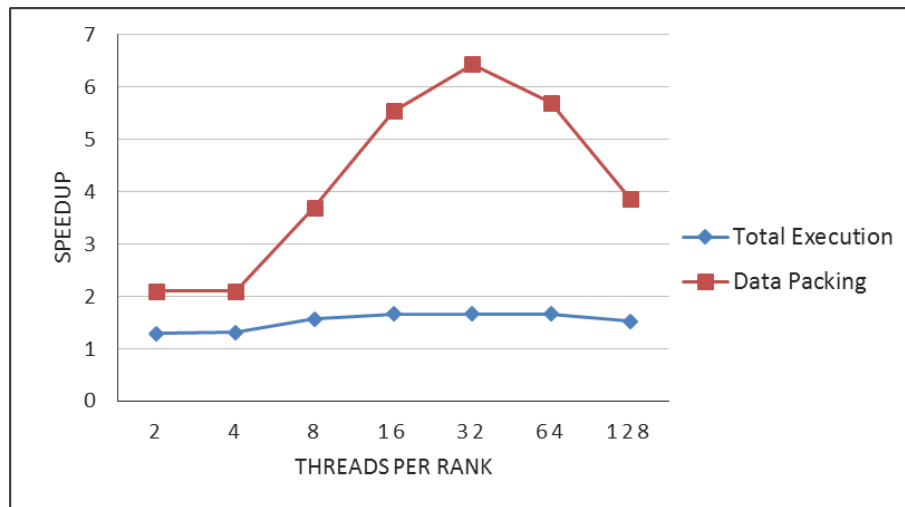


## Steps to do the transpose

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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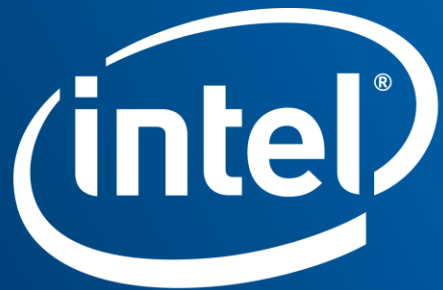
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