MT-MPI: Multithreaded MPI for Many-Core Environments

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Presentation Overview

- Background and Motivation
- Proposal and Challenges
- Design and Implementation
  - OpenMP Runtime Extension
  - MPI Internal Parallelism
- Evaluation
- Conclusion

Many-core Architectures

- Massively parallel environment
- Intel® Xeon Phi co-processor
  - 60 cores inside a single chip, 240 hardware threads
  - SELF-HOSTING in next generation, NATIVE mode in current version

- Blue Gene/Q
  - 16 cores per node, 64 hardware threads

- Lots of “light-weight” cores is becoming a common model

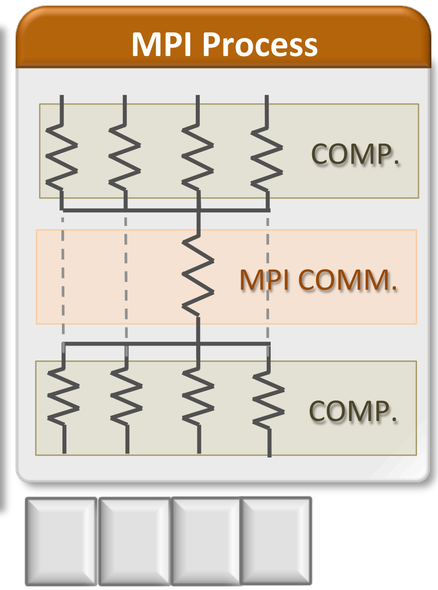
MPI programming on Many-Core Architectures

Thread Single mode

```
/* user computation */

MPI_Function ( );


/* user computation */
```

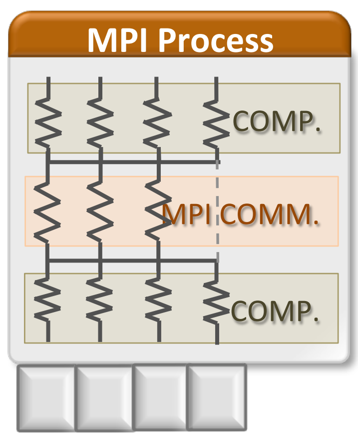
Funneled / Serialized mode

```
#pragma omp parallel
{ /* user computation */ }

MPI_Function ( );

#pragma omp parallel
{ /* user computation */ }
```



Multithreading mode

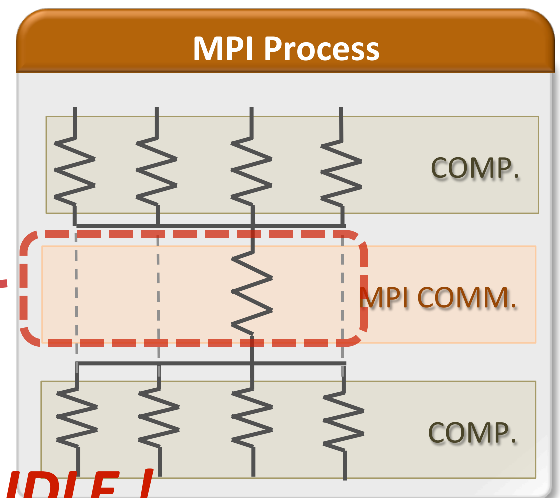
```
#pragma omp parallel
{
   /* user computation */

   MPI_Function ( );

   /* user computation */
}
```



Problem in Funneled / Serialized mode

- Funneled / Serialized mode
  - Multiple threads are created for user computation
  - Single thread issues MPI

```
#pragma omp parallel
{ /* user computation */ }

MPI_Function ( );

#pragma omp parallel
{ /* user computation */ }
```



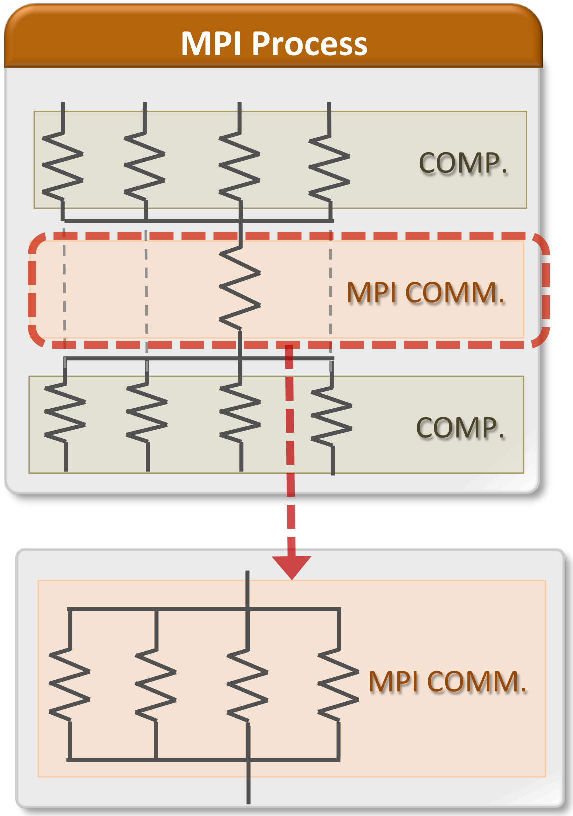
ISSUE

1. ***Many threads are IDLE !***
2. ***Single lightweight core delivers poor performance***

Our Approach

- Sharing Idle Threads with Application inside MPI

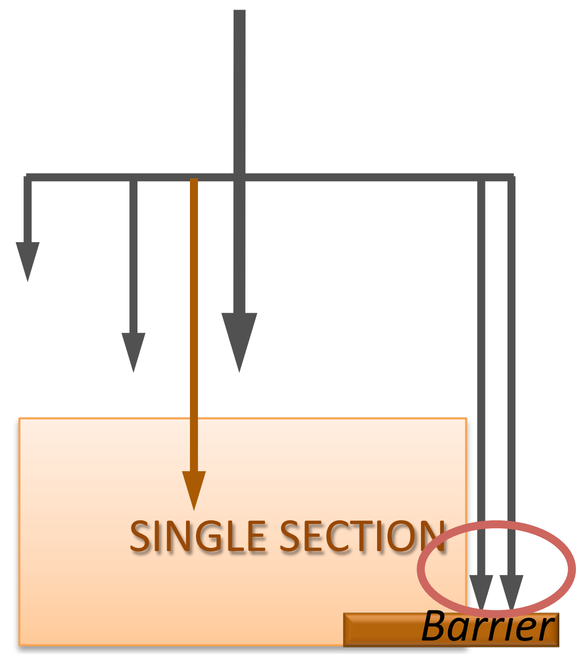
```
#pragma omp parallel
{ /* user computation */ }

MPI_Function ( ){
            #pragma omp parallel
            {
                  /* MPI internal task */
            }
}

#pragma omp parallel
{ /* user computation */ }
```



Challenges (1/2)

- Some parallel algorithms are not efficient with insufficient threads, need tradeoff
- But the number of available threads is **UNKNOWN** !

```
#pragma omp parallel
{
        /* user computation */

        #pragma omp single
        {
                /* MPI_Calls */
        }
}
```



Challenges (2/2)

- Nested parallelism
  - Simply creates new Pthreads, and offloads thread scheduling to OS,
  - Causes threads **OVERRUNNING** issue

```
#pragma omp parallel
{
    #pragma omp single
    {
        #pragma omp parallel
        { … }
    }
}
```

Creates N Pthreads !

Creates N Pthreads !

ONLY use IDLE threads

Design and Implementation

- OpenMP Runtime Extension
- MPI Internal Parallelism

Implementation is based on Intel OpenMP runtime (version 20130412)

Guaranteed Idle Threads VS Temporarily Idle Threads

- Guaranteed Idle Threads
  - Guaranteed idle until Current thread exits
- Temporarily Idle Threads
  - Current thread does not know when it may become active again

Example 1

```
#pragma omp parallel
{
        #pragma omp single
        {…
        }   Barrier
}
```

Example 2

```
#pragma omp parallel
{
        #pragma omp critical
        {…
        }
}
```

Example 3

```
#pragma omp parallel
{
        #pragma omp single nowait
        {…
        }

        #pragma omp critical
        {…
        }
}
```

Expose Guaranteed Idle Threads

- MPI uses Guaranteed Idle Threads to schedule its internal parallelism efficiently (i.e. change algorithm, specify number of threads)

```
#pragma omp parallel
#pragma omp single
{
        MPI_Function {
           num_idle_threads = omp_get_num_guaranteed_idle_threads( );
           if ( num_idle_threads < N ) {
                   /* Sequential algorithm */
           } else {
                   #pragma omp parallel num_threads(num_idle_threads)
                   { ... }
           }
        }
}
```

Design and Implementation

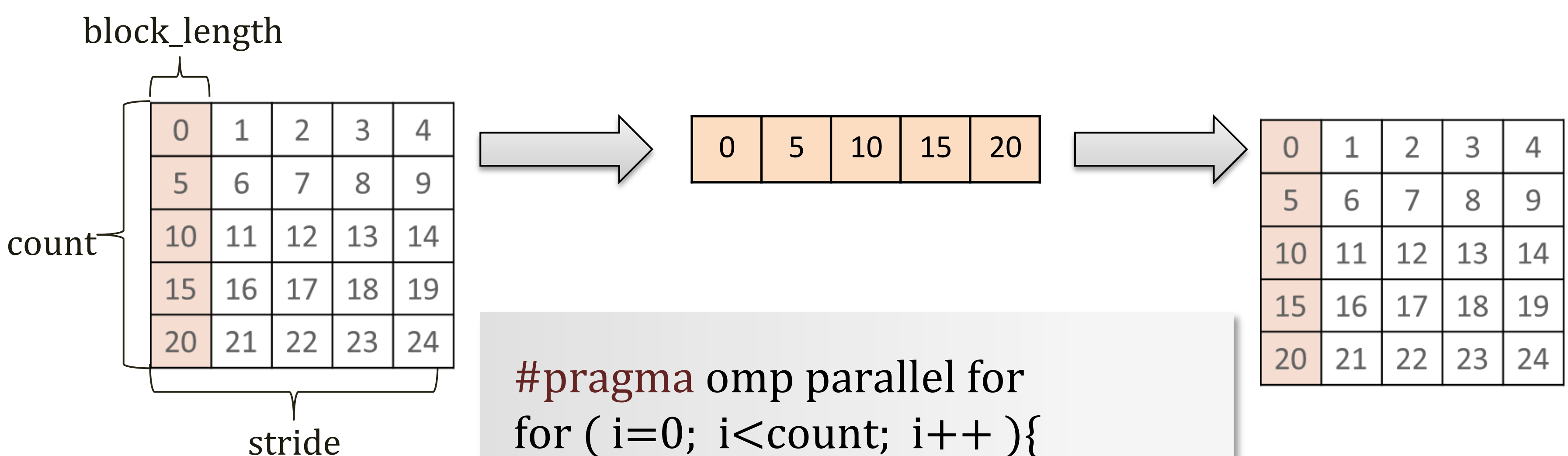
- OpenMP Runtime Extension
- MPI Internal Parallelism

1. Derived Datatype Related Functions
2. Shared Memory Communication
3. Network-specific Optimizations

Implementation is based on MPICH v3.0.4

1. Derived Datatype Packing Processing

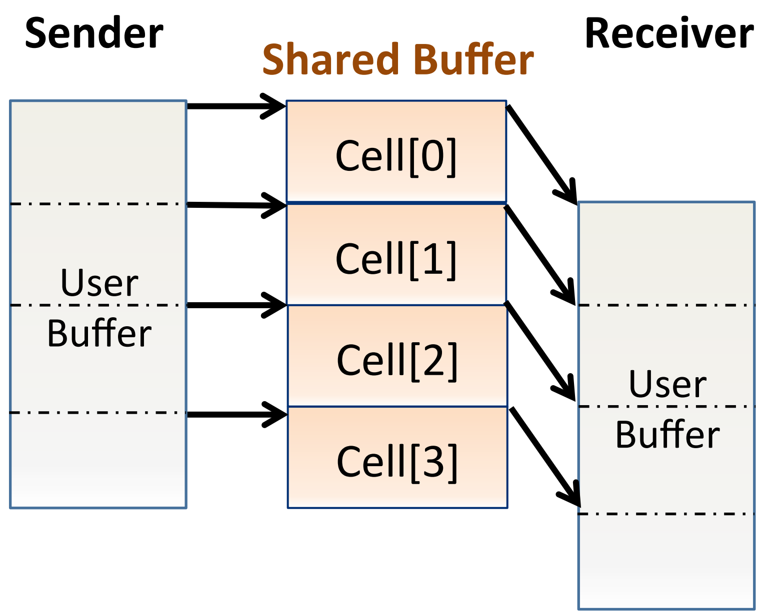
- MPI_Pack / MPI_Unpack
- Communication using Derived Datatype
  - Transfer non-contiguous data
  - Pack / unpack data internally



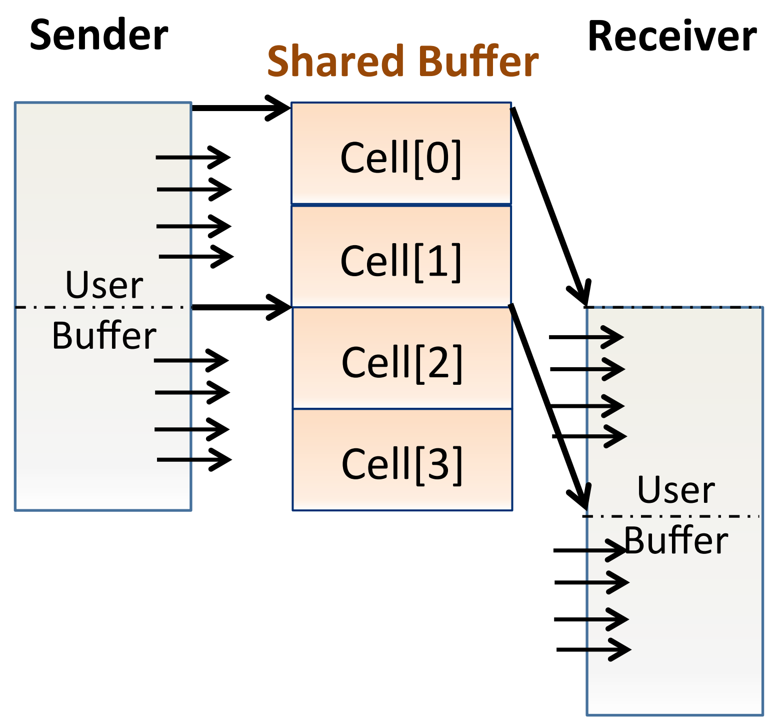

```
#pragma omp parallel for
for ( i=0;  i<count;  i++ ){
        dest[i] = src[i * stride];
}
```

2. Shared Memory Communication

- Original sequential algorithm
  - Shared user space buffer between processes
  - Pipelining copy on both sender side and receiver side
- Parallel algorithm
  - Get as many available cells as we can
  - Parallelize large data movement



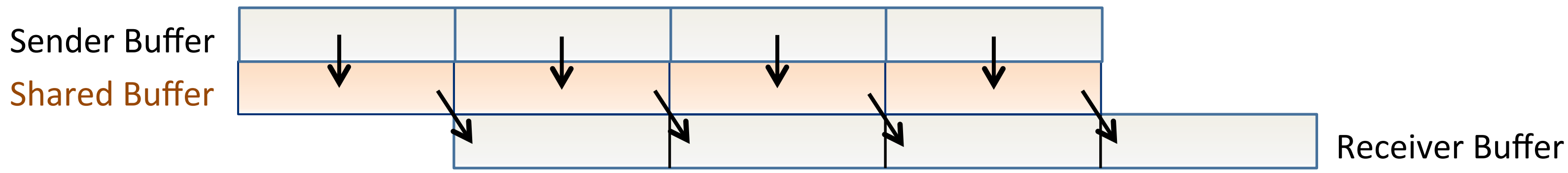
(a) Sequential Pipelining



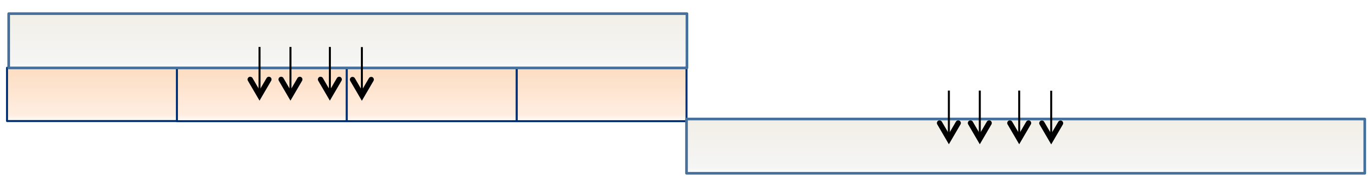
(b) Parallel pipelining

Sequential Pipelining VS Parallelism

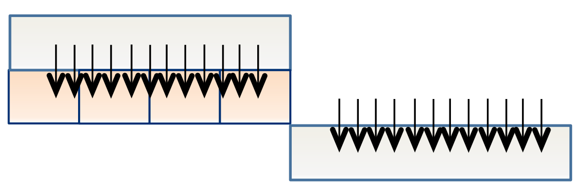
- Small Data transferring (< 128K)
  - Threads synchronization overhead > parallel improvement
- Large Data transferring
  - Data transferred using Sequential Fine-Grained Pipelining



  - Data transferred using Parallelism with only a few of threads (worse)

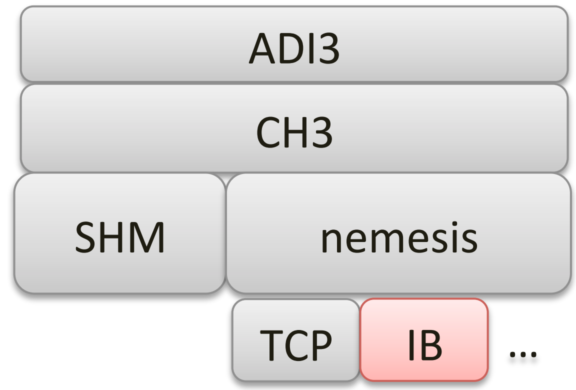


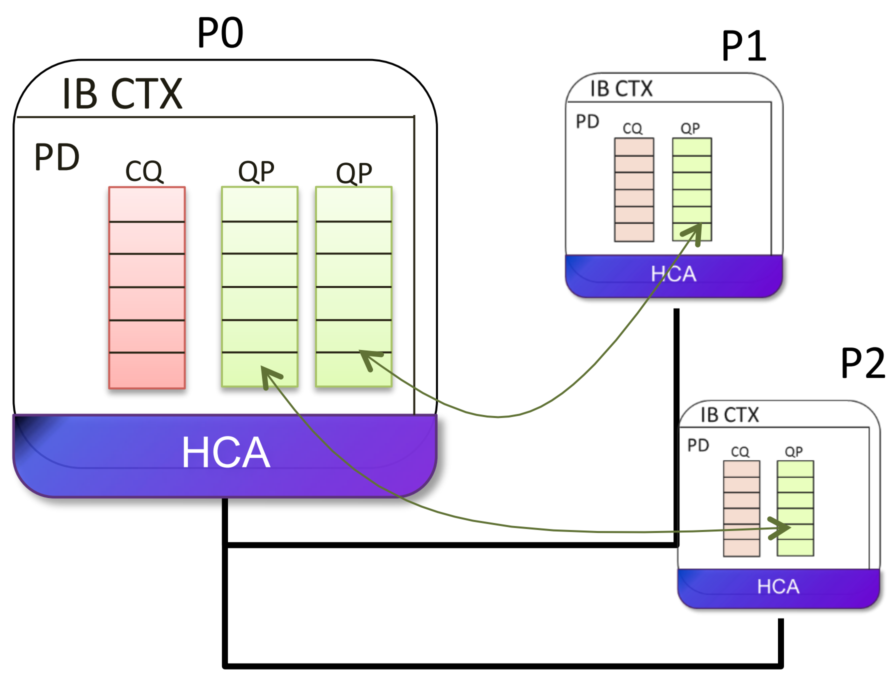
  - Data transferred using Parallelism with many threads (better)



3. InfiniBand Communication

- Structures
  - IB context
  - Protection Domain
  - **Queue Pair** *(critical)*
    - 1 QP per connection
  - **Completion Queue** *(critical)*
    - Shared by 1 or more QPs
- RDMA communication
  - Post RDMA operation to QP
  - Poll completion from CQ
- OpenMP contention issue





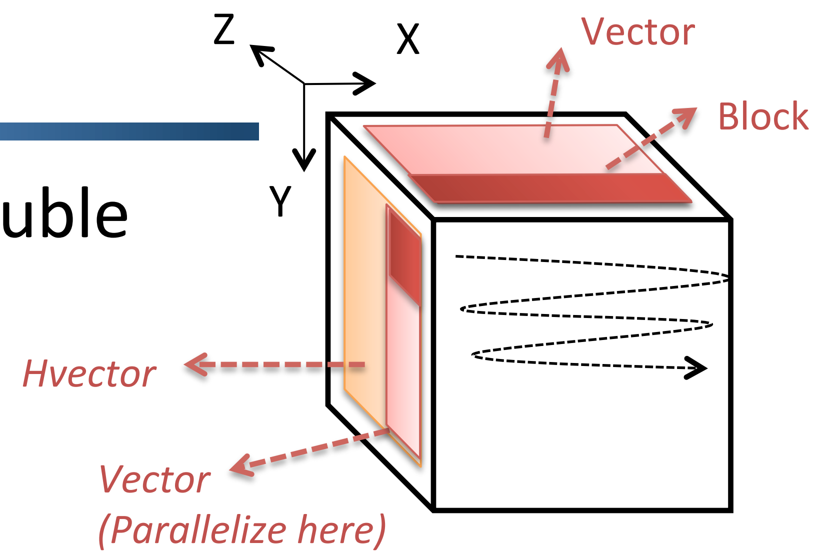
Evaluation

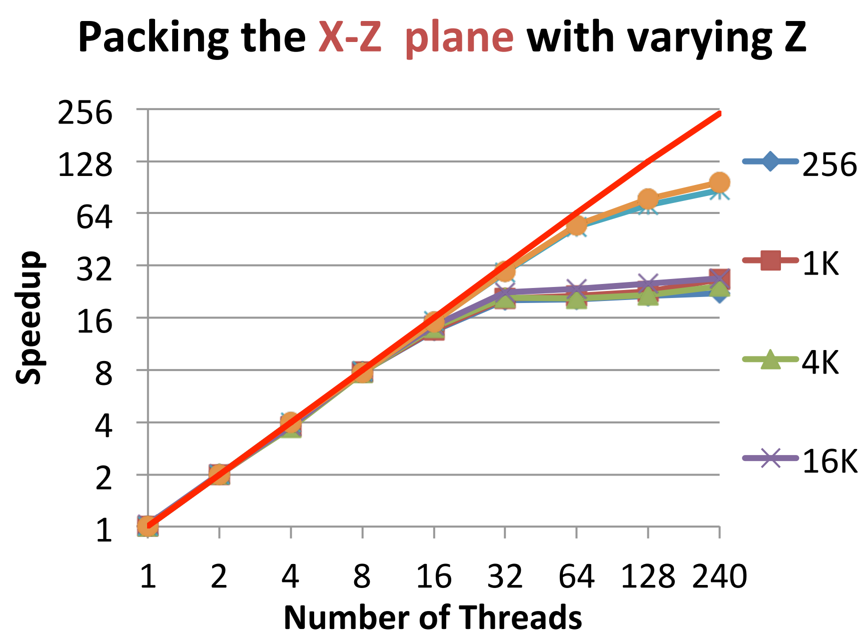
1. Derived Datatype Related Functions
2. Shared Memory Communication
3. Network-specific Optimizations

*All our experiments are executed on the **Stampede supercomputer** at the Texas Advanced Computing Center (https://www.tacc.utexas.edu/stampede/).*

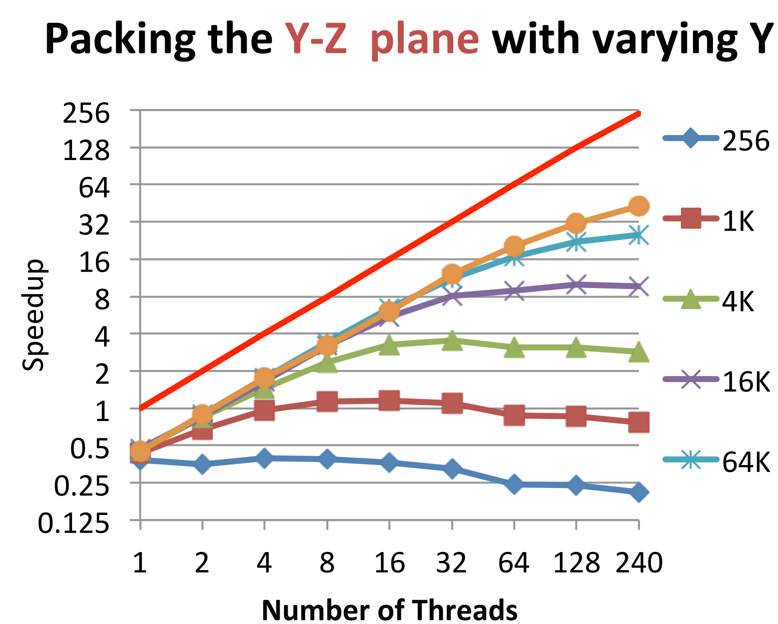
Derived Datatype Packing

Parallel packing 3D matrix of double



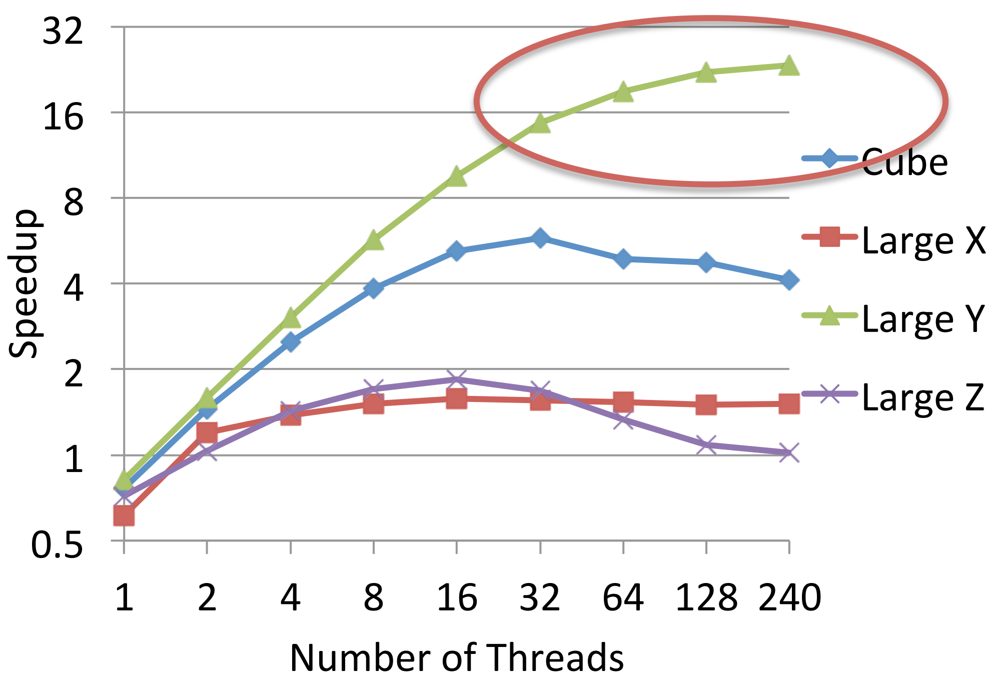


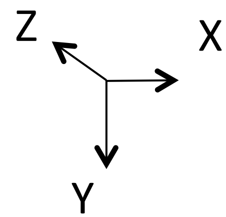
Graph Data:
Fixed matrix volume 1 GB
Fixed length of Y: 2 doubles
Length of Z: graph legend



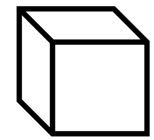
Graph Data:
Fixed matrix volume 1 GB
Fixed length of X: 2 doubles
Length of Y: graph legend

3D internode halo exchange using 64 MPI processes

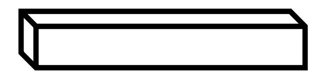




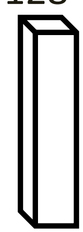
Cube 512*512*512 double



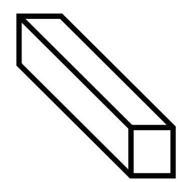
Large X 16K*128*64 double



Large Y 64*16K*128 double



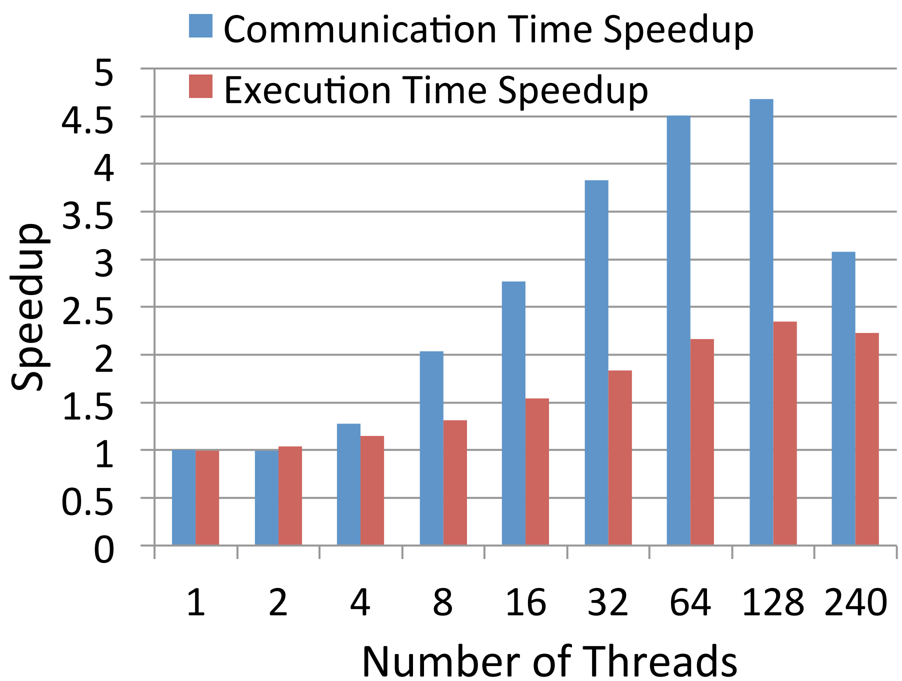
Large Z 64*128*16K double



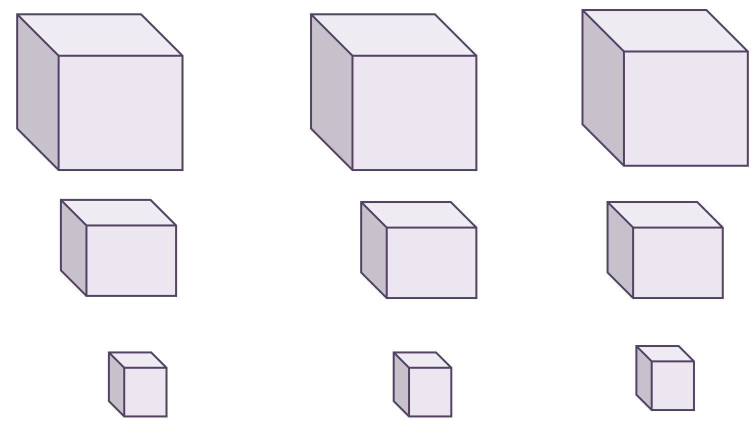
Not strong scaling

BUT we are using **IDLE RESOURCES** !

Hybrid MPI+OpenMP NAS Parallel MG benchmark



V-cycle multi-grid algorithm to solve a 3D discrete Poisson equation.

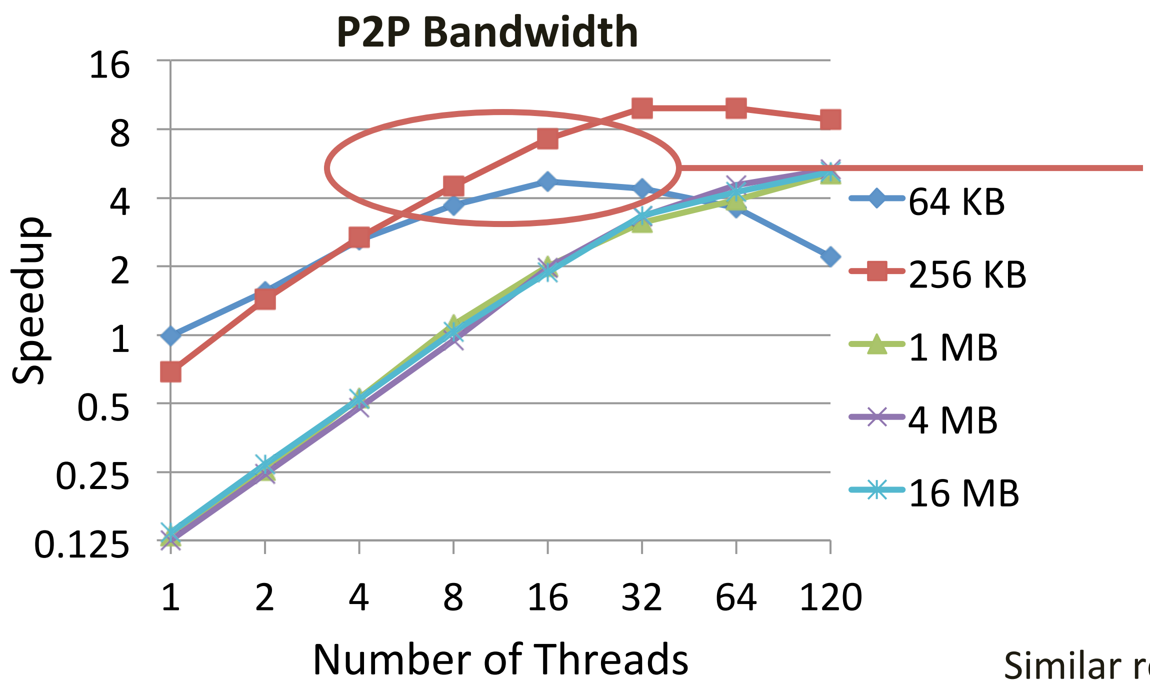


Halo exchanges with various dimension sizes from 2 to 514 doubles in class E with 64 MPI processes

Graph Data:
Class E using 64 MPI processes

Shared Memory Communication

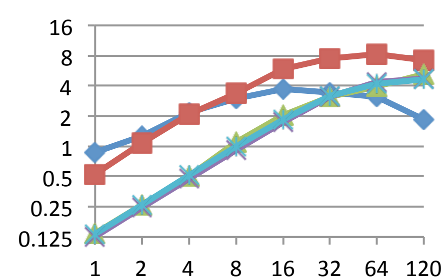
- OSU MPI micro-benchmark

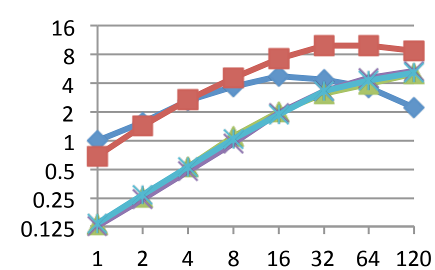


Caused by poor sequential performance due to too small Eager/Rendezvous communication threshold on Xeon Phi.
Not by MT-MPI !

Poor pipelining but worse parallelism

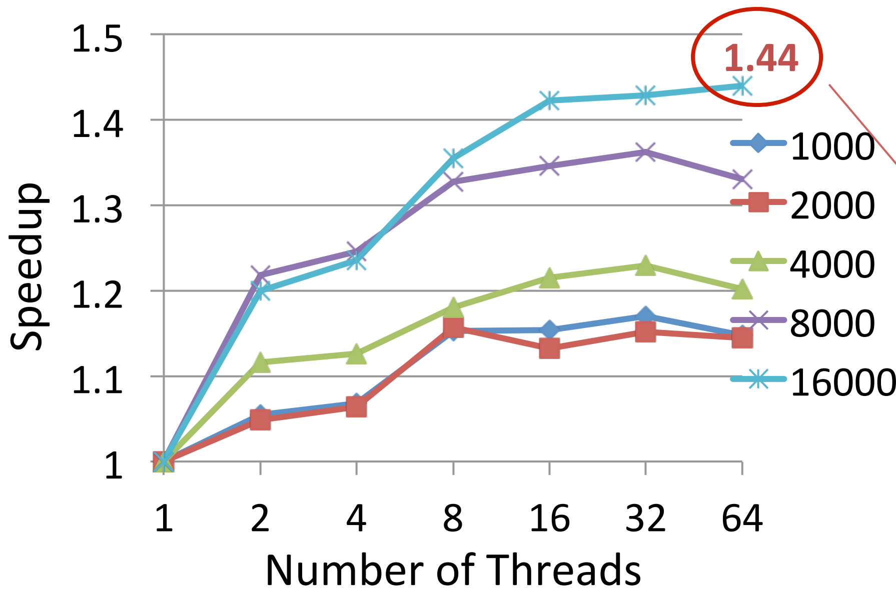
Similar results of Latency and Message rate

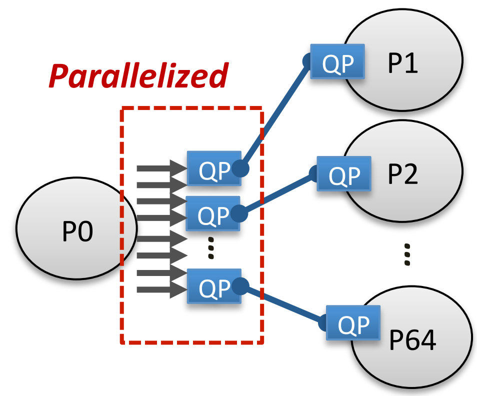


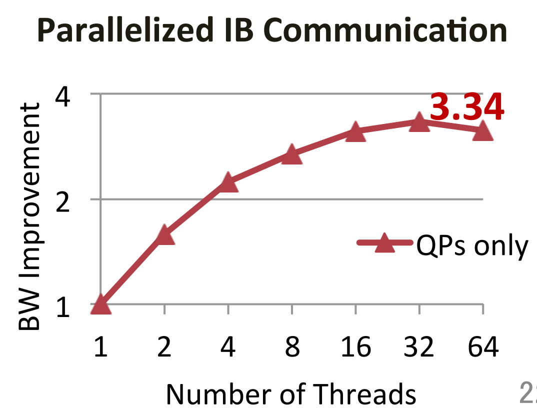


One-sided Operations and IB netmod Optimization

- Micro benchmark
  - One to All experiment using 65 processes
    - root sends many MPI_PUT operations to all the other 64 processes (64 IB QPs)







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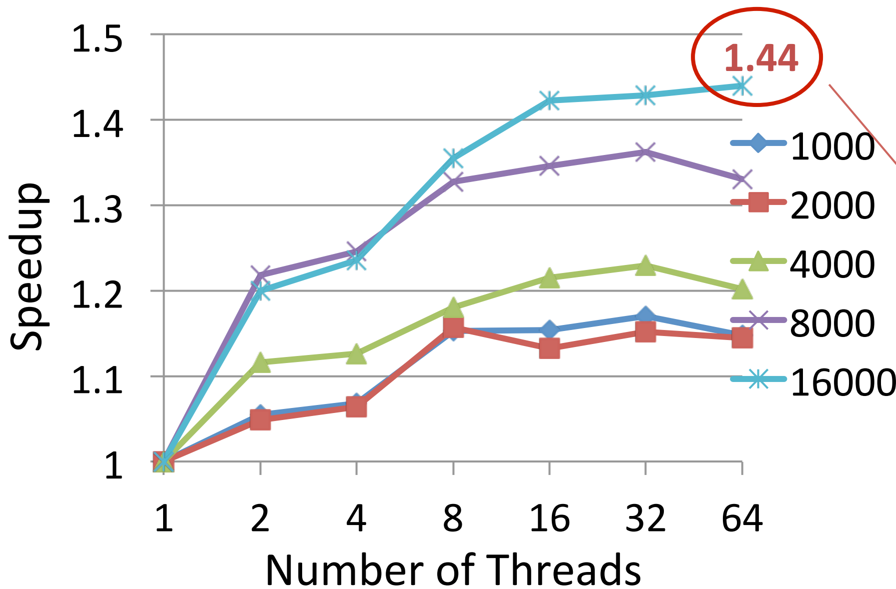
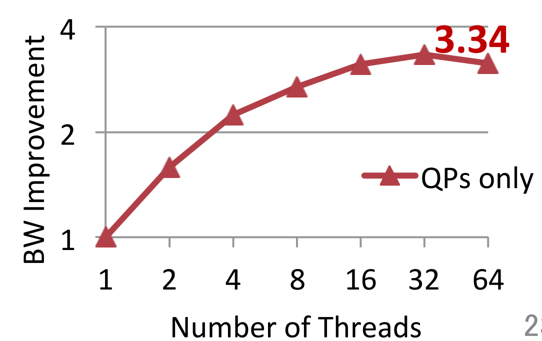


Profile of the experiment issuing 16000 operations

Nthreads	Time(s)		
	Total	SP	SP/Total
1	5.8	2.2	37.9%

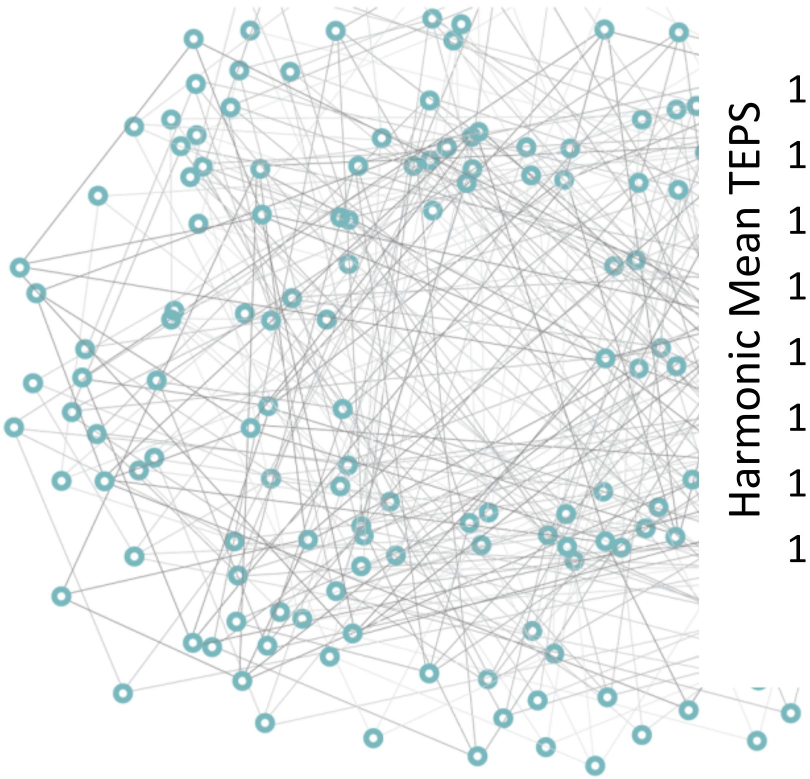
Ideal Speedup = 1.61

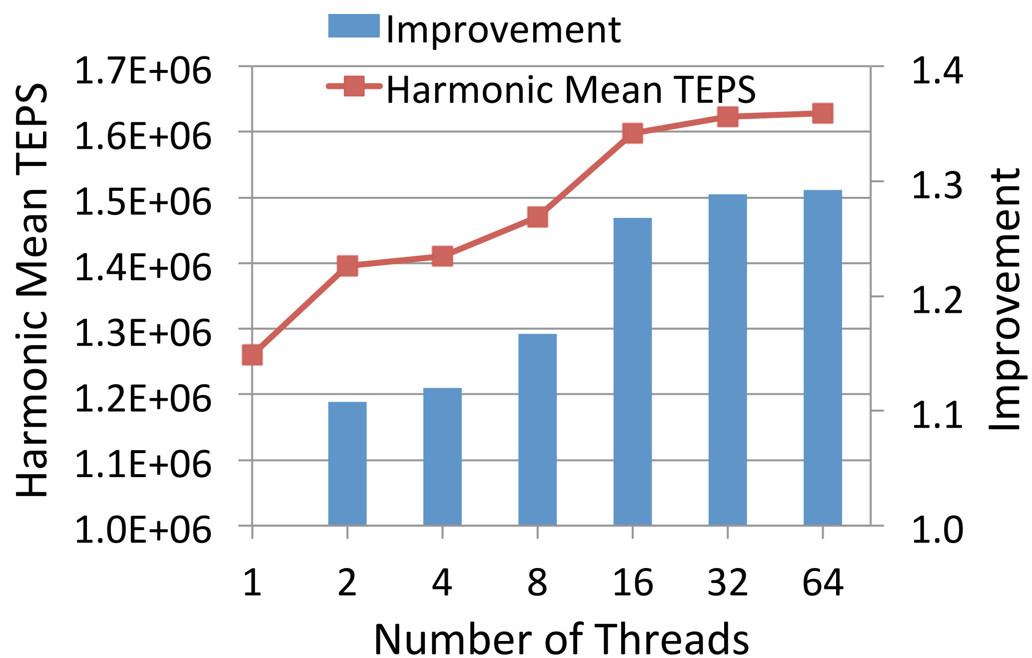
Parallelized IB Communication



One-sided Graph500 benchmark

- Every process issues many MPI_Accumulate operations to the other processes in every breadth first search iteration.
- Scale 2^{22}, 16 edge factor, 64 MPI processes





Conclusion

- Many-core Architectures
- Most popular Funneled / Serialized mode in Hybrid MPI + threads programming model
  - Many threads parallelize user computation
  - Only single thread issues MPI calls
- **Threads are IDLE during MPI calls !**
- We **utilize these IDLE threads to parallelize MPI internal tasks**, and delivers better performance in various aspects
  - Derived datatype packing processing
  - Shared memory communication
  - IB network communication