Near-Optimal Placement of MPI Processes on Hierarchical NUMA Architecture

Emmanuel Jeannot, Guillaume Mercier

LaBRI/INRIA Bordeaux Sud-Ouest/ENSEIRB

Runtime Team

Emmanuel.Jeannot@inria.fr

CCGSC in France?

Introduction

- MPI is the main standard for programming parallel applications
- It provides portable code across platforms
- What about performance portability?

Performance of MPI programs

Depend on many factors:

- Implementation of the standard (e.g. collective com.)
- Parallel algorithm(s)
- Implementation of the algorithm
- Underlying libraries (e.g. BLAS)
- Hardware (processors, cache, network)
- etc.
- and …

Process placement

The MPI model makes little (no?) assumption on the way MPI processes are mapped to resources

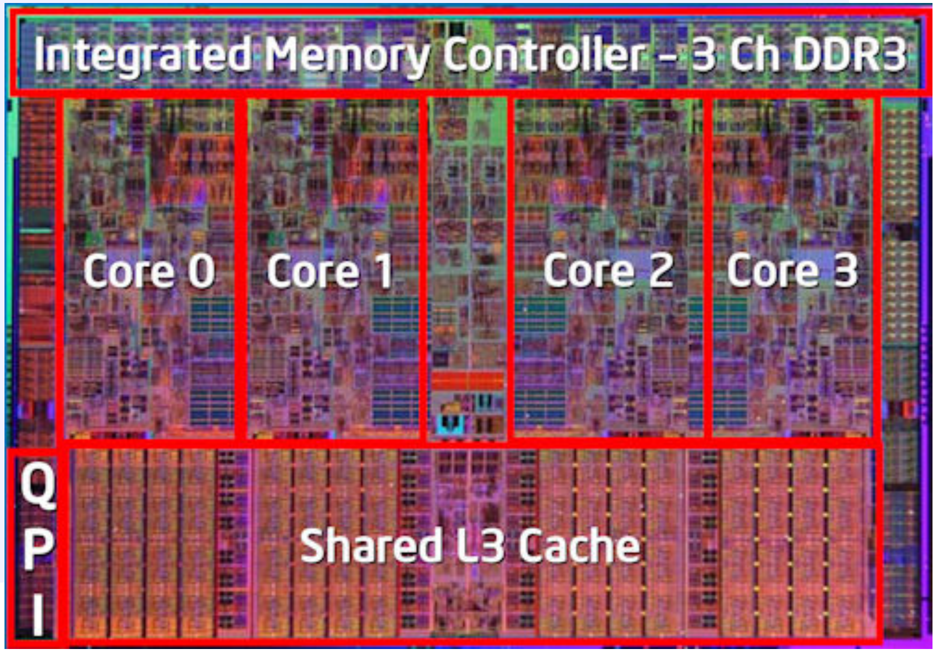
It is often assume that the network topology is flat and hence the process mapping has little impact on the performance

The network topology is not flat

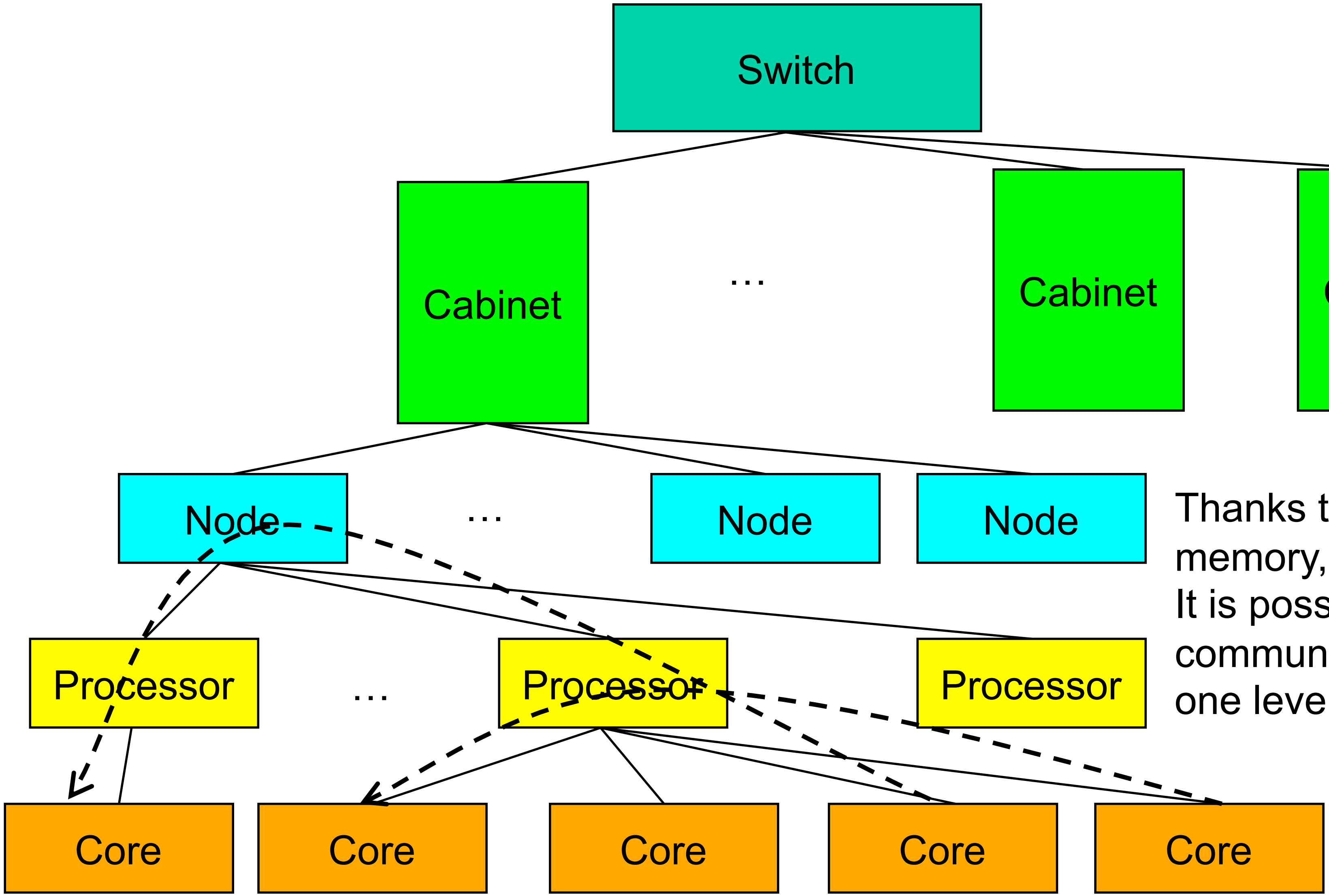
Due to multicore processors current and future parallel machines are hierarchical

Communication speed depend on:

- receptor and emitter
- Cache hierarchy
- Memory bus
- Interconnection network
- etc.



Example of typical parallel machine



Thanks to cache, memory, network, etc. It is possible to communicate inside one level

Rationale

Not all the processes exchange the same amount of data

The speed of the communications, and hence performance of the application depend on the way processes are mapped to resources.

Process placement problem

Given:

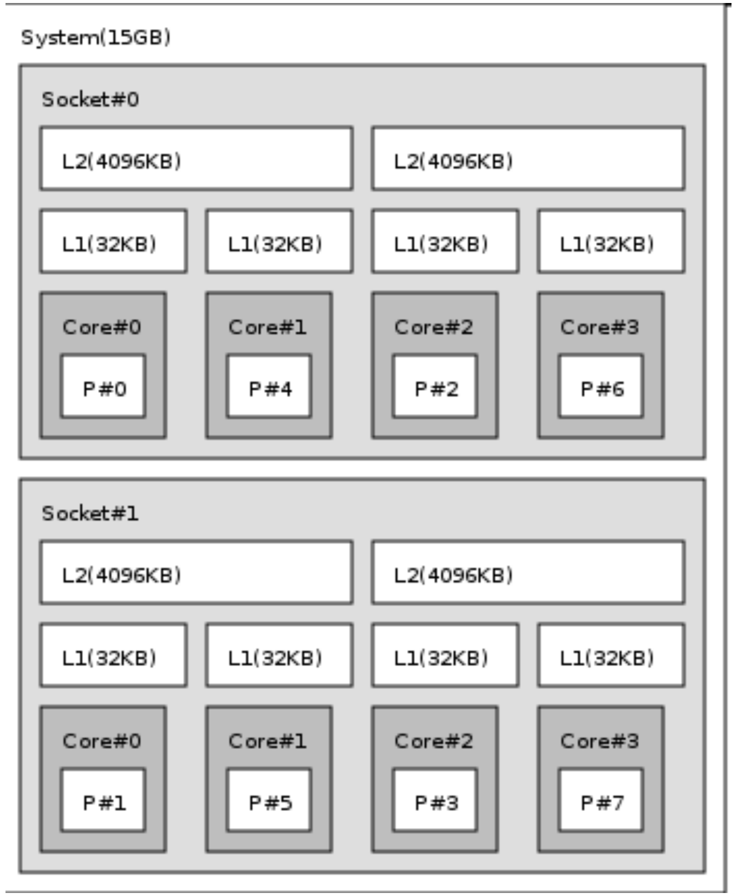
- The parallel machine topology
- The processes communication pattern

Map processes to resources (cores) to reduce the communication cost.

Obtaining the toplogy

HWLOC (portable hardware locality)

- Runtime and OpenMPI team
- portable abstraction (across OS, versions, architectures, ...)
- Hierarchical topology
- Modern architecture (NUMA, cores, caches, etc.)
- ID of the cores
- C library to play with
- etc.



Obtaining the communication pattern

No automatic way so far

For now done through application monitoring

Left to future work (static code analysis?)

State of the art

Process placement fairly well studied problem:

- Graph Partitioning (Scotch/Metis): do not take hierarchy into account.
- [Träff 2002]: placement through graph embedding and graph partitioning
- MPIPP [Chen et al. 2006]: placement through local exchange of processes until no gain is achievable
- [Clet-Ortega & Mercier 09] : placement through graph renumbering

Example

T: topology matrix

0	100	100	10	1000	100	100	10
100	0	10	100	100	1000	10	100
100	10	0	100	100	10	1000	100
10	100	100	0	10	100	100	1000
1000	100	100	10	0	100	100	10
100	1000	10	100	100	0	10	100
100	10	1000	100	100	10	0	100
10	100	100	1000	10	100	100	0

Communication speed between processor 2 and processor 3

C: communication matrix

0	1000	10	1	100	1	1	1
1000	0	1000	1	1	100	1	1
10	1000	0	1000	1	1	100	1
1	1	1000	0	1	1	1	100
100	1	1	1	0	1000	10	1
1	100	1	1	1000	0	1000	1
1	1	100	1	10	1000	0	1000
1	1	1	100	1	1	1000	0

Amount of data exchanged between process 1 and process 3

Formal problem

Input: T and C two n by n matrices

Output: σ a permutation of size n

Constraint: minimize

$$\sum_{i \neq j} C(i,j) / T(\sigma_i, \sigma_j)$$

Example of solutions:

Round-robin:	0 1 2 3 4 5 6 7	241.3
Graph embedding:	3 7 4 0 6 2 5 1	210.52
Optimal (B&B):	0 4 1 5 2 6 3 7	29.08

Complexity of the problem

Finding the optimal permutation is NP-Hard

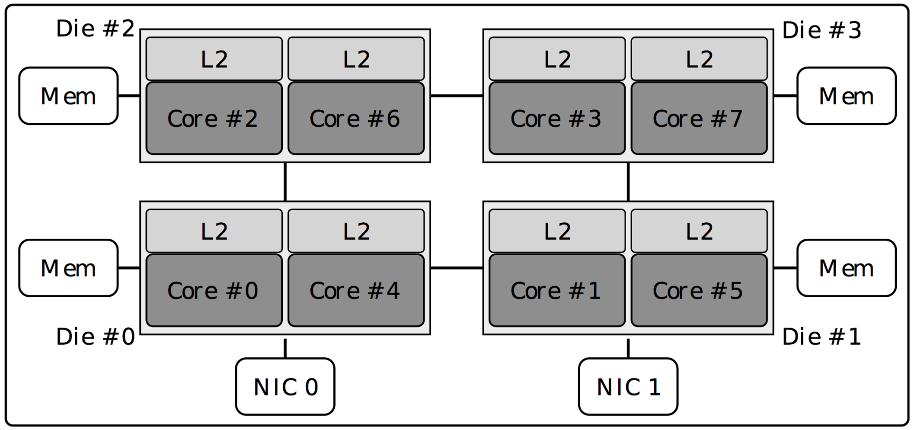
However, posed this way the problem does not take into account the hierarchy of the topology

Question: does taking the hierarchy into consideration help?

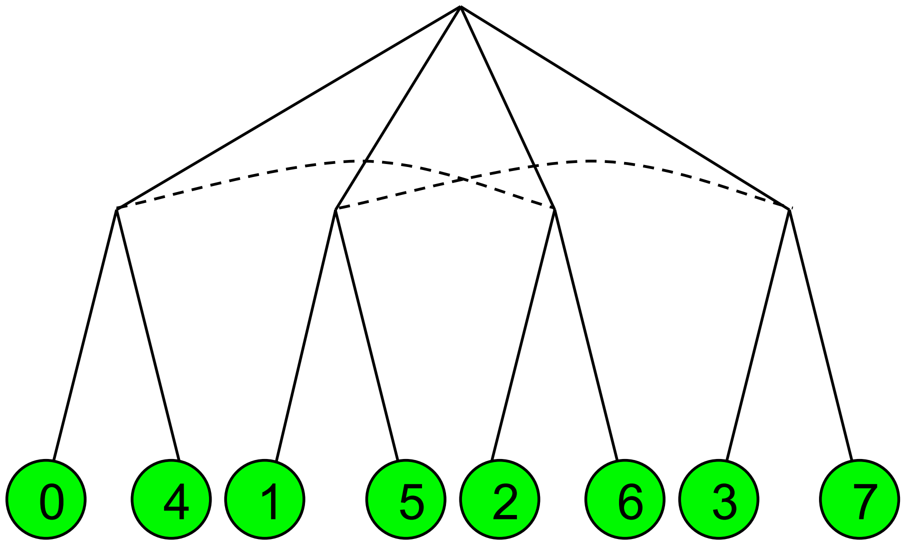
Taking into account the hierarchy

Topology matrix

0	100	100	10	1000	100	100	10
100	0	10	100	100	1000	10	100
100	10	0	100	100	10	1000	100
10	100	100	0	10	100	100	1000
1000	100	100	10	0	100	100	10
100	1000	10	100	100	0	10	100
100	10	1000	100	100	10	0	100
10	100	100	1000	10	100	100	0



HWLOC output



Mapping the communication matrix to the topology tree: the TreeMatch algorithm

Idea: for each level of the tree, group nodes to minimize remaining communication.

Group size should be equal to the arity of the considered level

Example

C: communication matrix

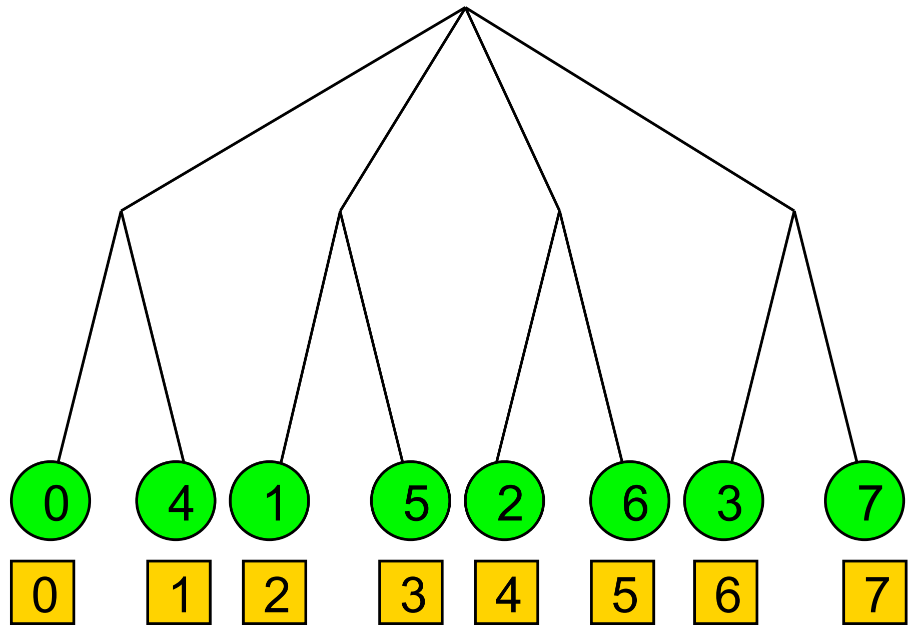
0	1000	10	1	100	1	1	1
1000	0	1000	1	1	100	1	1
10	1000	0	1000	1	1	100	1
1	1	1000	0	1	1	1	100
100	1	1	1	0	1000	10	1
1	100	1	1	1000	0	1000	1
1	1	100	1	10	1000	0	1000
1	1	1	100	1	1	1000	0

0 ↔ 1   2 ↔ 3   4 ↔ 5   6 ↔ 7

+

Grouped matrix

0	1012	202	4
1012	0	4	202
202	4	0	1012
4	202	1012	0



A more complex example

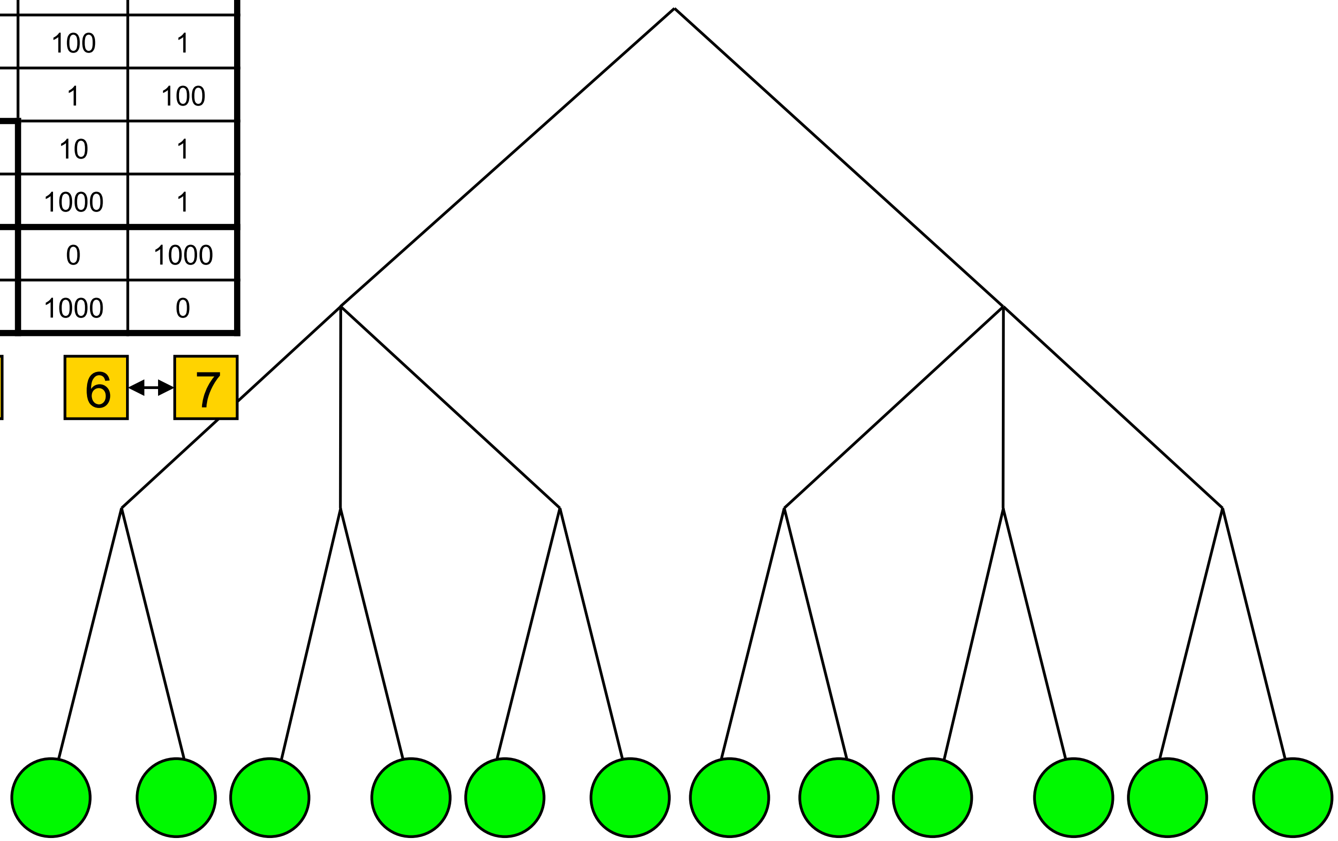
0	1000	10	1	100	1	1	1
1000	0	1000	1	1	100	1	1
10	1000	0	1000	1	1	100	1
1	1	1000	0	1	1	1	100
100	1	1	1	0	1000	10	1
1	100	1	1	1000	0	1000	1
1	1	100	1	10	1000	0	1000
1	1	1	100	1	1	1000	0

0 ↔ 1   2 ↔ 3   4 ↔ 5   6 ↔ 7

+

Grouped matrix

0	1012	202	4
1012	0	4	202
202	4	0	1012
4	202	1012	0



A more complex example

0 ↔ 1   2 ↔ 3   4 ↔ 5   6 ↔ 7

Grouped matrix

0	1012	202	4
1012	0	4	202
202	4	0	1012
4	202	1012	0

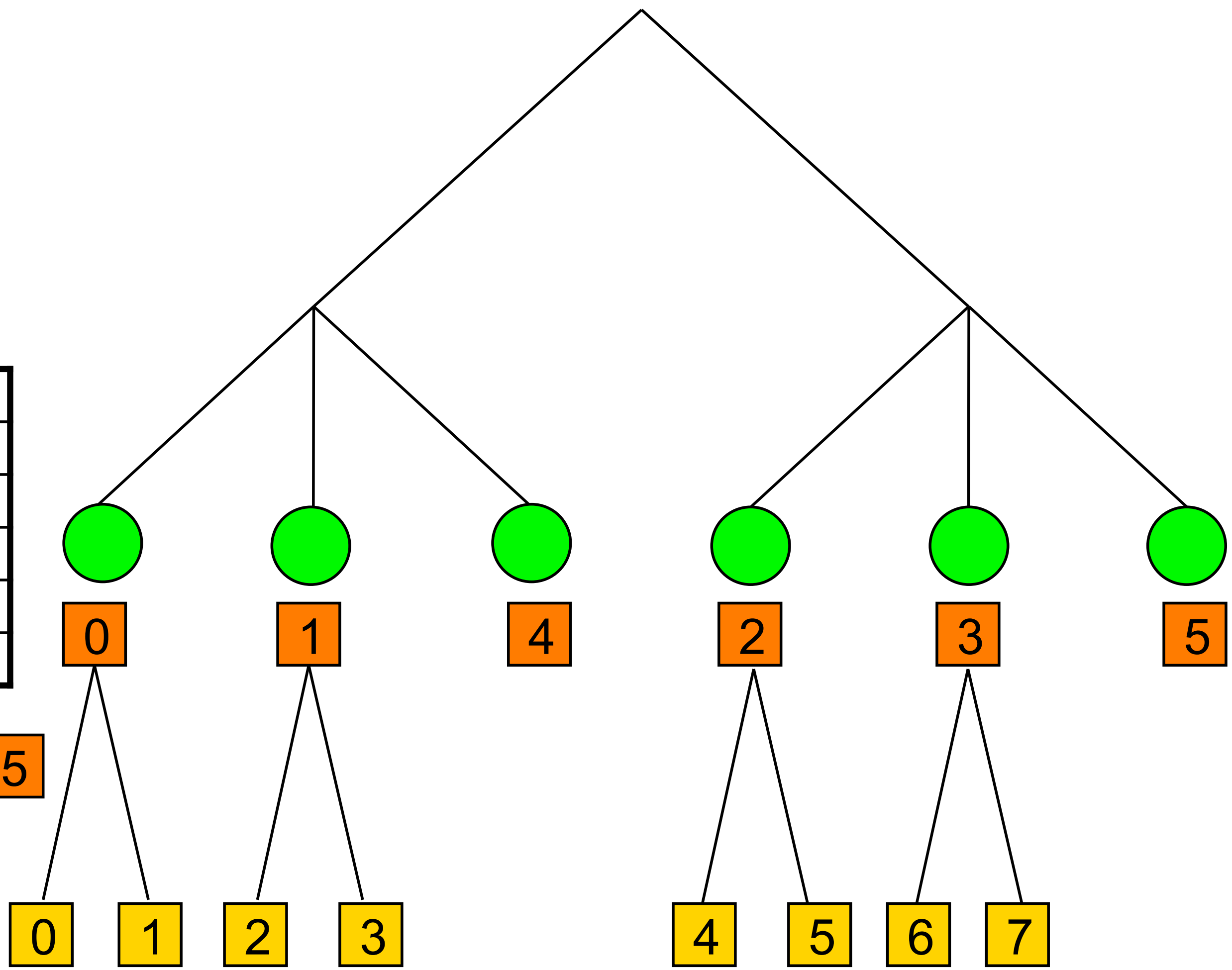
Extended grouped matrix

0	1012	202	4	0	0
1012	0	4	202	0	0
202	4	0	1012	0	0
4	202	1012	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

0 ↔ 1 ↔ 4   2 ↔ 3 ↔ 5

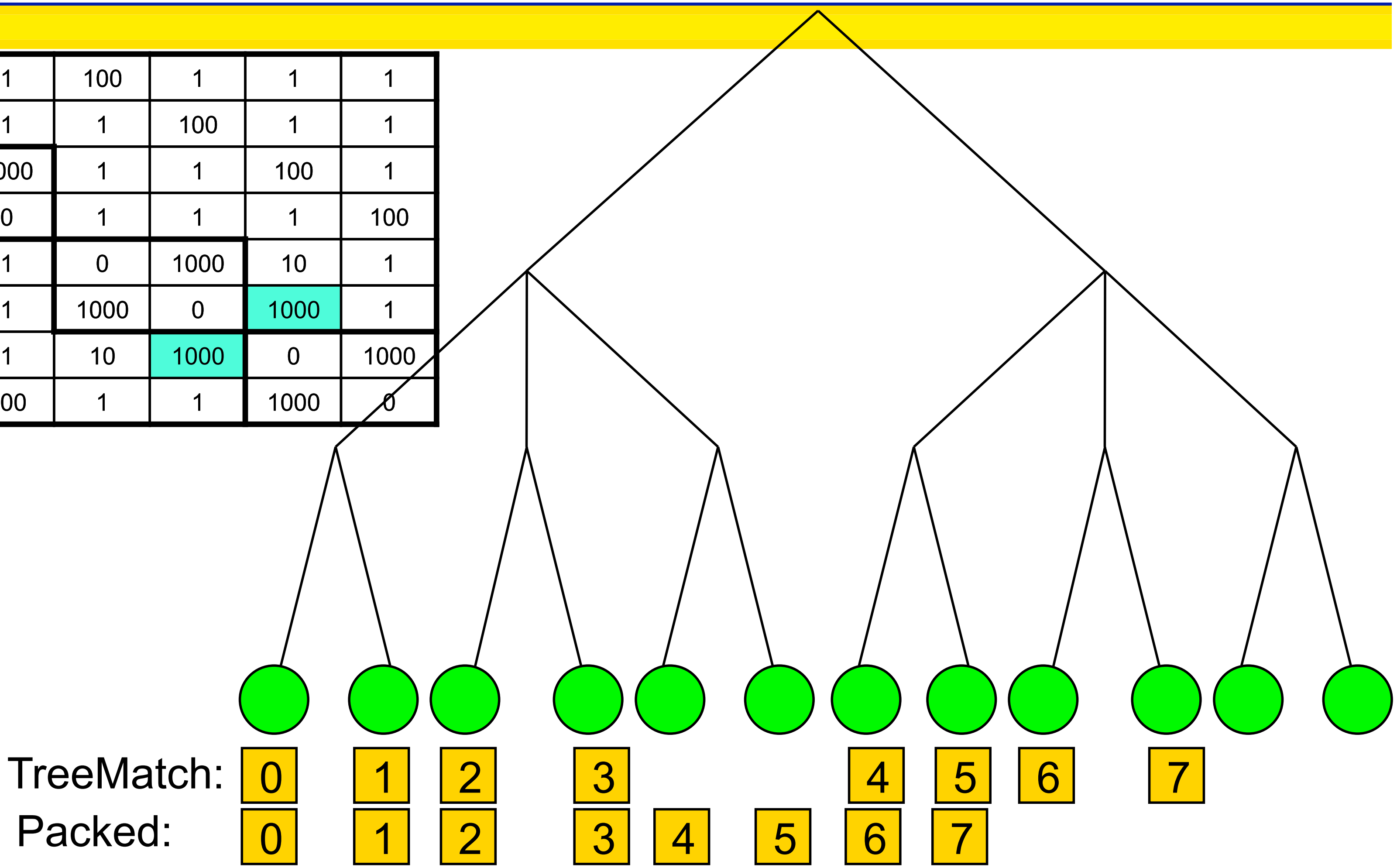
Grouped matrix

0	412
412	0



A more complex example

0	1000	10	1	100	1	1	1
1000	0	1000	1	1	100	1	1
10	1000	0	1000	1	1	100	1
1	1	1000	0	1	1	1	100
100	1	1	1	0	1000	10	1
1	100	1	1	1000	0	1000	1
1	1	100	1	10	1000	0	1000
1	1	1	100	1	1	1000	0



Packed solution worst than the TreeMatch one because there is a large communication between processes 5 and 6

TreeMatch properties

- Work if there is more cores than processes (by adding virtual processes that do not communicate)
- Work whatever the arity of a given level (do not need to be binary)
- **Optimal** if the communication pattern is hierarchic and symmetric and the topology tree is balanced

Complexity

n: size of the matix, k: arity of the level

n/k: size of the grouped matrix

$\binom{n}{k} \le O\left(n^k\right)$ number of such groups

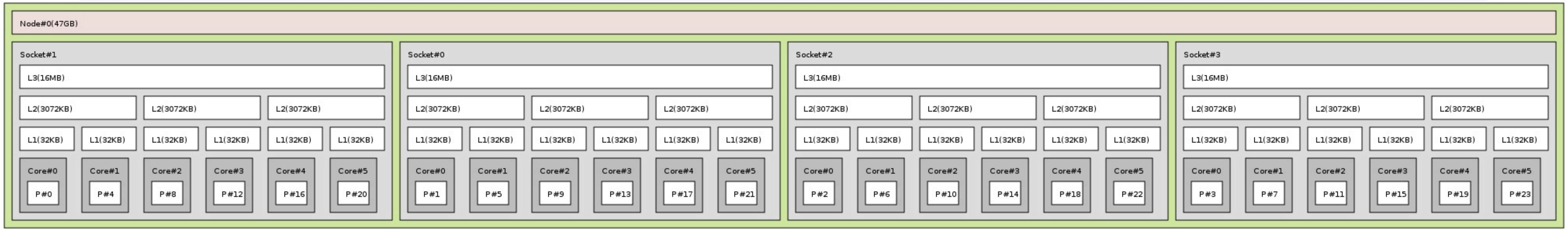
Ok if the arity of the tree is not too large.

We can manage a reasonable complexity in decomposing k in primes number: a vertex of arity 32 will be consider as a binary tree of 5 levels

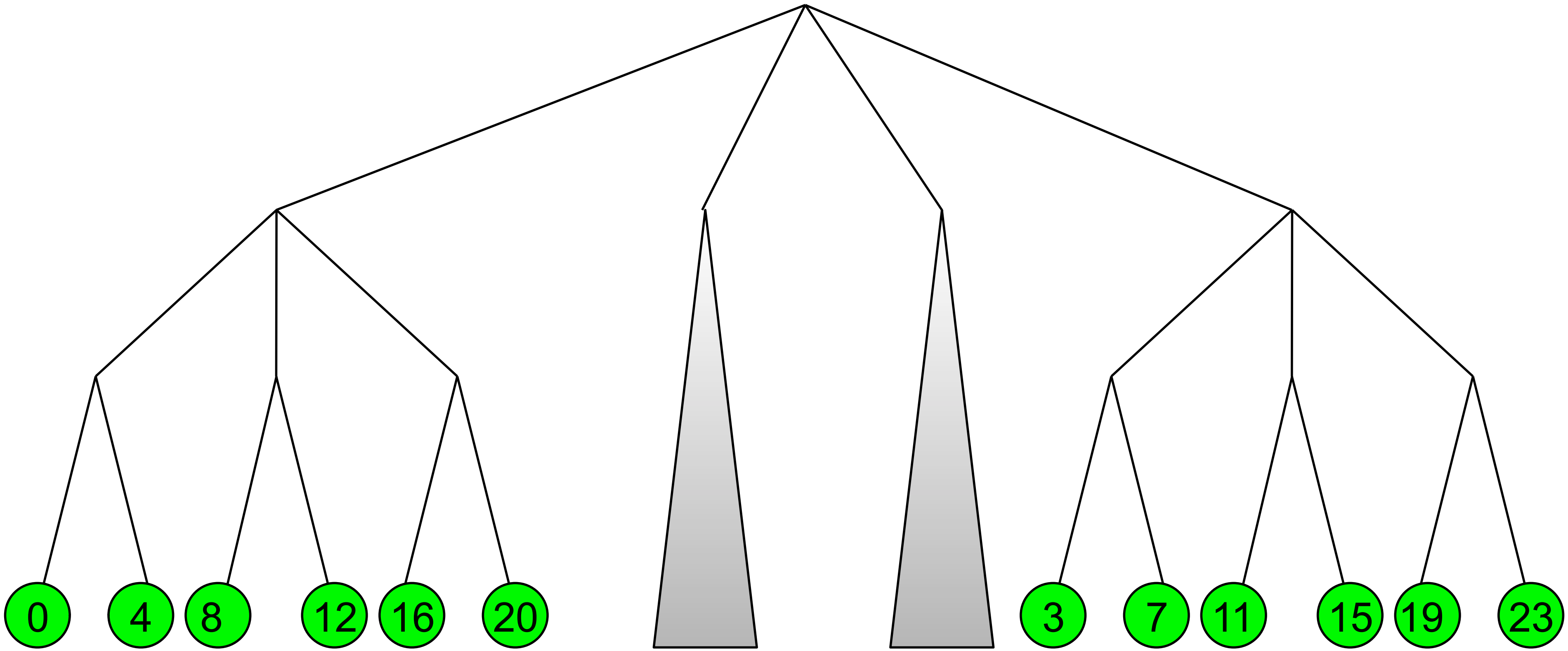
Experiments

We use the NAS benchmarks:

- All the kernels
- Class: A,B,C,D
- Size: 16, 32/36, 64
- On highly NUMA machine (4 nodes of 4 Xeon quad-core Dunnington)
- Comparison with : MPIPP [Chen et al. 2006] (two versions), Packed (by sub-tree), Round-Robin (process i to core i).

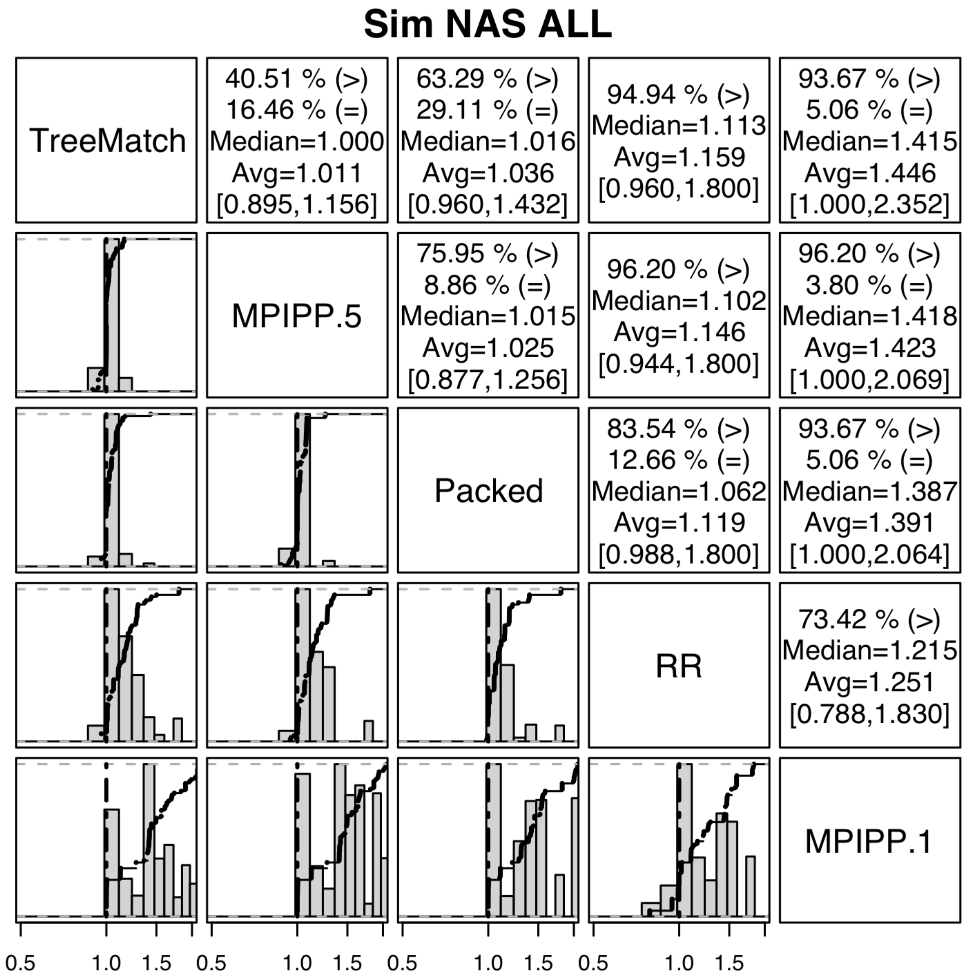


1of the 4 nodes of the target machine



Simulation Results

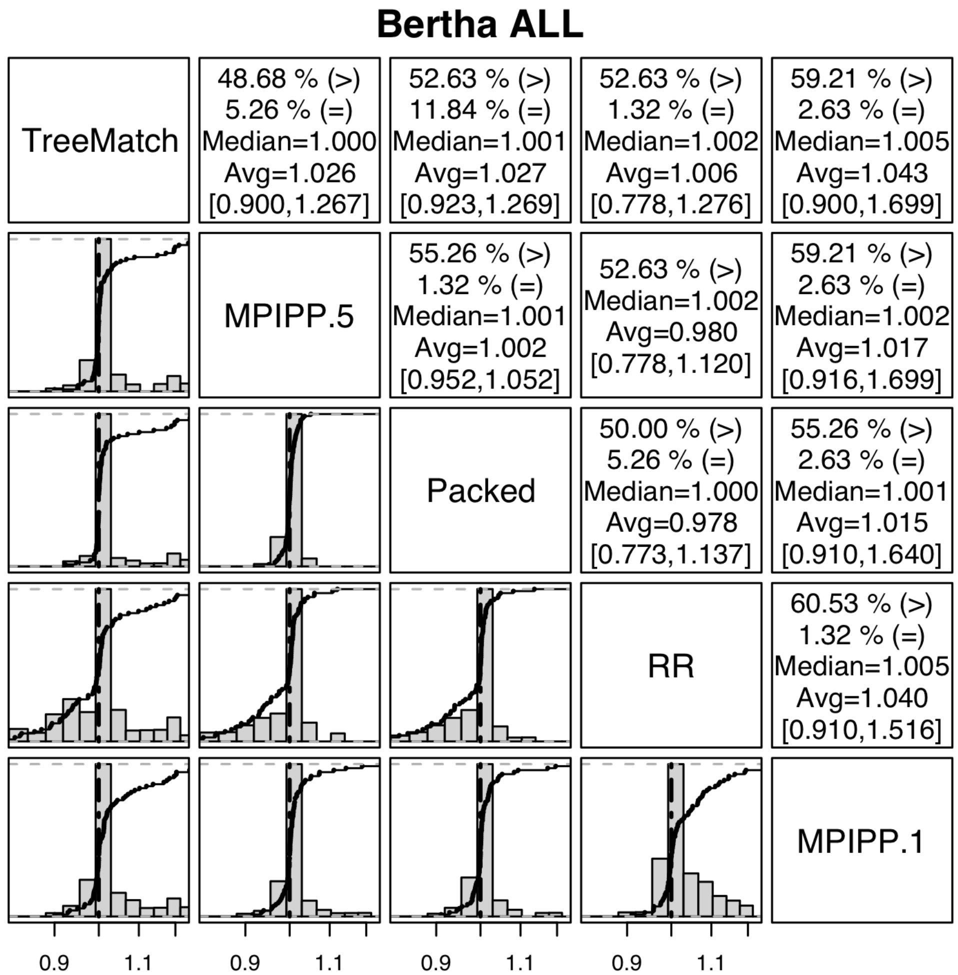
We simulate the execution time using our model



NAS on the real machine

Best strategy: TreeMatch

Some very bad results against round-robin

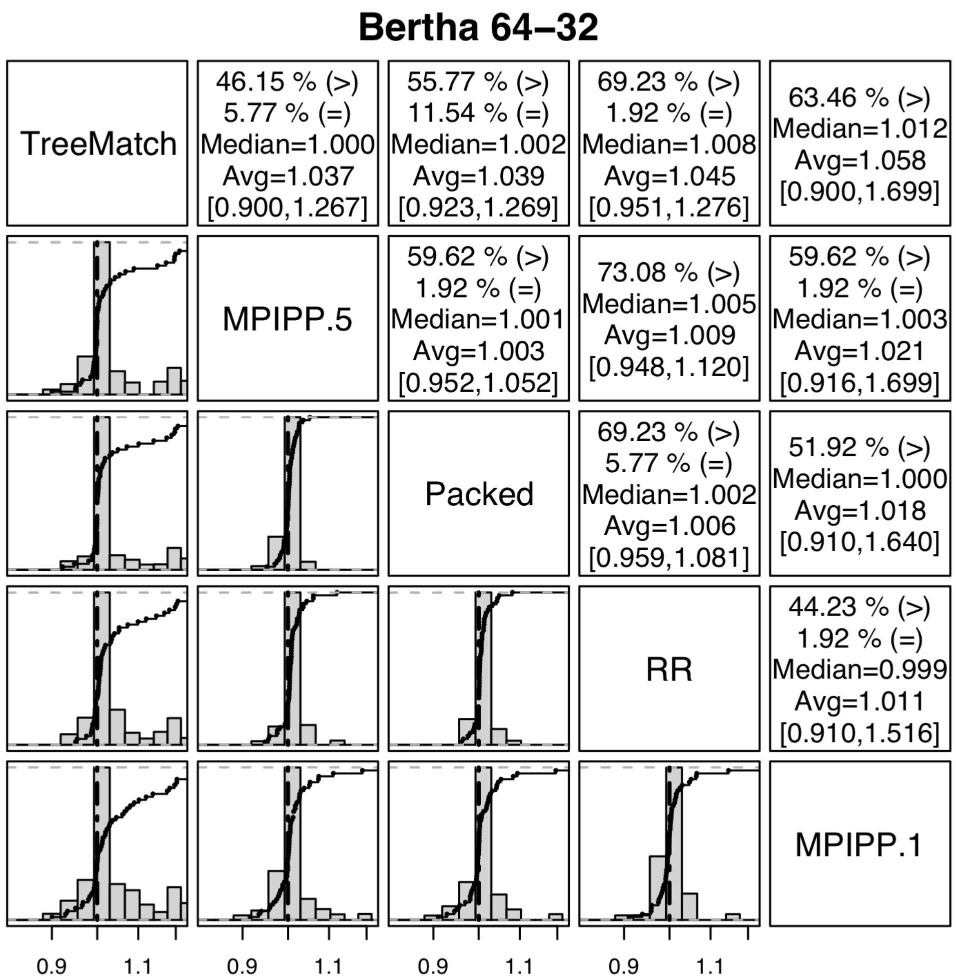


32-64 processes

Several nodes are used

Best: TreeMatch (up to 27% improvement).

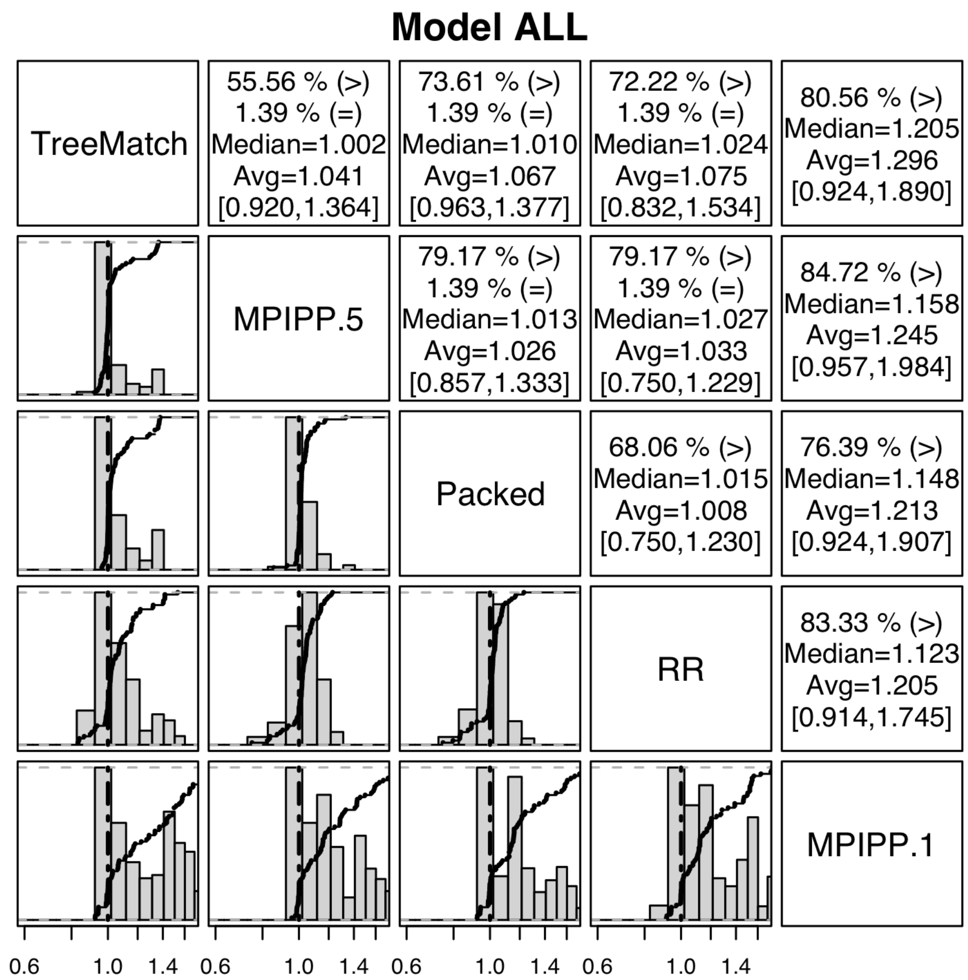
Comparable to MPIPIP.5 (but faster runtime)



Communication Only Application

We extract the communication pattern of the NAS

Up to 37% improvement



Conclusion

Mapping processes can help to reduce the communication cost

TreeMatch: an algorithm to perform such mapping

- Bottom-up
- Fast
- Does not require that the number process equals the number of cores /processors
- Optimal in some cases

Early results:

- TreeMatch: best method on average
- Works well when more than one node is used
- Difference between model and reality

Future work

On going work

Future work:

- Test real applications
- Top Down?
- Improve model (NUMA effect)
- Hybrid case
- Dymamic adaptation
- Automation
- Process topology interface of MPI 2.2 (With J. L. Träff).