Communication Optimization for Medical Image Reconstruction Algorithms

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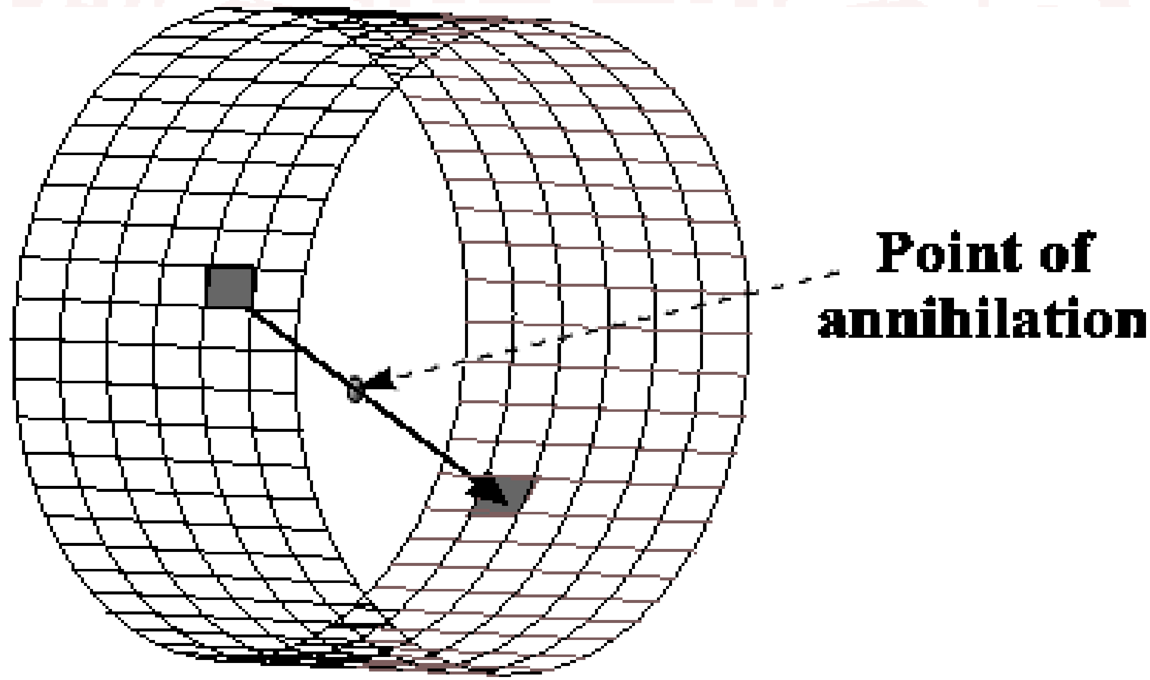
Positron Emission Tomography

- used to create high resolution images of the inside of a body
- computationally intensive post-processing
- most common is the list-mode OSEM algorithm
- needs many hours on a single CPU
- parallelization is an option to achieve higher performance

PET Details

- radiocative substance is applied to the patient
- patient is placed inside a scanner
- detectors of the scanner count events
- radiocative material emits positrons
- positrons collide with an electron in the surrounding tissue
- collision emits gamma rays which are detected by scanner



PET Parameters

- a single measurement results in $10^7\ to\ 5\times10^8$ events
- the algorithm computes a 3d image of the substance distribution
- Ordered Subset Expectation Maximation algorithm is used
- image f is vector of N voxels
- block-iterative method (m blocks of events)
- i-th row of mxN matrix A represents interaction between event i and a voxel

for each(iteration k){
 for each(subiteration l){
  for (event $i \in S_l$){
   compute A_i
   compute $c_l += (A_i)^t \dfrac{1}{A_i f_l^k}$}
  $f_{l+1}^k = f_l^k c_l$}
 $f_0^{k+1} = f_{l+1}^k$}

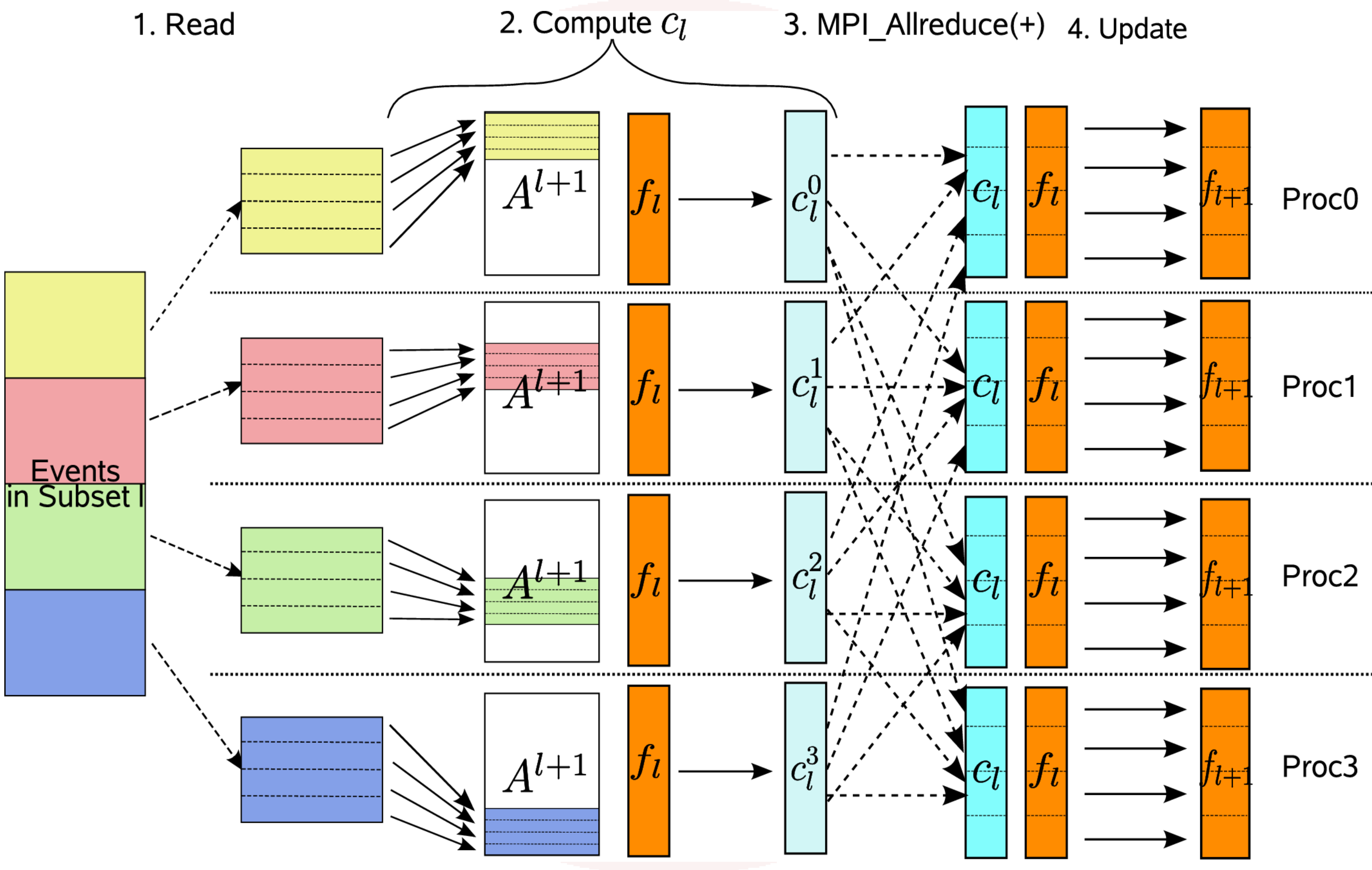
Parallelization Options

- two strategies:
  - Projection Space Decomposition (PSD)
  - Image Space Decomposition (ISD)
- PSD distributes events, was shown to be better

1. read m_s/P events
2. compute $c_{l,j} = \sum_{i \in S_{l,j}} (A_i)^t \frac{1}{A_i f_l}$. This includes the on-the-fly computation of A_i for each event in $S_{l,j}$.
3. sum up $c_{l,j} \in \mathbb{R}^N$ $(\sum_j c_{l,j} = c_l)$ with MPI_Allreduce
4. compute $f_{l+1} = f_l c_l$

- use OpenMP to parallelize computation of steps 2 and 4
- events are read with MPI/IO operations
- exclusive use of collective operations!

The algorithm (schematically)

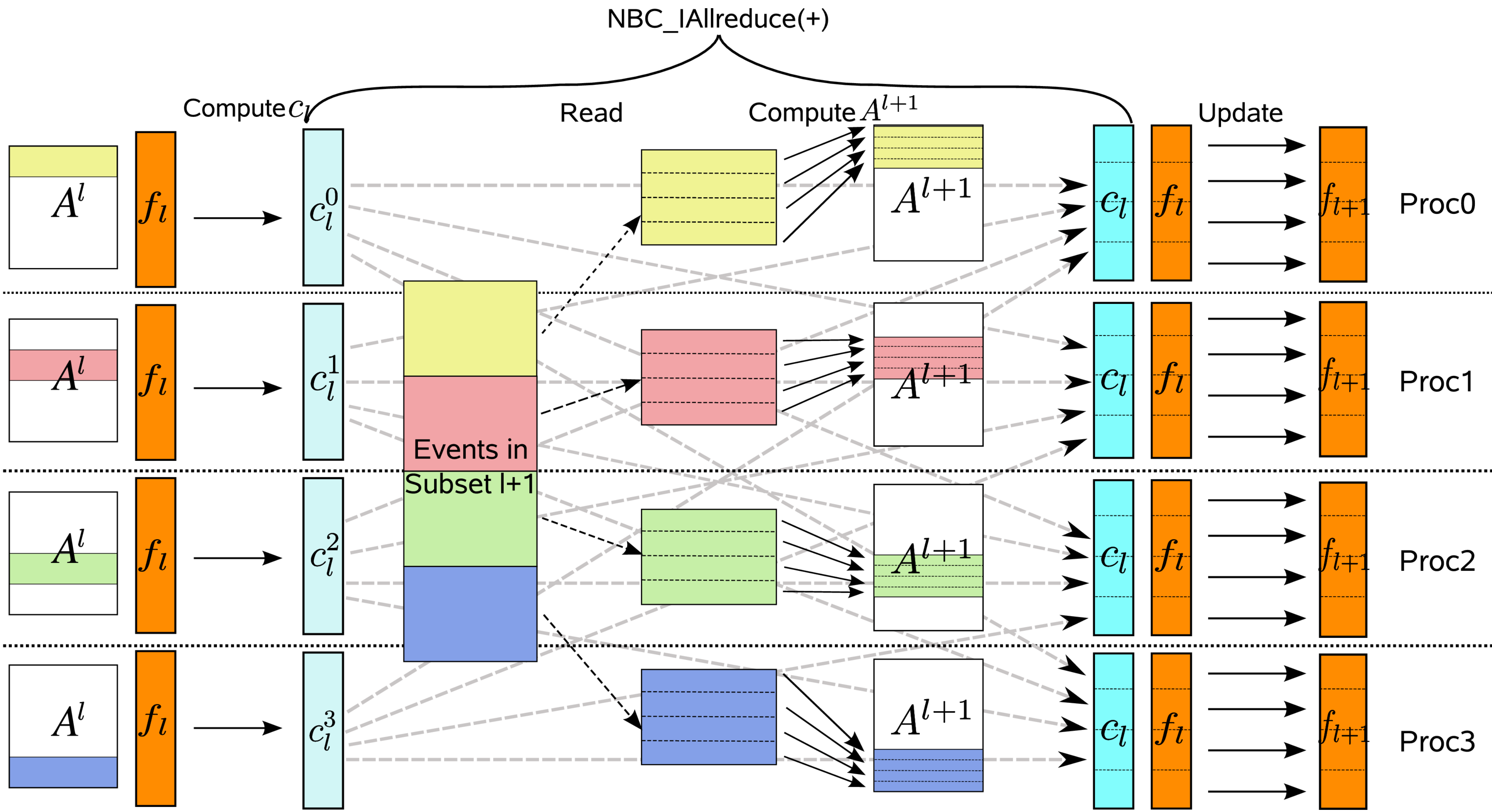


Optimization Options

- collective operations are already used
- hide overhead? (”overlap” computation and communication)
  - ➔ should be possible (at a small cost)!

1. read m_s/P events in the first subset
2. compute $c_{l,j} = \sum_{i \in S_{l,j}} (A_i)^t \frac{1}{A_i f_l}$. This includes the on-the-fly computation of A_i for each event in $S_{l,j}$ in the first subset. Beginning from the second subset, rows A_i have already been computed in parallel with NBC_Iallreduce
3. start NBC_Iallreduce for $c_{l,j}$ $(\sum_j c_{l,j} = c_l)$
4. in every but the last subset, each node reads the m_s/P events for subset $l+1$ and computes A_i for subset $l+1$
5. perform NBC_Wait to finish NBC_Iallreduce
6. compute $f_{l+1} = f_l c_l$

The new algorithm (schematically)

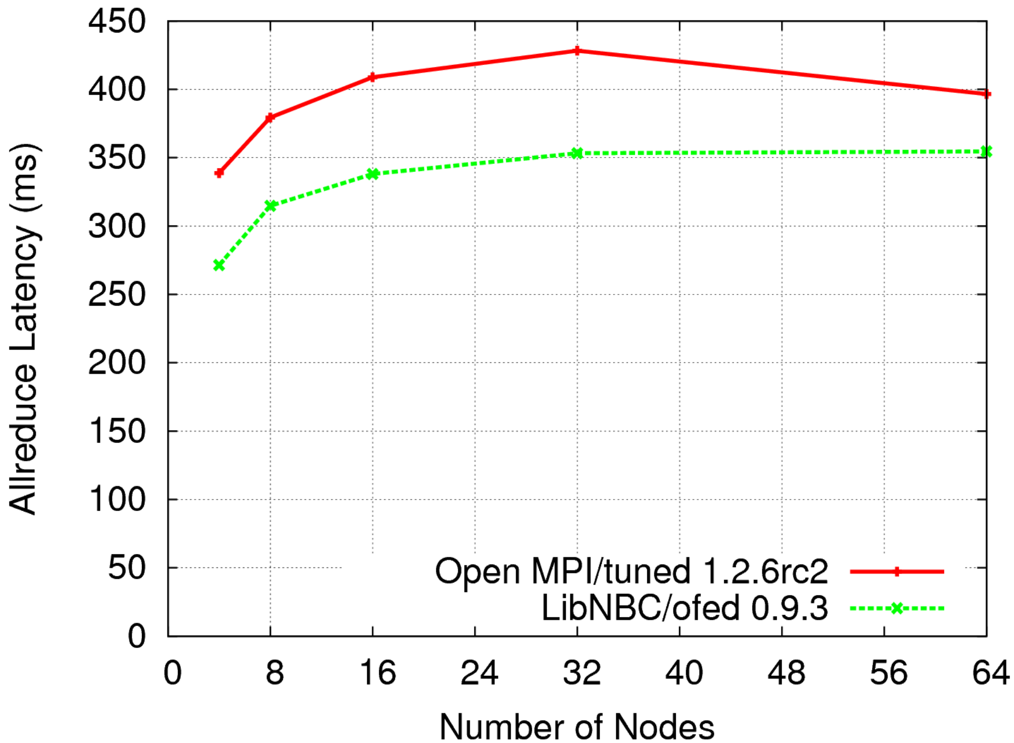


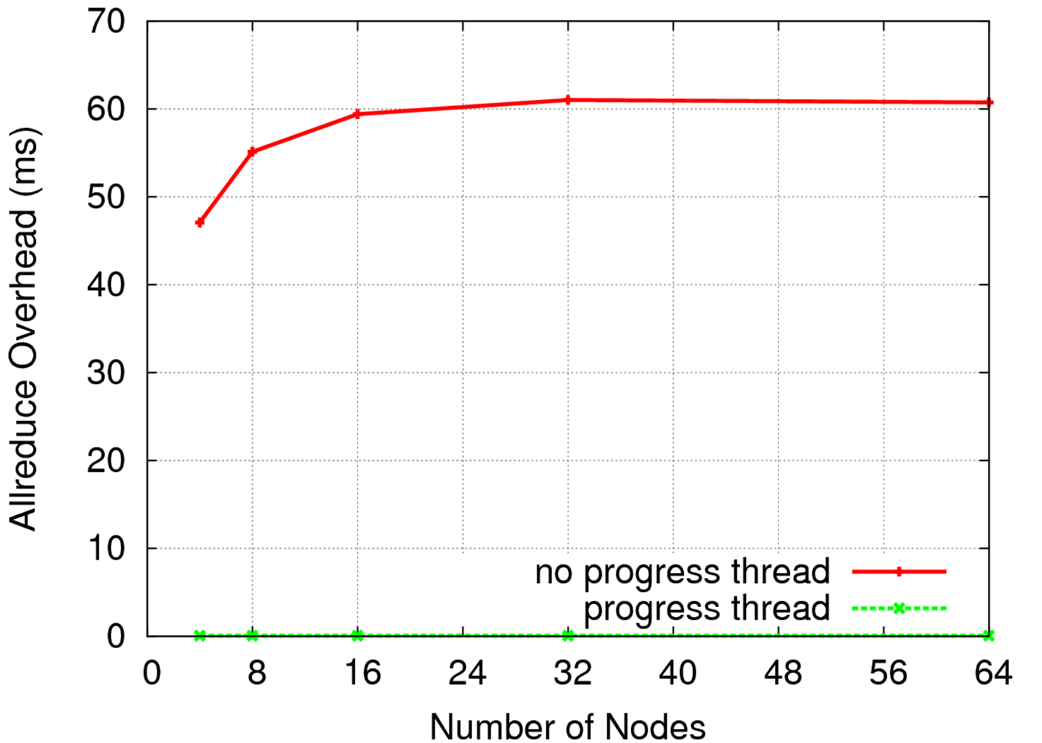
Potential Overlap

- need enough computation to overlap communication
- but: read-time and computation-time decrease linearly with P
- computation time decreases linearly with number of threads T
  - but: OpenMP doesn't scale that well (investigating)
  - delivers speedup of approx. 2 on 4 cores
- overlap potential:
  - parallelization works against us!
- how much do we need?
  - → as much time as the reduction takes!
- reduction-size is scanner dependent (approx. 48 MiB)

48 MiB Allreduce Options

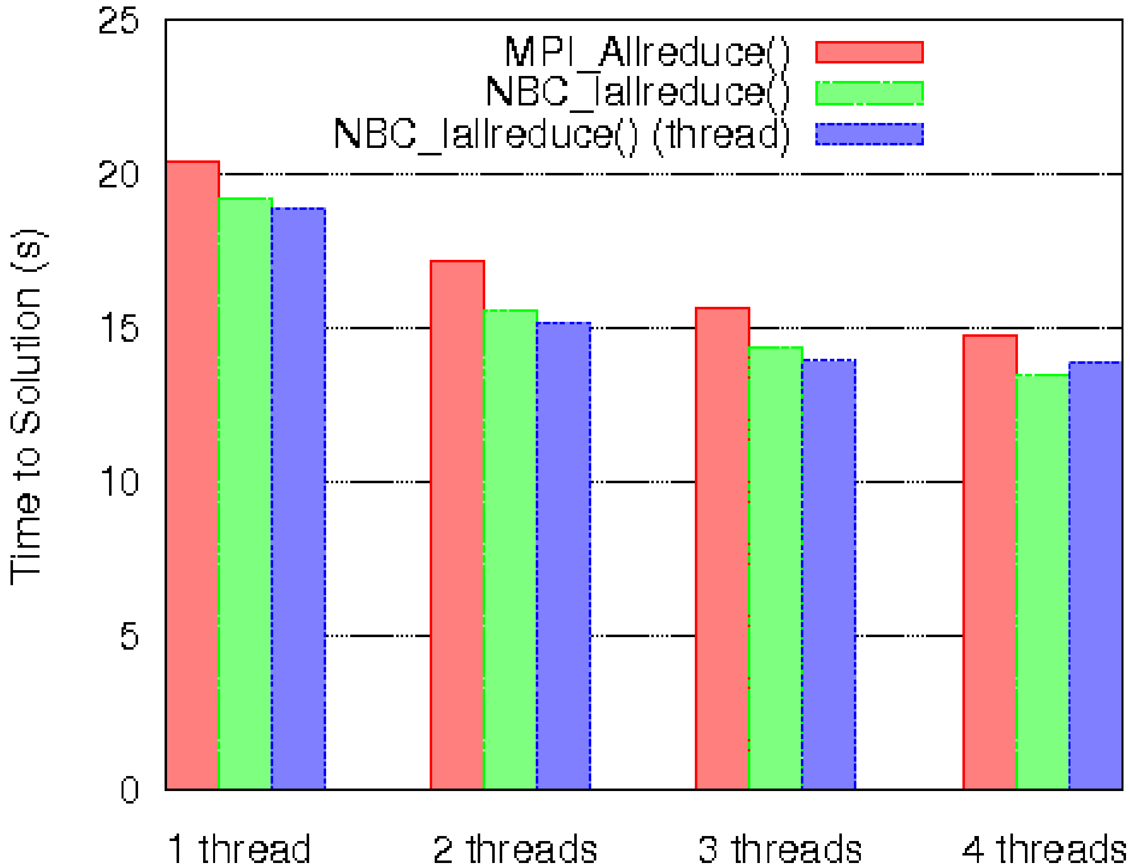
- expect small communicators
  - chunk data into P pieces
  - reduce in ring: 2P-2 comm/comp cycles





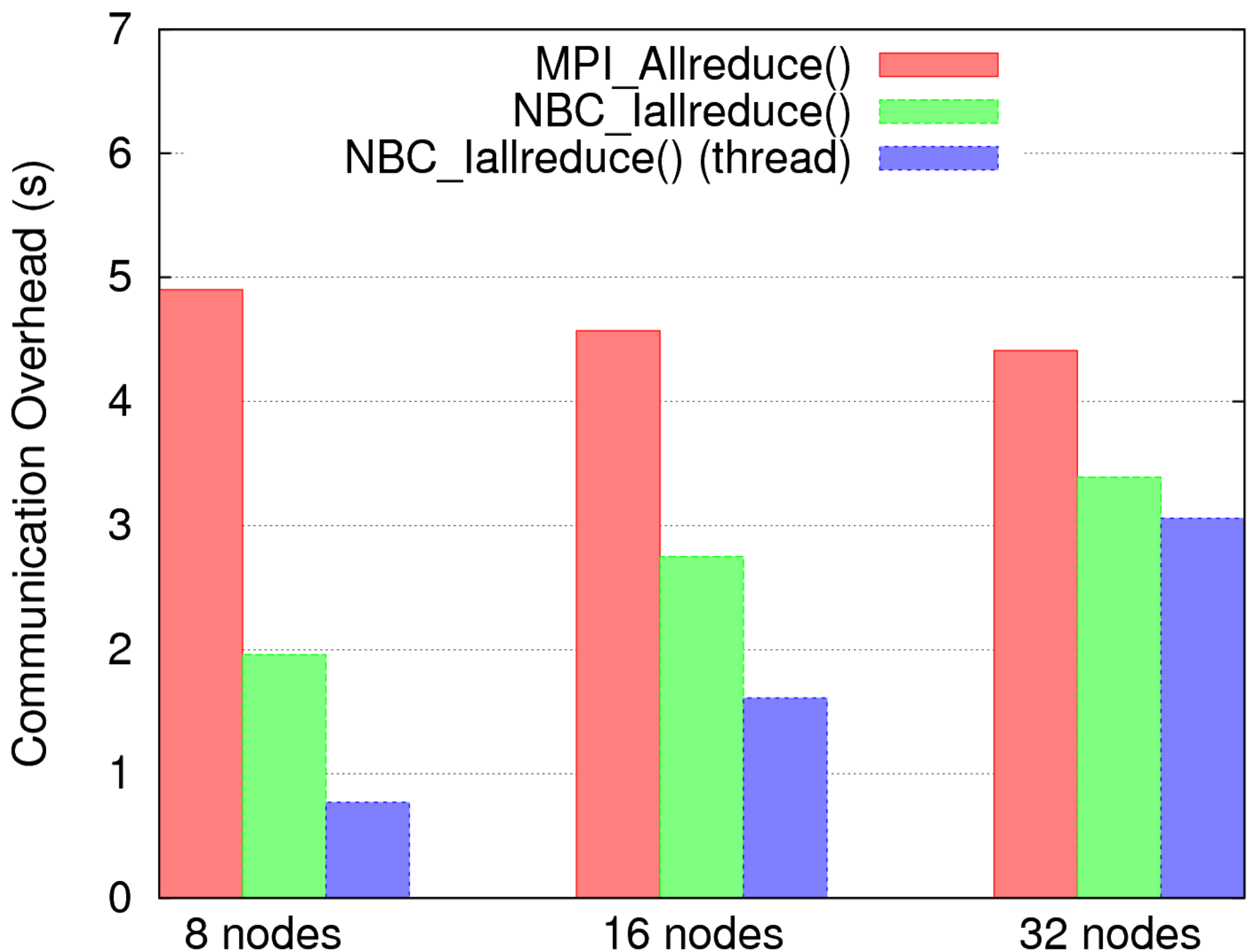
What to expect?

- overhead nearly an order of magnitude lower
- two orders of magnitude with thread and spare core
- we expect the overlap to decrease with increasing P and T
- threaded progression will have problems without spare core
- 32-node application runtime results:



What is the Overhead?

- Allreduce overhead with a single thread per node
- communication overhead is decreased
- computation time slightly increased (cache misses)



Conclusions

- Non-blocking Allreduce is easy to apply
  - Needs small code-reorganization to maximize overlap
  - Might cause other slowdowns (cache misses)
- Analysis of overlap potential has to be done before!
  - Also analyze scaling behavior!
  - Parallel scaling works against overlap in some cases
- Progression issues remain complex
  - Threaded vs. Test-based progression
  - Progress thread might cause CPU congestion
- OpenMP and MPI can be combined (also with NBC)