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PARALLELIZING MPI USING TASKS FOR HYBRID PROGRAMMING MODELS

Presenter: Surabhi Jain

Contributors: Surabhi Jain, Gengbin Zheng, Maria Garzaran, Jim Cownie, Taru Doodi, and Terry L. Wilmarth

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Notices

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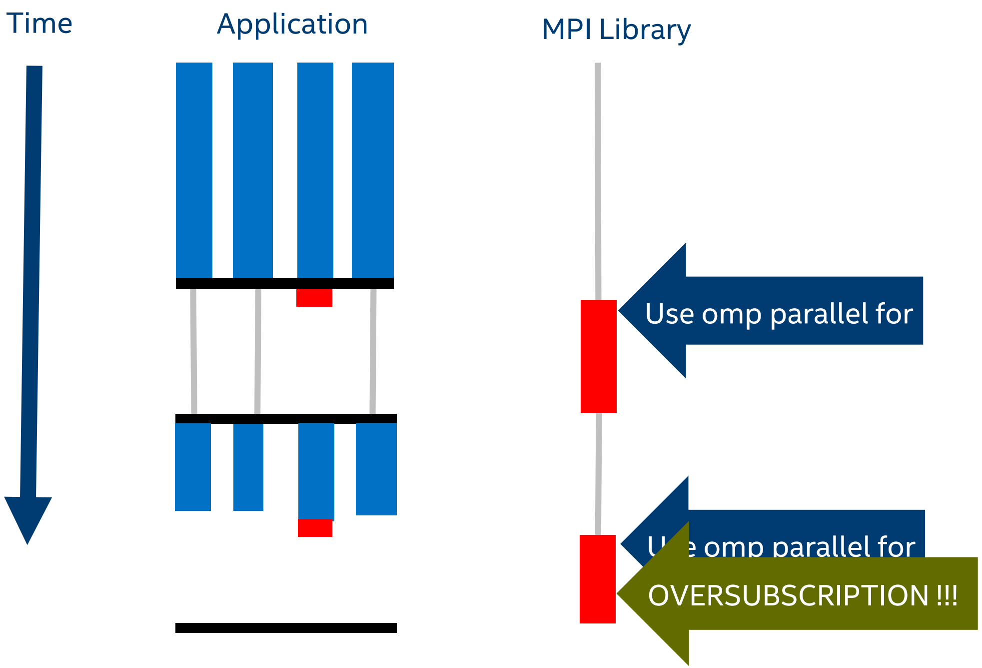
Example: Hybrid (MPI+OpenMP*) Application



- 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.

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)

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

Approaches (MPI+X, X = OpenMP)

Thread Partitioning

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

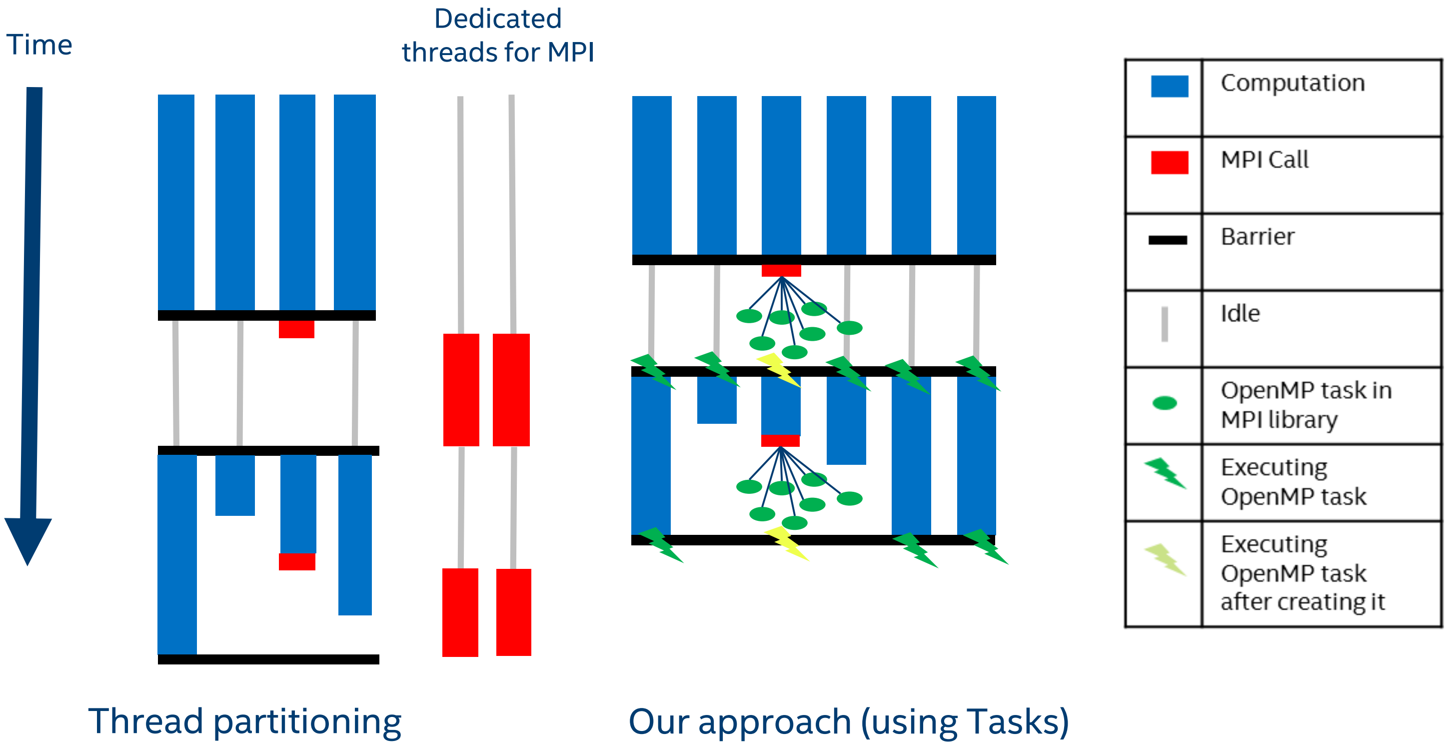
Modify OpenMP library

- 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.

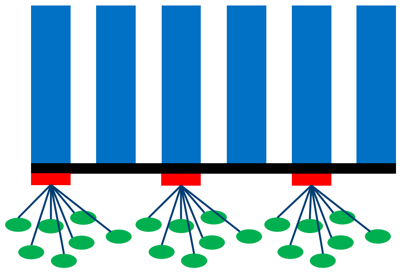
Create tasks in MPI (Our approach)

- 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



Our approach orthogonal to MPI_THREAD_MULTIPLE



Computation (blue)	Computation
MPI Call (red)	MPI Call
Barrier (black)	Barrier
OpenMP task (green)	OpenMP task in MPI library

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

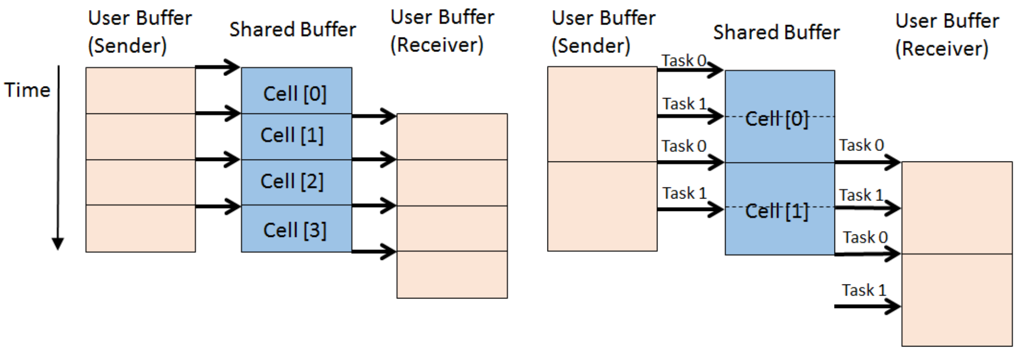
Creating OpenMP tasks in MPI

```
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

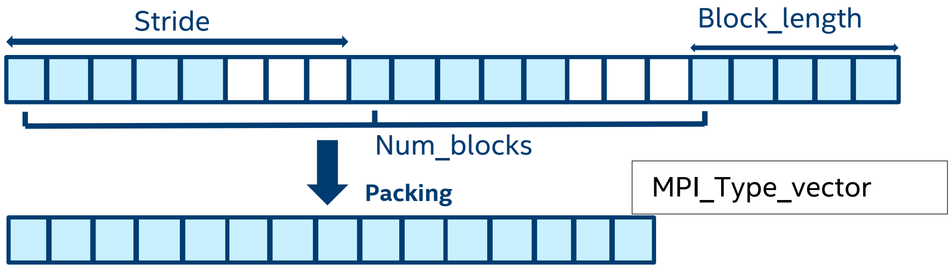
Shared Memory Communication

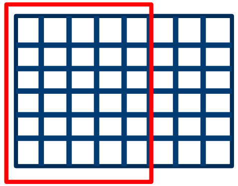


(a) Sequential Data Copying (b) Parallel Data Copying

- 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





Stride = 8
Block_length = 5
Num_blocks = 6

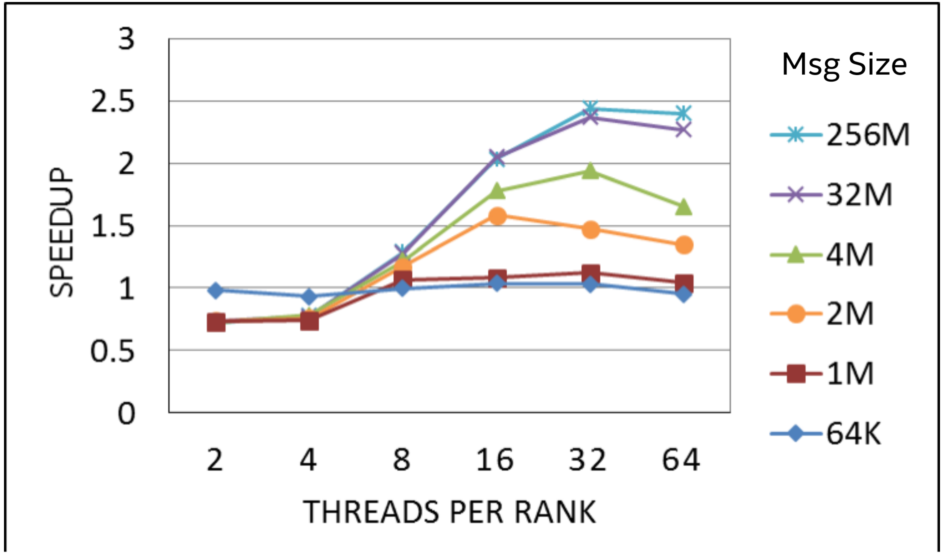
Derived types

- 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

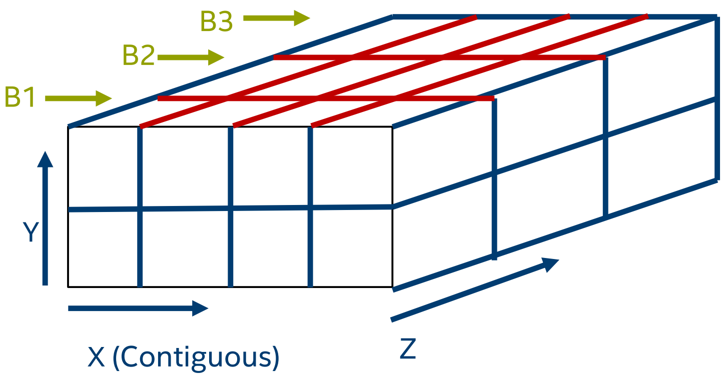
- Intel® Xeon Phi Processor 7210 (1.3 GHz, 64 cores, 4 threads/core) (Knights Landing)
- 32KB L1 data and instruction cache, 1MB L2 cache
- 96GB DDR, 16GB MCDRAM
- KNL memory mode – Flat, cluster mode – Quadrant, No SNC
- Data placed on MCDRAM (using numactl –m 1)
- Compiler from Intel® Parallel Studio 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

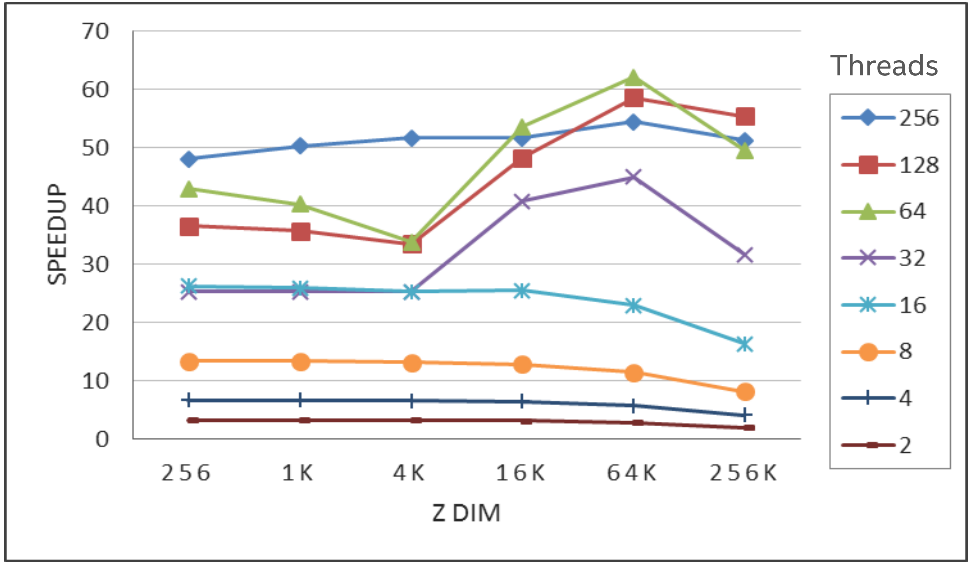
Top Pack Benchmark (from MT-MPI* paper)



- 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

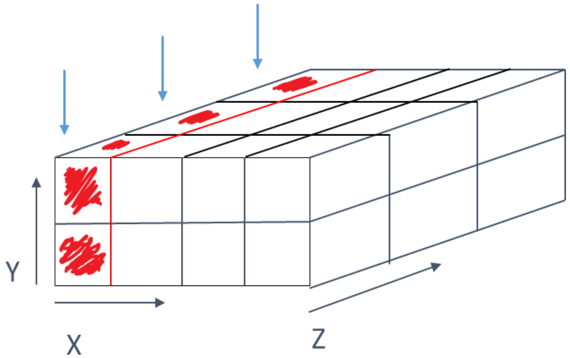
*Si et al . MT-MPI: Multithreaded MPI for many-core Environments . ICS'14

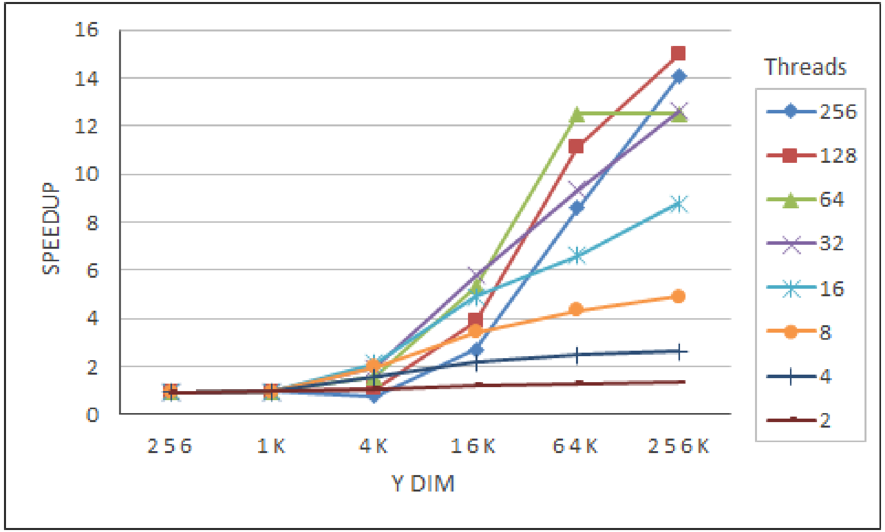
Results: Top Pack, MPI_Type_vector



- 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





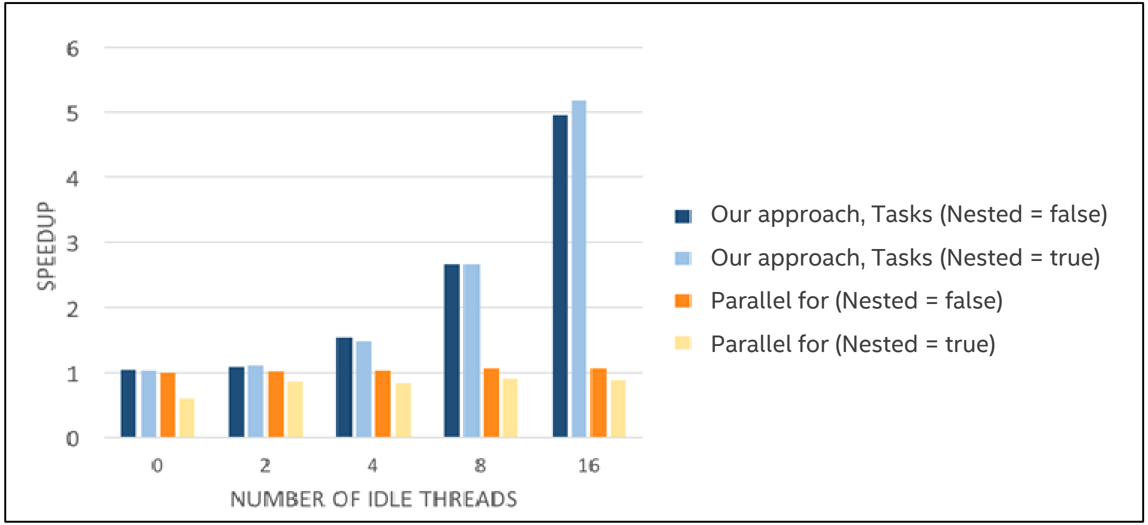
- Tasks at leaf level – Parallelize over Y dimension (vector datatype)
- Tasks at higher level – Parallelize over Z dimension (vector of vectors datatype)

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
}
```

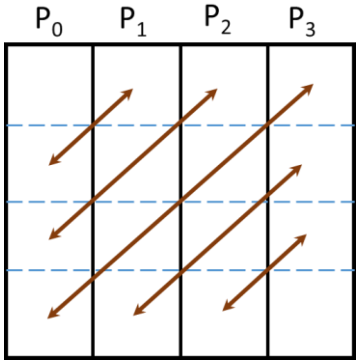
- Uses MPI_THREAD_MULTIPLE mode
- Threads are divided into 3 groups -
  - Threads calling MPI_Pack(). Create OpenMP task in MPICH
  - Idle threads. Wait at the barrier and execute tasks
  - Compute threads. Can help in executing tasks when reach the barrier

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*

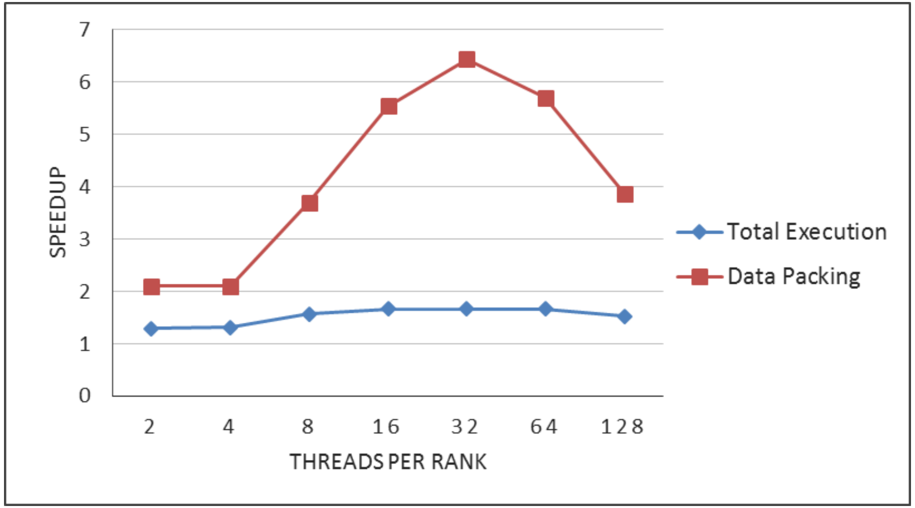


Steps to do the transpose

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 ?

surabhi.jain@intel.com

https://www.linkedin.com/in/surabhi-jain-9066821a/

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