Non-Blocking Collectives for MPI-2

– overlap at the highest level –

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Outline

1. Some Considerations about Interconnects
2. Why Non blocking Collectives?
3. LibNBC
4. And Applications?
5. Ongoing Efforts

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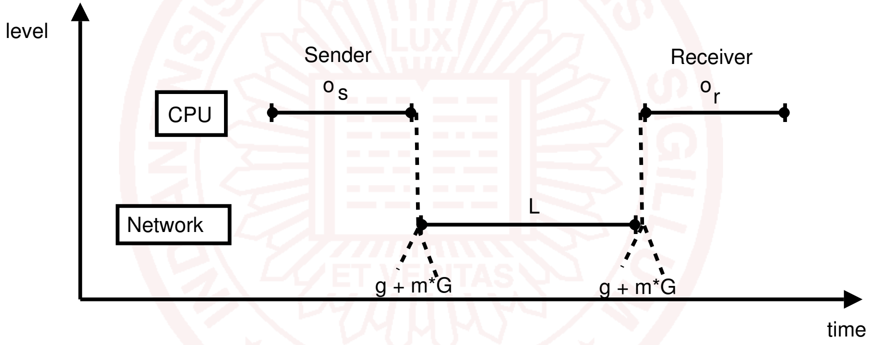
The LogGP Model



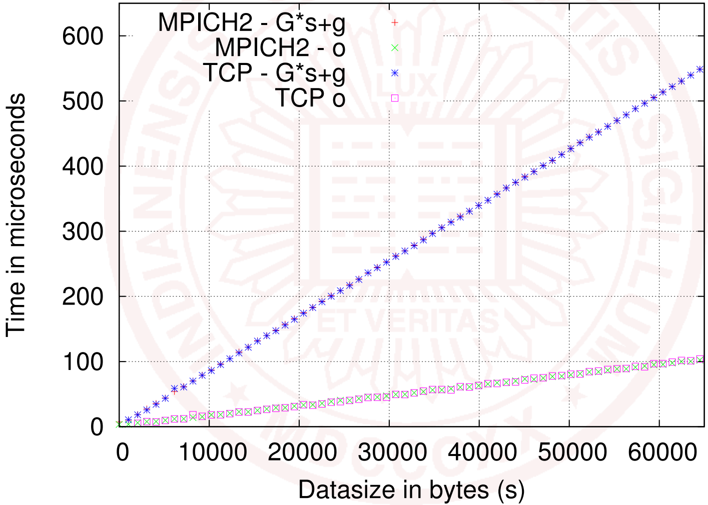
Interconnect Trends

Technology Change

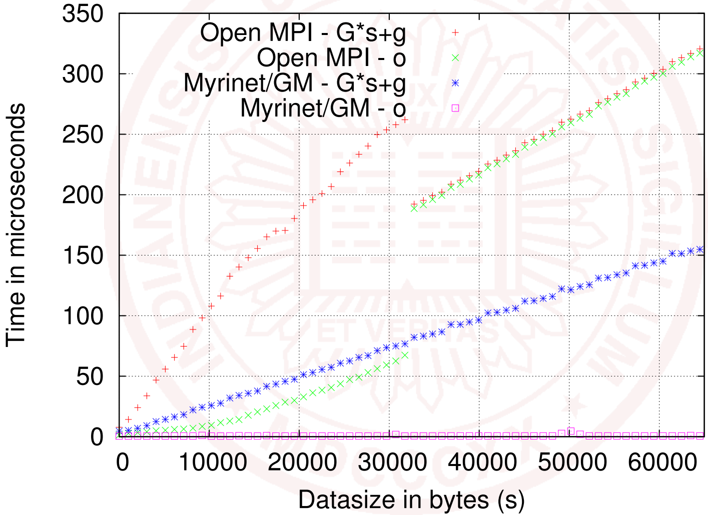
- modern interconnects offload communication to co-processors (Quadrics, InfiniBand, Myrinet)
- TCP/IP is optimized for lower host-overhead (e.g., Gamma)
- even Ethernet supports protocol offload
- $L + g + m \cdot G >> o$

⇒ we prove our expectations with benchmarks of the user CPU overhead

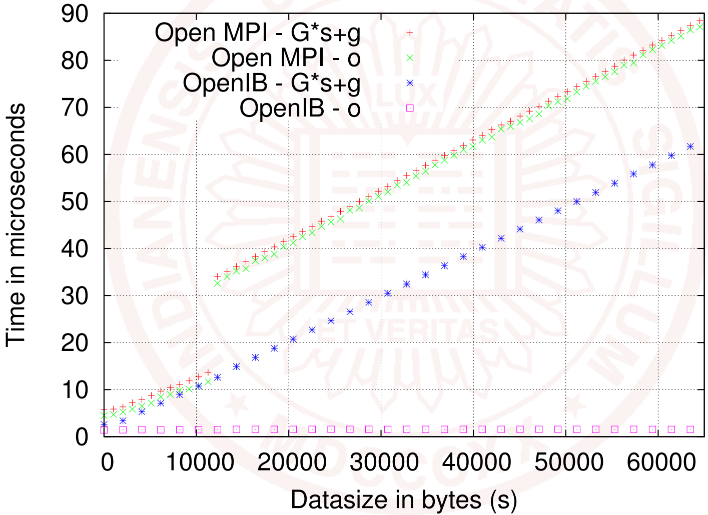
LogGP Model Examples - TCP



LogGP Model Examples - Myrinet/GM



LogGP Model Examples - InfiniBand/OpenIB



Literature

[1] T. Hoefler, A. Lichei, and W. Rehm: *Low-Overhead LogGP Parameter Assessment for Modern Interconnection Networks. In Proceedings of the 21st IEEE International Parallel & Distributed Processing Symposium*

[2] T. Hoefler, J. Squyres, G. Fagg, G. Bosilca, W. Rehm and A. Lumsdaine: *A New Approach to MPI Collective Communication Implementations. In proceedings of the 6th Austrian-Hungarian Workshop on Distributed and Parallel Systems*

[3] T. Hoefler, M. Reinhardt, F. Mietke, T. Mehlan, and W. Rehm: *Low Overhead Ethernet Communication for Open MPI on Linux Clusters. In Chemnitzer Informatik Berichte CSR-06, Nr. 06*

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Modelling the Benefits

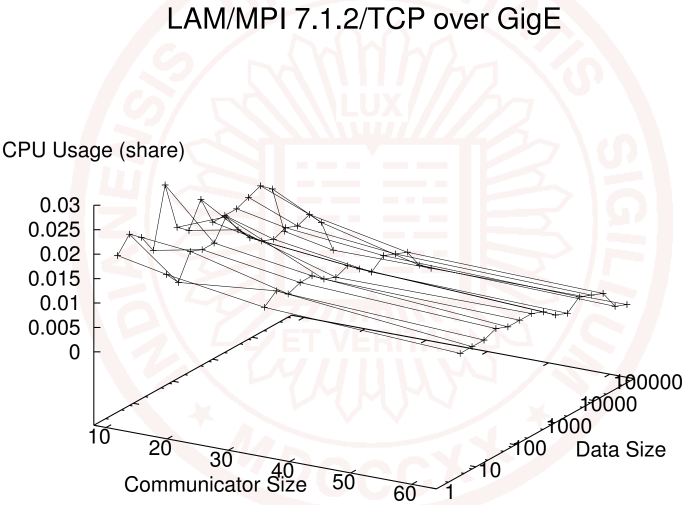
LogGP Models for Collective Operations

$$\begin{aligned}
t_{barr} &= (2o + L) \cdot \lceil log_2 P \rceil \\
t_{allred} &= 2 \cdot (2o + L + m \cdot G) \cdot \lceil log_2 P \rceil + m \cdot \gamma \cdot \lceil log_2 P \rceil \\
t_{bcast} &= (2o + L + m \cdot G) \cdot \lceil log_2 P \rceil
\end{aligned}$$

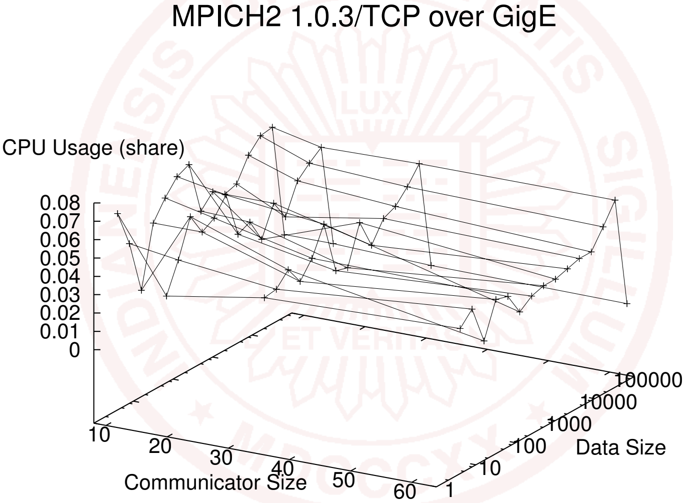
Split into CPU and Network parts

$$\begin{aligned}
t_{barr}^{CPU} &= 2o \cdot \lceil log_2 P \rceil & t_{barr}^{NET} &= L \cdot \lceil log_2 P \rceil \\
t_{allred}^{CPU} &= (4o + m \cdot \gamma) \cdot \lceil log_2 P \rceil & t_{allred}^{NET} &= 2 \cdot (L + m \cdot G) \cdot \lceil log_2 P \rceil \\
t_{bcast}^{CPU} &= 2o \cdot \lceil log_2 P \rceil & t_{bcast}^{NET} &= (L + m \cdot G) \cdot \lceil log_2 P \rceil
\end{aligned}$$

CPU Overhead Benchmarks

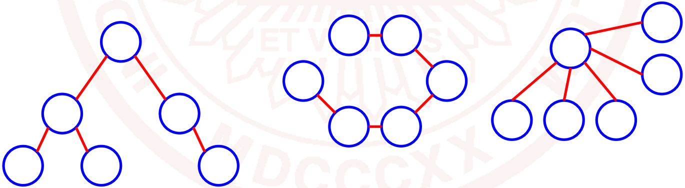


CPU Overhead Benchmarks



Why non blocking Collectives

- many collectives synchronize unneccessarily
- scale typically with $O(log_2 P)$ sends
- wasted CPU time: $log_2 P \cdot (L + G_{all})$
  - Fast Ethernet: L = 50-60
  - Gigabit Ethernet: L = 15-20
  - InfiniBand: L = 2-7
  - $1 \mu s \approx$ 4000 FLOPs on a 2GHz Machine



Isend/Irecv is there - Why Collectives?

- Gorlach, '04: "Send-Receive Considered Harmful"
- ⇔ Dijkstra, '68: "Go To Statement Considered Harmful"

point to point

```
if ( rank == 0) then
   call MPI_SEND(...)
else
   call MPI_RECV(...)
end if
```

vs. collective

```
call MPI_GATHER(...)
```

cmp. math libraries vs. loops

Putting Everything Together

- non blocking collectives?
- JoD mentions ”split collectives”
- example:
  - MPI_Bcast_begin(...)
  - MPI_Bcast_end(...)
- no nesting with other colls
- very limited
- not in the MPI-2 standard
- votes: 11 yes, 12 no, 2 abstain

Performance Benefits

overlap

- leverage hardware parallelism (e.g. InfiniBand^{TM})
- overlap similar to non-blocking point-to-point

pseudo synchronization

- avoidance of explicit pseudo synchronization
- limit the influence of OS noise

⇒ we analyze Barrier, Allreduce and Bcast

Process Skew

- caused by OS interference or unbalanced application
- worse if processors are overloaded
- multiplies on big systems
- can cause dramatic performance decrease
- all nodes wait for the last

Example

Petrini et. al. (2003) *”The Case of the Missing Supercomputer Performance: Achieving Optimal Performance on the 8,192 Processors of ASCI Q”*

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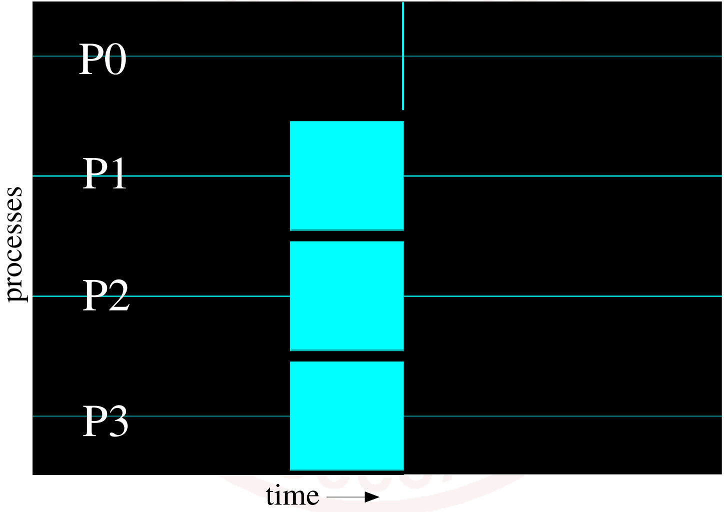
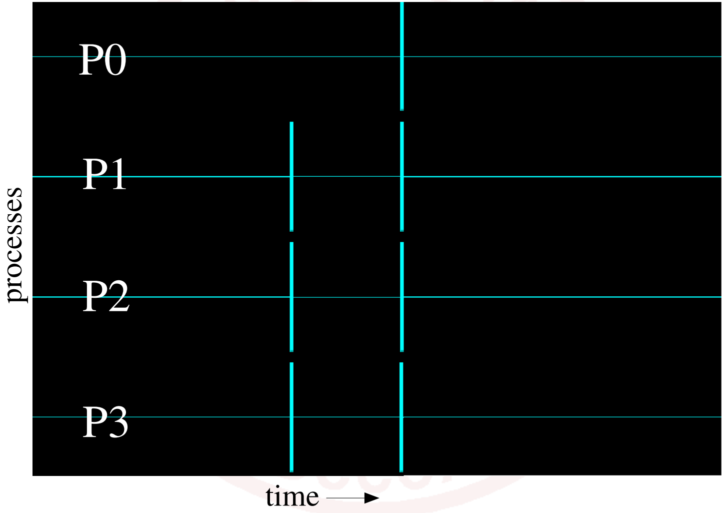
MPI_Bcast with P0 delayed - Jumpshot



MPI_Ibcast with P0 delayed + overlap - Jumpshot



Literature

[4] T. Hoefler, J. Squyres, W. Rehm, and A. Lumsdaine: *A Case for Non-Blocking Collective Operations*. *In Frontiers of High Performance Computing and Networking, pages 155-164, Springer Berlin / Heidelberg, ISBN: 978-3-540-49860-5 Dec. 2006*

[5] T. Hoefler, J. Squyres, G. Bosilca, G. Fagg, A. Lumsdaine, and W. Rehm: *Non-Blocking Collective Operations for MPI-2*. *Open Systems Lab, Indiana University. presented in Bloomington, IN, USA, School of Informatics, Aug. 2006*

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Non-Blocking Collectives - Interface

- extension to MPI-2
- ”mixture” between non-blocking ptp and collectives
- uses MPI_Requests and MPI_Test/MPI_Wait

Interface

```
MPI_Ibcast(buf, count, MPI_INT, 0, comm, &req);
MPI_Wait(&req);
```

Proposal

Hoefler et. al. (2006): *”Non-Blocking Collective Operations for MPI-2”*

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Non-Blocking Collectives - Implementation

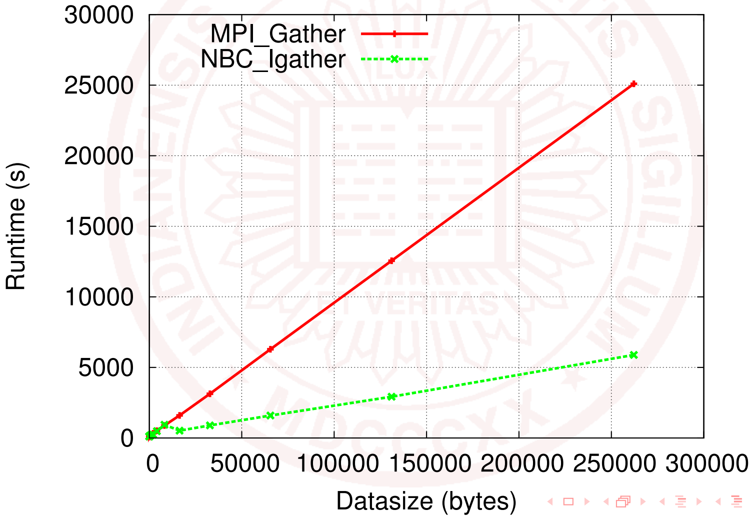
- implementation available with LibNBC
- written in ANSI-C and uses only MPI-1
- central element: collective schedule
- a coll-algorithm can be represented as a schedule
- trivial addition of new algorithms

Example: dissemination barrier, 4 nodes, node 0:

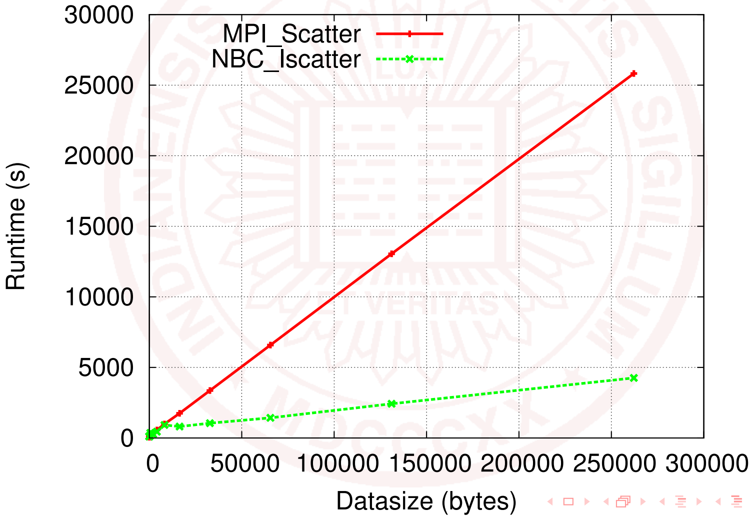
send to 1	recv from 3	end	send to 2	recv from 2	end

LibNBC download: `http://www.unixer.de/NBC`

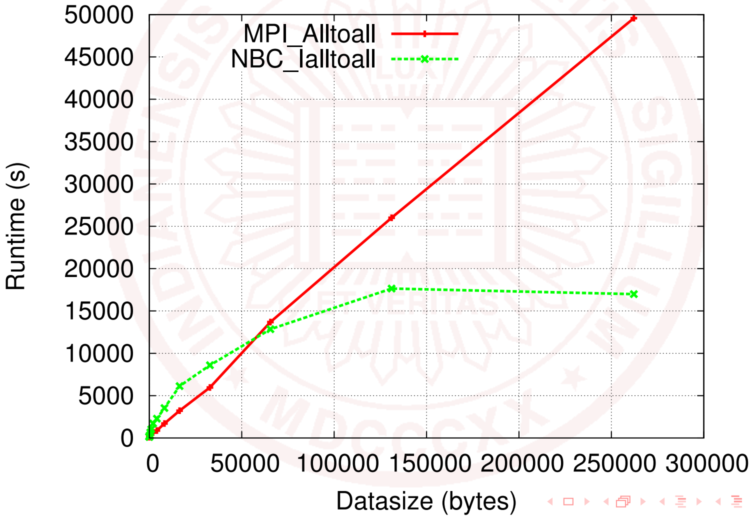
Overhead Benchmarks - Gather with InfiniBand/MVAPICH on 64 nodes



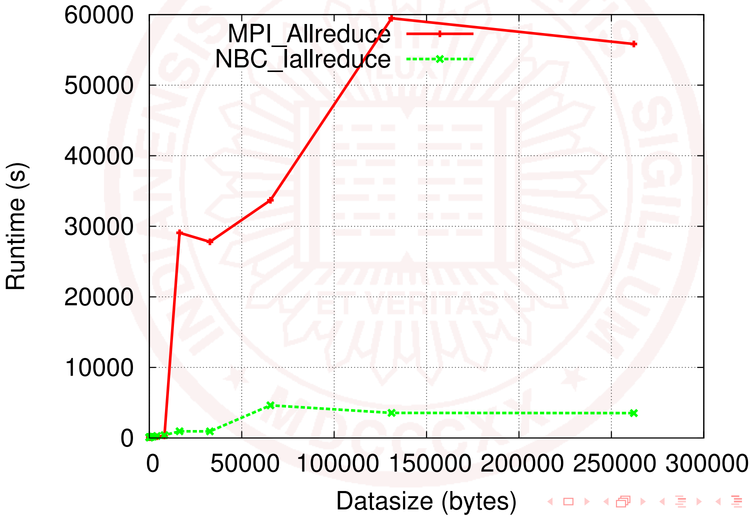
Overhead Benchmarks - Scatter with InfiniBand/MVAPICH on 64 nodes



Overhead Benchmarks - Alltoall with InfiniBand/MVAPICH on 64 nodes



Overhead Benchmarks - Allreduce with InfiniBand/MVAPICH on 64 nodes



Literature

[6] T. HOEFLER, A. LUMSDAINE AND W. REHM: *Implementation and Performance Analysis of Non-Blocking Collective Operations for MPI. Accepted for publication at the Supercomputing 2007 (SC07)*

[7] T. HOEFLER, P. KAMBADUR, R. L. GRAHAM, G. SHIPMAN AND A. LUMSDAINE: *A Case for Standard Non-Blocking Collective Operations*. *In Proceedings of the 14th European PVM/MPI User's Group Meeting 2007*

[8] T. HOEFLER AND A. LUMSDAINE: *Design, Implementation, and Usage of LibNBC*. *Open Systems Lab, Indiana University. presented in Bloomington, IN, USA, School of Informatics, Aug. 2006*

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Linear Solvers - Domain Decomposition

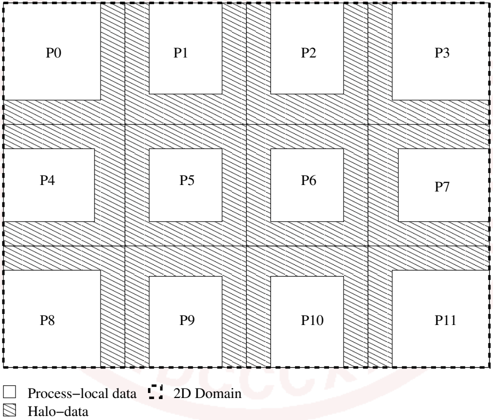
First Example

Naturally Independent Computation - 3D Poisson Solver

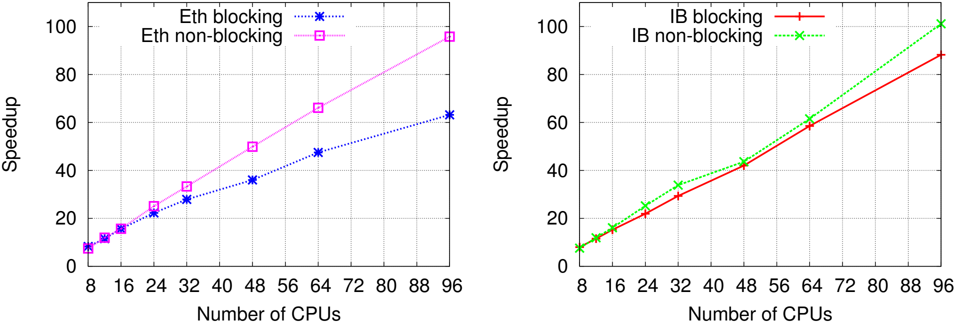
- iterative linear solvers are used in many scientific kernels
- often used operation is vector-matrix-multiply
- matrix is domain-decomposed (e.g., 3D)
- only outer (border) elements need to be communicated
- can be overlapped

Domain Decomposition

- nearest neighbor communication
- can be implemented with MPI_Alltoallv



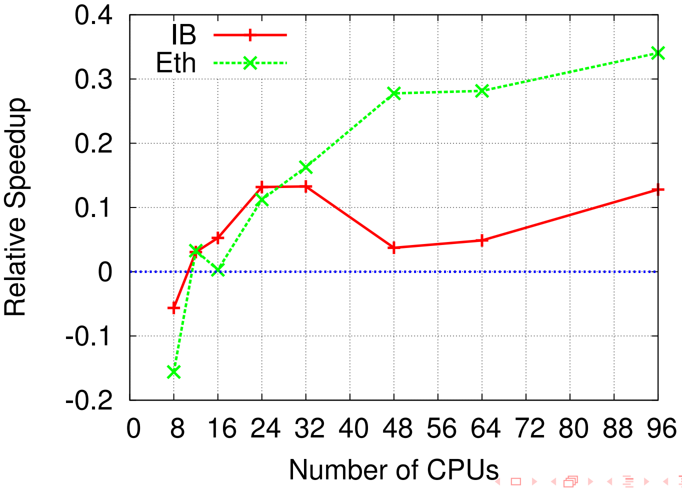
Parallel Speedup (Best Case)



- Cluster: 128 2 GHz Opteron 246 nodes
- Interconnect: Gigabit Ethernet, InfiniBand^{TM}
- System size 800x800x800 (1 node ≈ 5300s)

Parallel Gain with Non-Blocking Communication

$$gain = t_{nbl} / t_{bl}$$



Parallel Data Compression

Second Example

Data Parallel Loops - Parallel Compression

Automatic transformations (C++ templates)

typical loop structure:

```
for (i=0; i < N/P; i++) {
  compute(i);
}
comm(N/P);
```

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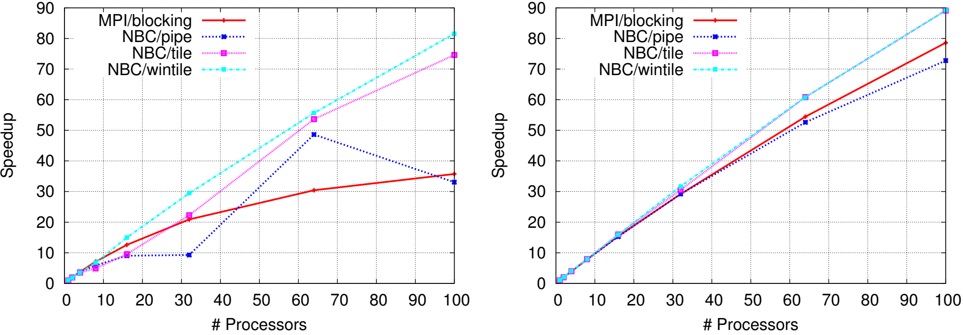
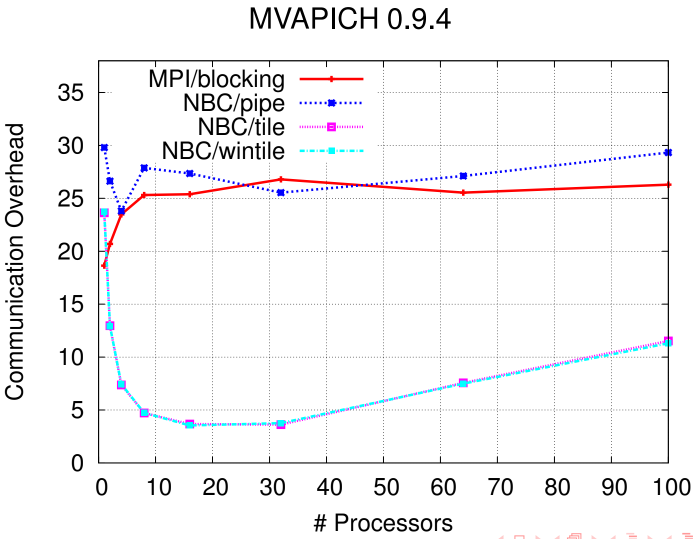


- Cluster: 64 2 GHz Opteron 246 nodes
- Interconnect: Gigabit Ethernet, InfiniBand^{TM}
- System size 64*50 MB

Communication Overhead



Parallel 3d Fast Fourier Transform

Third Example

Specialized Algorithms - A parallel 3d-FFT with overlap

Specialized design to achieve the highest overlap. Less cache-friendly!

Non-blocking Collectives - 3D-FFT

Derivation from “normal” implementation

- distribution identical to “normal” 3D-FFT
- first FFT in z direction and index-swap identical

Design Goals to Minimize Communication Overhead

- start communication as early as possible
- achieve maximum overlap time

Solution

- start MPI_Ialltoall as soon as first xz-plane is ready
- calculate next xz-plane
- start next communication accordingly ...
- collect multiple xz-planes (tile factor)

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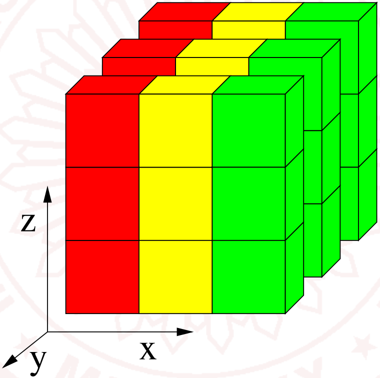
Transformation in z Direction

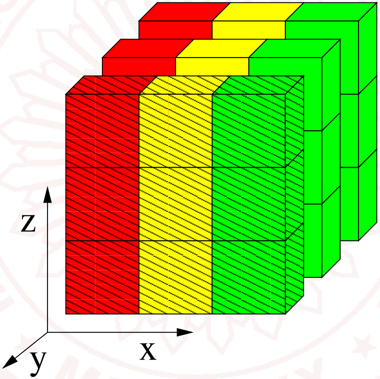
Data already transformed in y direction



1 block = 1 double value (3x3x3 grid)

Transformation in z Direction

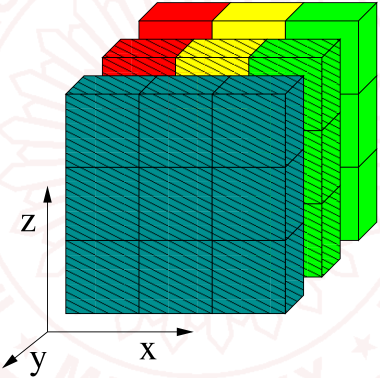
Transform first xz plane in z direction



pattern means that data was transformed in y and z direction

Transformation z Direction

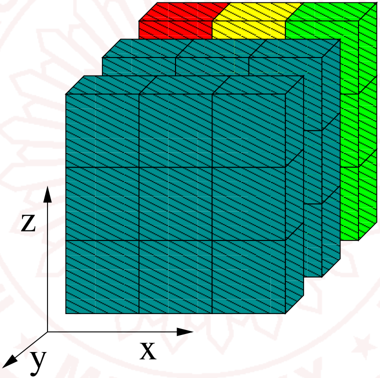
start MPI_Ialltoall of first xz plane and transform second plane



cyan color means that data is communicated in the background

Transformation in z Direction

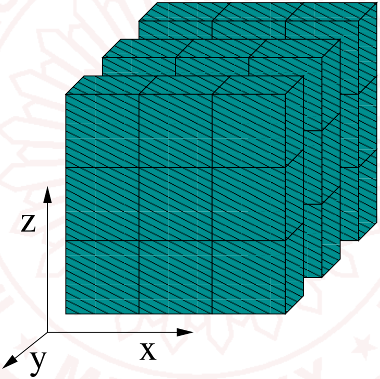
start MPI_Ialltoall of second xz plane and transform third plane



data of two planes is not accessible due to communication

Transformation in x Direction

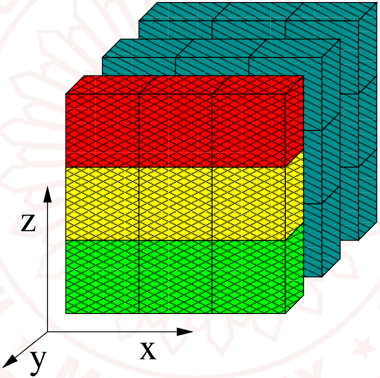
start communication of the third plane and ...



we need the first xz plane to go on ...

Transformation in x Direction

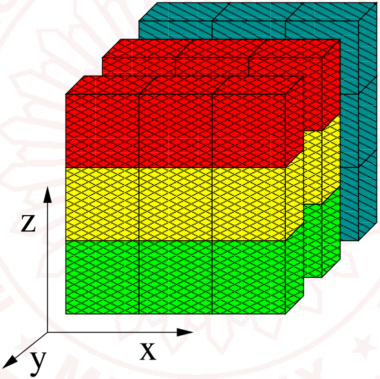
... so MPI_Wait for the first MPI_Ialltoall!



and transform first plane (new pattern means xyz transformed)

Transformation in x Direction

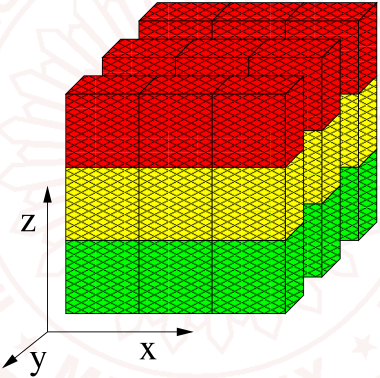
Wait and transform second xz plane



first plane's data could be accessed for next operation

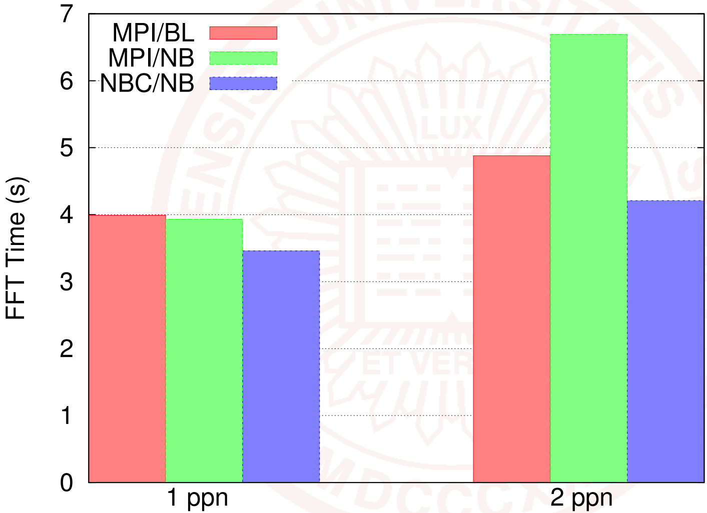
Transformation in x Direction

wait and transform last xz plane



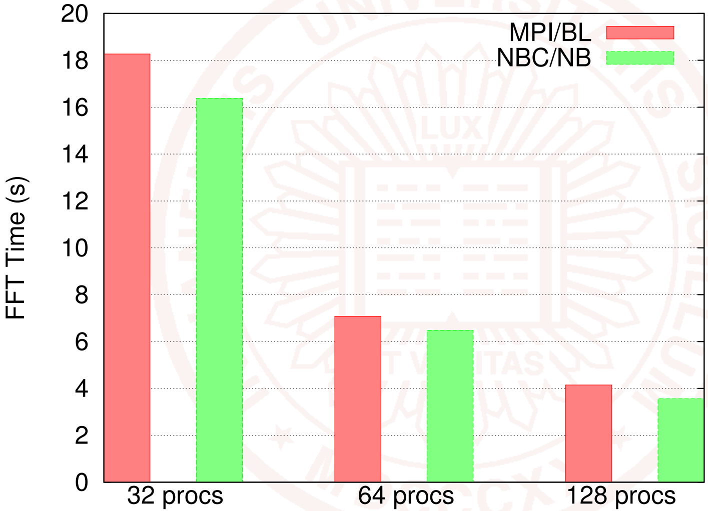
done! → 1 complete 1D-FFT overlaps a communication

1024^3 3d-FFT over InfiniBand



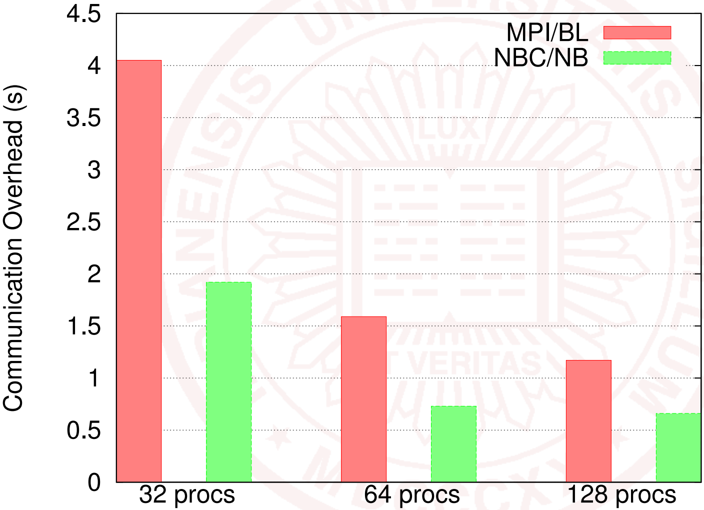
- P=128, “Coyote”@LANL - 128/64 dual socket 2.6GHz Opteron nodes

1024^3 3d-FFT on the XT4



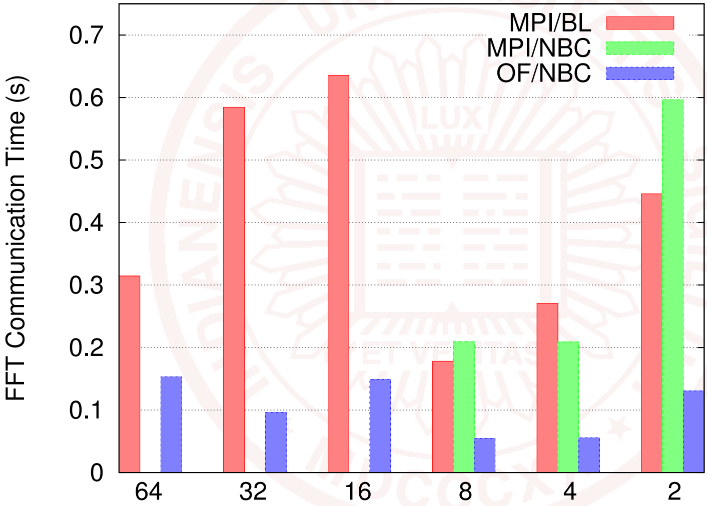
- “Jaguar”@ORNL - Cray XT4, dual socket dual core 2.6GHz Opteron

1024^3 3d-FFT on the XT4 (Communication Overhead)



- “Jaguar”@ORNL - Cray XT4, dual socket dual core 2.6GHz Opteron

640^3 3d-FFT InfiniBand (Communication Overhead)



- "Odin"@IU - dual socket dual core 2.6GHz Opteronm InfiniBand

Literature

[9] T. HOEFLER P. GOTTSCHLING, W. REHM AND A. LUMSDAINE: *Optimizing a Conjugate Gradient Solver with Non-Blocking Collective Operations*. *Elsevier Journal of Parallel Computing (PARCO). Vol 33, Nr. 9, pages 624-633*

[10] T. HOEFLER, P. GOTTSCHLING AND A. LUMSDAINE: *Transformations for enabling non-blocking collective communication in high-performance applications*. *Under submission (ask me for a copy)*

[11] T. HOEFLER AND A. LUMSDAINE: *Optimizing non-blocking Collective Operations for InfiniBand*. *Under submission (ask me for a copy)*

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Ongoing Work

LibNBC

- distribute as part of Open MPI 1.3
- optimized collectives

Collective Communication

- optimized collectives for InfiniBand^{TM}
- using special hardware support

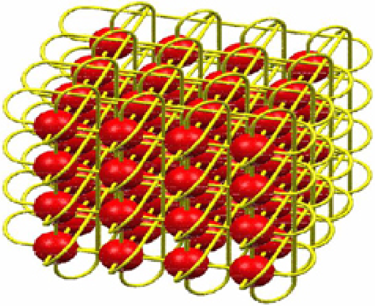
Network Modelling

- refined LogGP model parametrization
- modelling of collective algorithms

Discussion

THE END

Questions?



Thank you for your attention!