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How to scale Nested OpenMP Applications on the ScaleMP vSMP Architecture

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Agenda

- **ScaleMP Overview**
- **Kernel Benchmarks**
  - Page Access Benchmark
  - STREAM
  - SMXV
  - Memory Allocation Tests
  - EPCC Microbenchmarks
- **Real World Applications**
  - Flexible Image Retrieval Engine (FIRE)
  - Simulator for Heat and Mass Transport (SHEMAT-Suite)
- **Conclusions**

ScaleMP Overview

1. ScaleMP

1. 13 board connected via Infiniband
2. each 2 x Intel Xeon E5420 @ 2,5 GHz
3. cache coherency by virtualization software (vSMP)
4. 13 x 16 = 208 GB RAM

   ~38 GB reserved for vSMP = 170 GB available

2. Tigerton (Fujitsu-Siemens RX600): (reference system)

1. 4 x Intel Xeon X7350 @ 2,93 GHz
2. 1 x 64 GB RAM

Page Access Benchmark

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Benchmarks to measure page access time:

1. **read a remote page**
2. **write a remote page**
3. **write a local page**

	ScaleMP	Tigerton
read_from_other	43,37	2,97
write_from_other	40,44	2,13
write_self	2,34	1,64

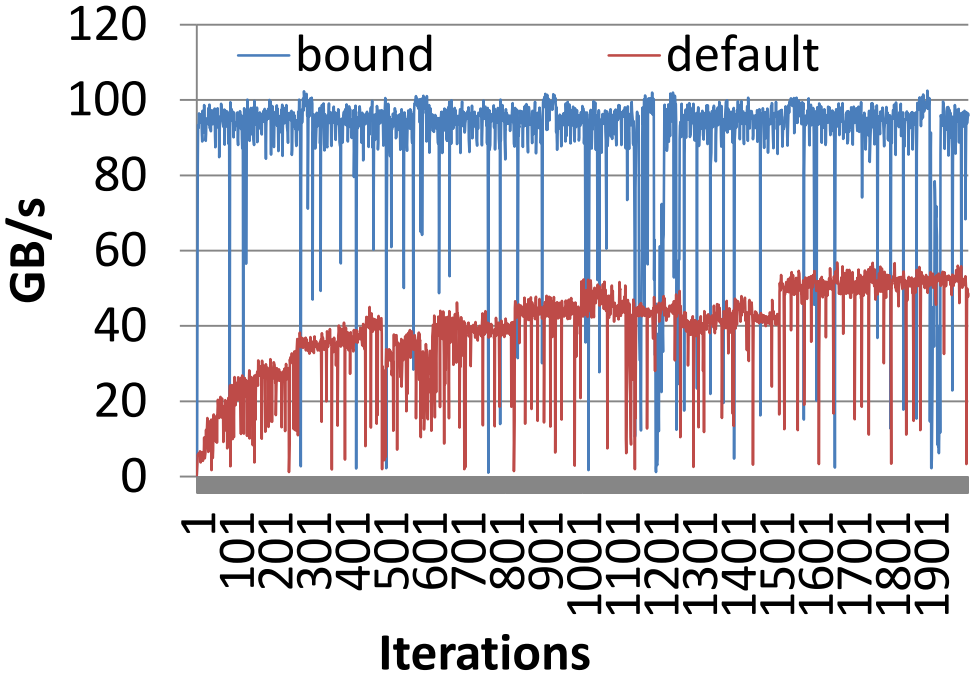
results in microseconds

- **remote accesses 15 - 20 X more expensive on ScaleMP**
- **local accesses not affected by vSMP Software**

STREAM - Triad

default:

- memory bandwidth not constant over time
- threads are slowly migrated to other boards
- reached maximum ~45 GB/s



apply fix thread placement

bound:

- reached bandwidth ~95 GB/s
- maximum reached from beginning

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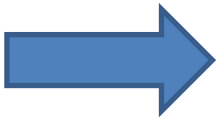

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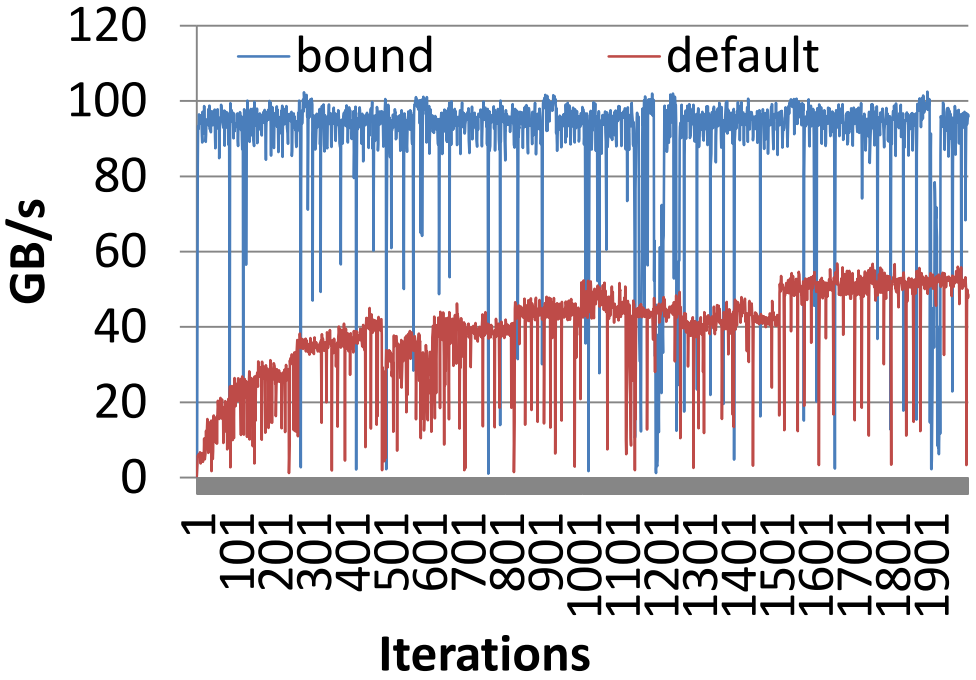
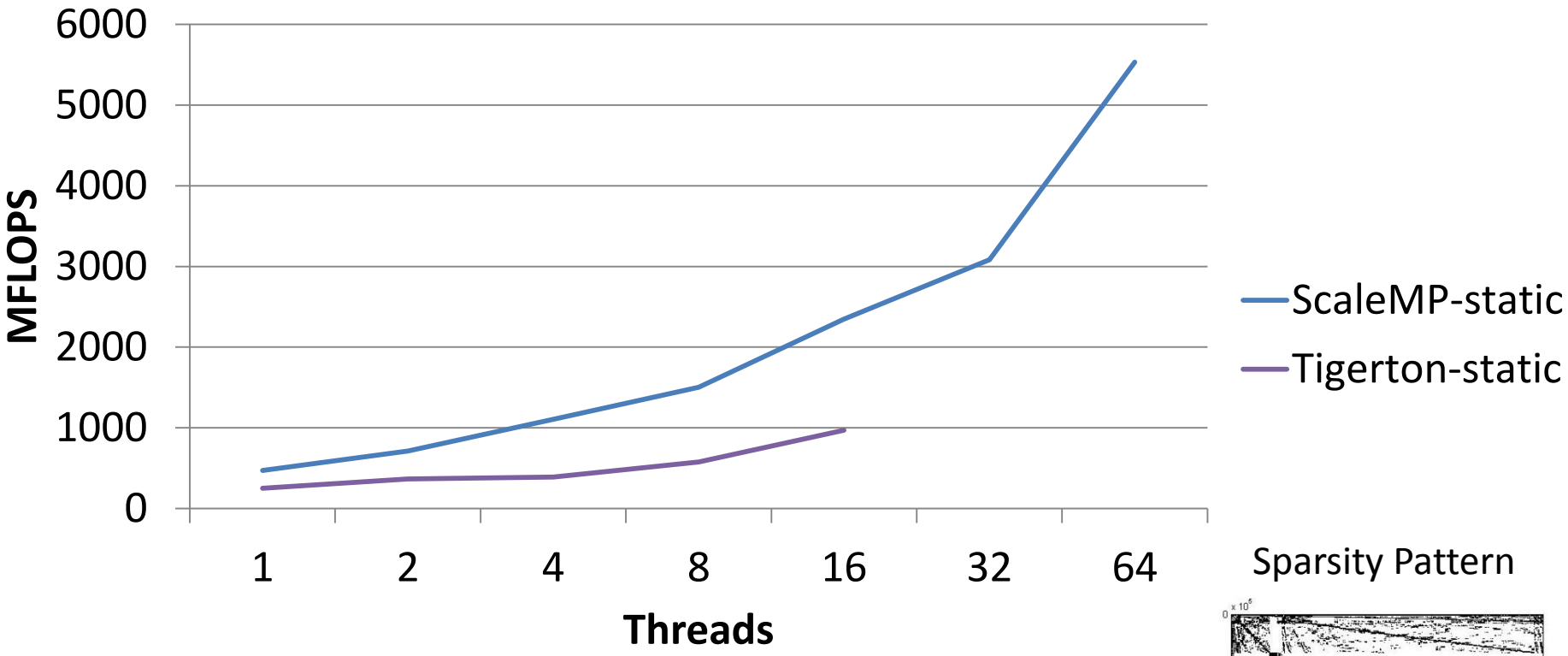


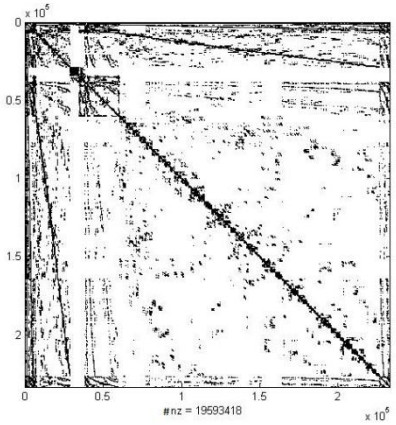
Conclusion:

- high bandwidth possible for aligned memory accesses
- thread placement is important on ScaleMP

SMXV



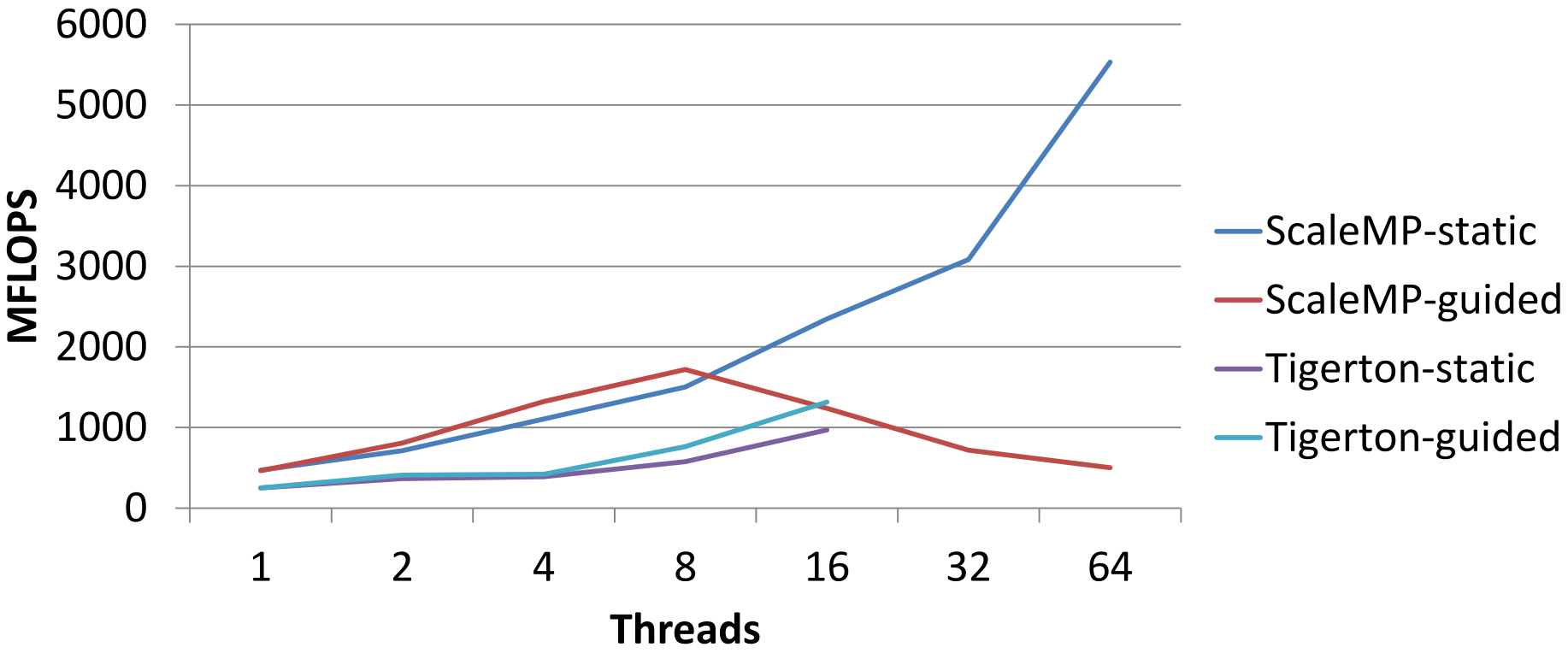
Sparsity Pattern



static schedule:

- **high performance compared to SMP system**
- **load imbalance not addressed**

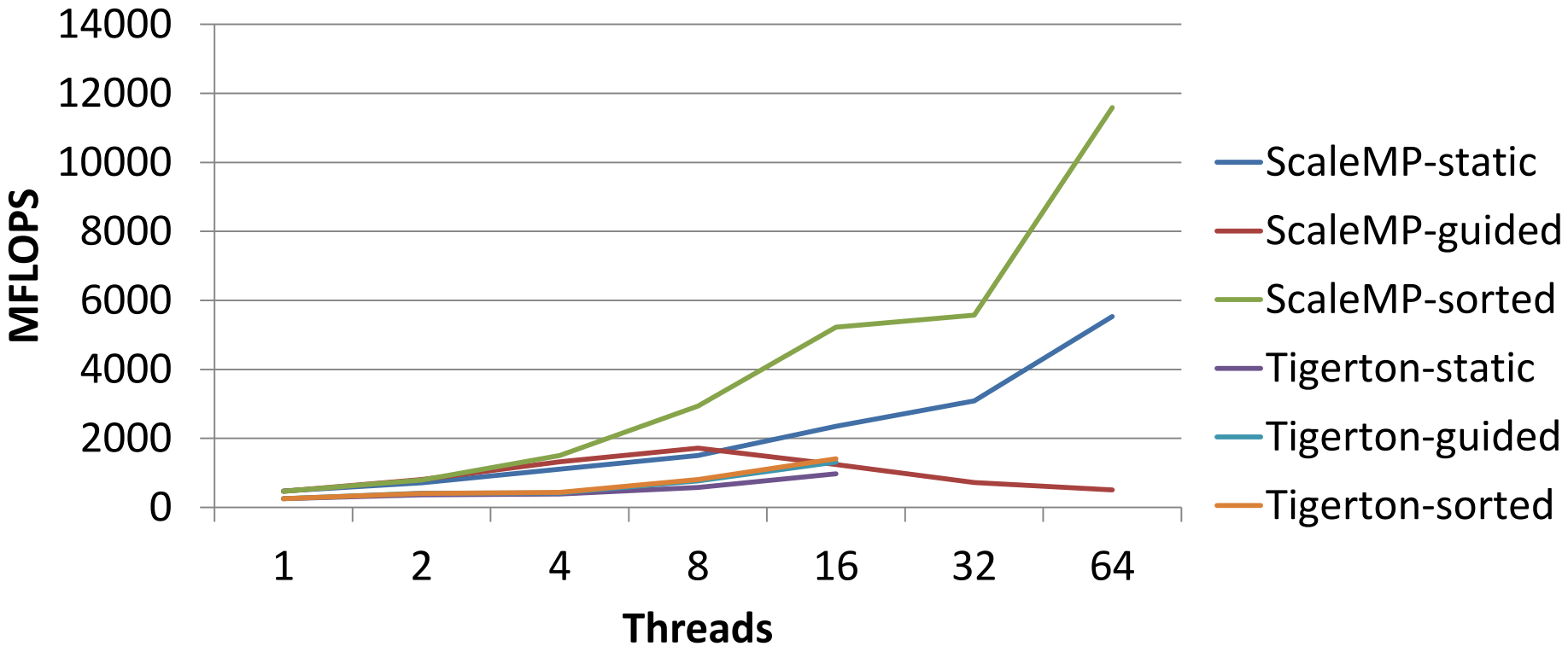
SMXV



guided schedule:

- **performance improvement on the SMP system**
- **bad performance on ScaleMP**
- **guided schedule introduces high number of remote accesses**

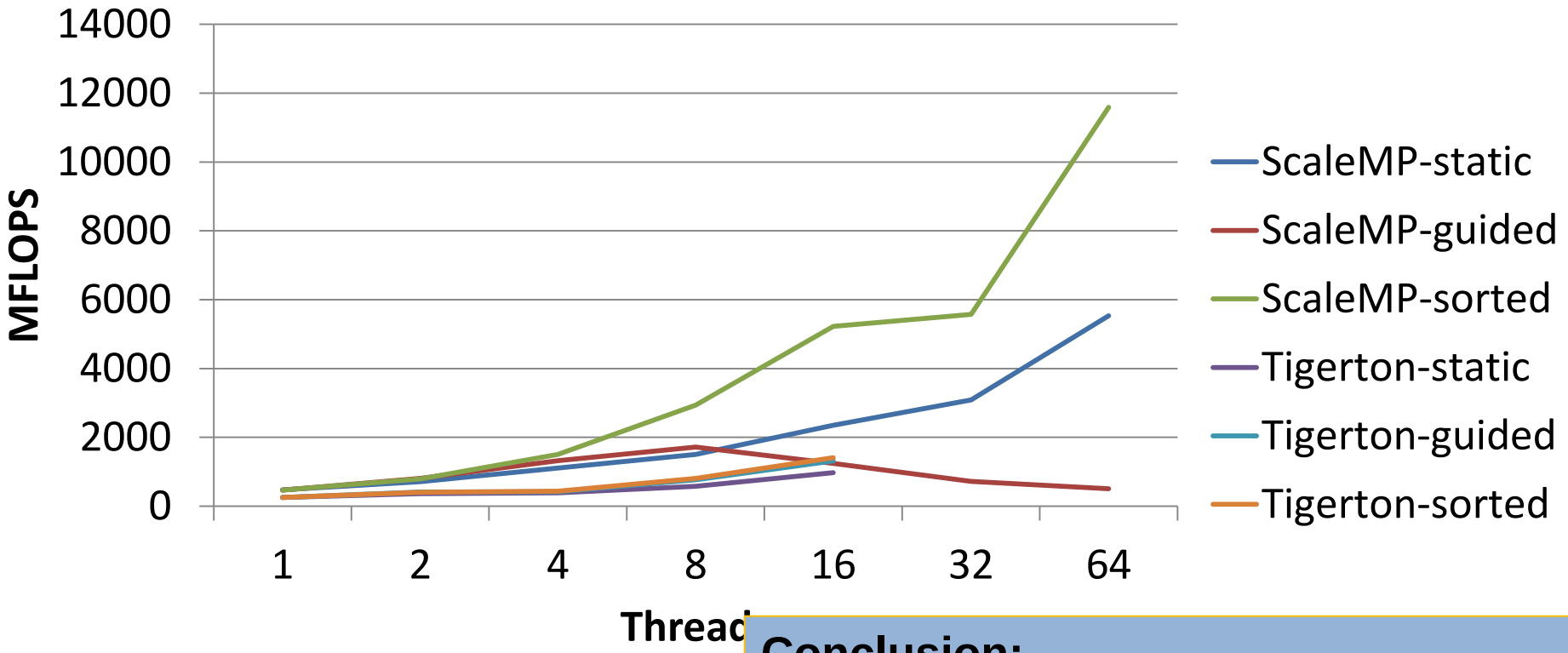
SMXV



sorted schedule:

- **nearly no changes on the SMP**
- **good performance on ScaleMP +10X**

SMXV



sorted schedule:

- **nearly no changes on the SMP**
- **good performance on ScaleMP**

Conclusion:

- **high bandwidth also for sparse matrixes possible**
- **dynamic access patterns are a problem**
- **precomputed pattern needed**

Memory Allocation Test

- time (in sec.) to allocate and initialize a 15 GB array in parallel

	default pages	huge pages
Tigerton		
1 Thread	34,79	27,01
8 Threads	16,6	20,34
16 Threads	26,9	15,87
ScaleMP		
1 Thread	211,13	196,29
8 Threads	423,4	187,45
16 Threads	449,01	179,25
104 Threads	432,47	121,76

Default Pages (4 KB):

- allocation takes much longer on ScaleMP
- more Threads introduce larger overhead

Huge Pages (2 MB):

- nearly no benefit for one thread on ScaleMP
- scales better, but still not very well

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Huge Pages (2 MB):

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Conclusion:

- **memory allocation takes longer on ScaleMP**
- **codes with a lot of allocation and deallocation of memory will most likely run bad on these systems**

EPCC Microbenchmarks

ScaleMP	parallel	for	reduction
2 Threads on 1 boards	1,89	0,62	2,07
2 Threads on 2 boards	297,06	279,91	362,76
16 Threads on 2 boards	768,28	571,10	923,30
104 Threads on 13 boards	1453,30	1198,02	3185,69
Tigerton			
2 Threads	2,14	0,89	2,32
8 Threads	4,10	1,58	4,40
16 Threads	6,76	2,25	7,41

overhead in microseconds

- **~100 – 200 X more synchronization time when multiple boards are used**

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overhead in microseconds

- **~100 – 200 X more synchronization time when multiple boards are used**

Conclusion:

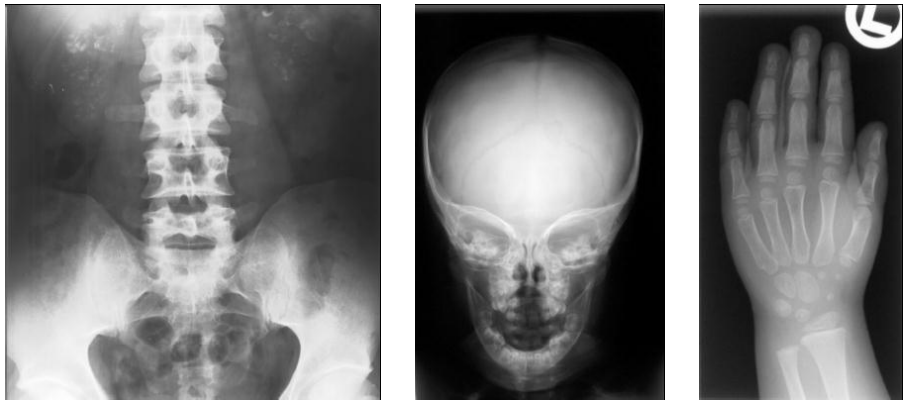
- **use as few synchronizations as possible**
- **if synchronizations are your performance bottleneck, then your code will most likely not run well on ScaleMP**

Flexible Image Retrieval Engine (FIRE)

FIRE = Flexible Image Retrieval Engine

- **Compare the performance of common features on different databases**
- **Analysis of correlation of different features**

Thomas Deselaers and Daniel Keysers,
RWTH I6: Chair for Human Language Technology and Pattern Recognition



Flexible Image Retrieval Engine (FIRE)

$$D(Q, X) := \sum_{m=1}^{M} w_m \cdot d_m(Q_m, X_m)$$

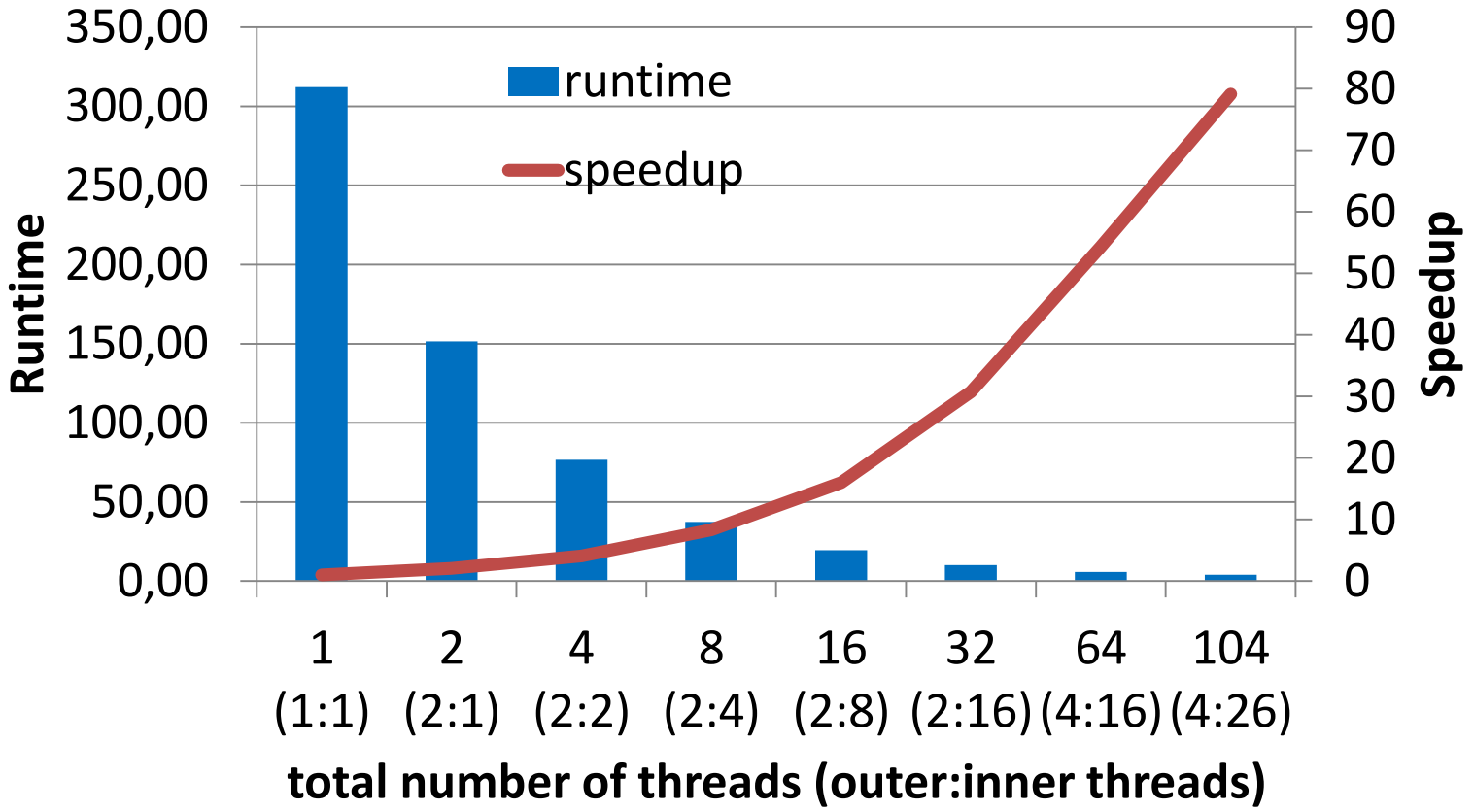
- Q: query image, X: set of database images
- Qm, Xm: m-th feature of Q and X
- dm: distance measure, wm: weighting coefficient
- Return the k images with lowest distance to query image

- Well-suited for Shared-Memory parallelization:
  Data Mining in a large image database!

- Two levels of parallelism:
  - Process multiple query images in parallel
  - Process database comparison for one query image in parallel

Flexible Image Retrieval Engine (FIRE)

- |Q| = 18
- |X| = 1000



- speedup of ~80 on 104 Cores
- small load imbalance due to small number of query Images

Simulator for Heat and Mass Transport (SHEMAT-Suite)

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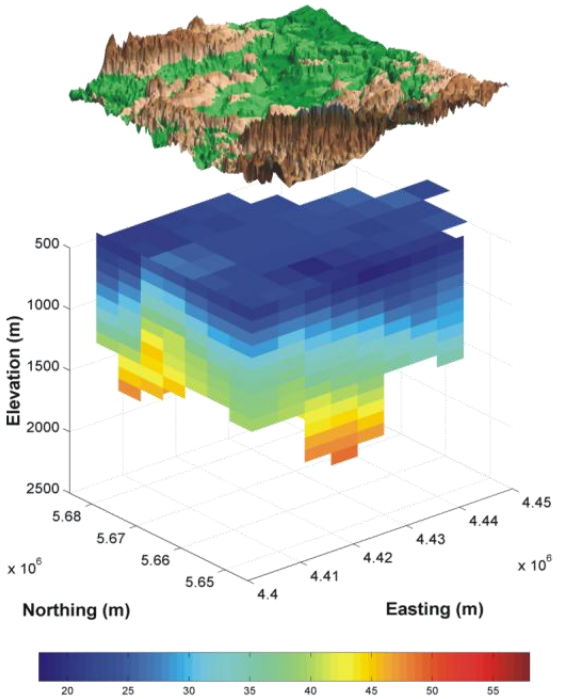
Geothermal Simulation Package to simulate groundwater flow, heat transport, and the transport of reactive solutes in porous media at high temperatures (3D)

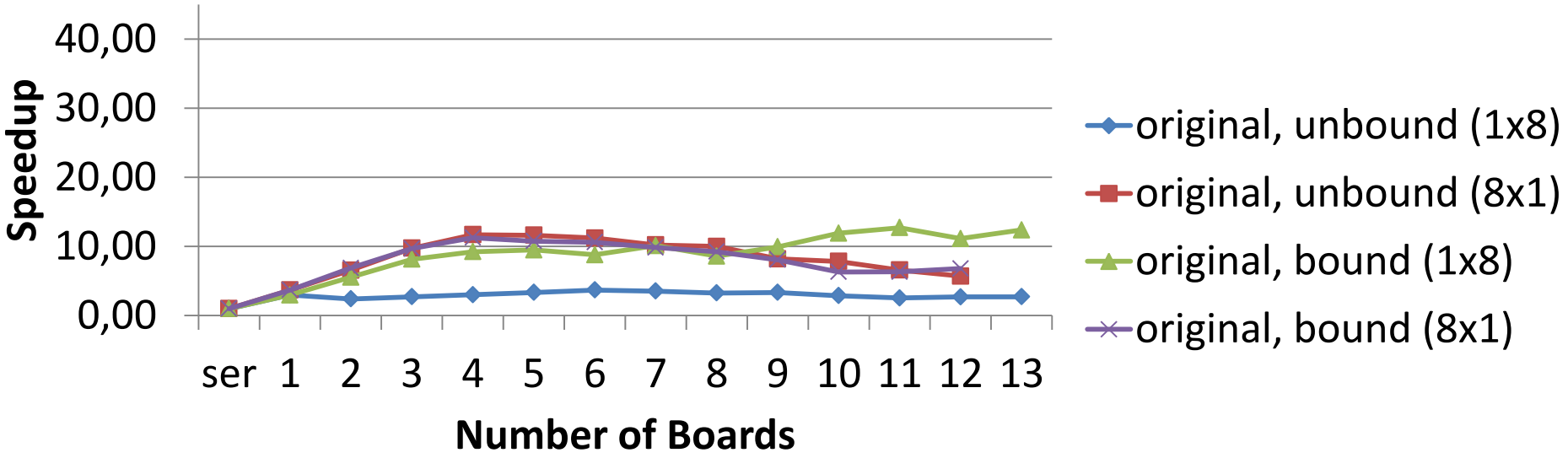


Applied Geophysics and Geothermal Energy, E.ON Energy Research Center

Written in Fortran, two levels of parallelism:

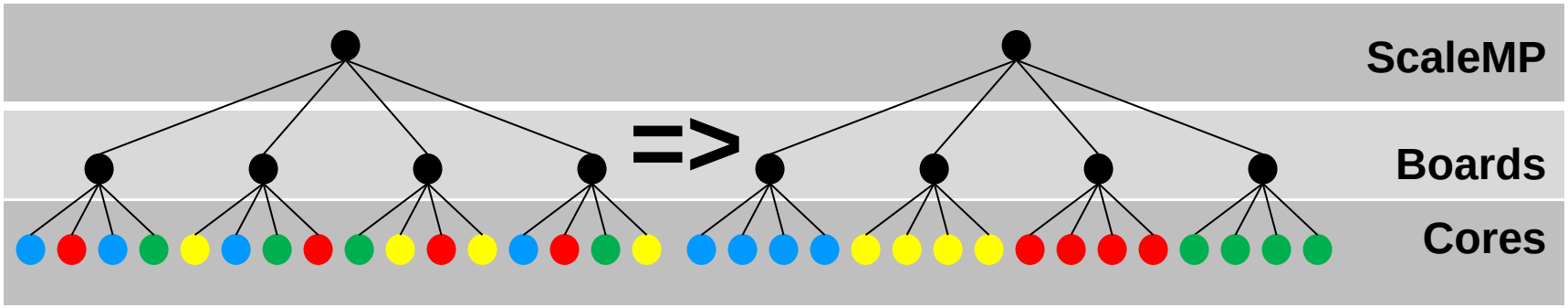
- **Independent Computations of the Directional Derivatives using AD**
- **Setup and Solving of linear equation systems**

Simulator for Heat and Mass Transport (SHEMAT-Suite)



- **Binding nested OpenMP programs was a problem, since there is no way to specify the mapping of inner teams to cores**

=> implement manual thread binding



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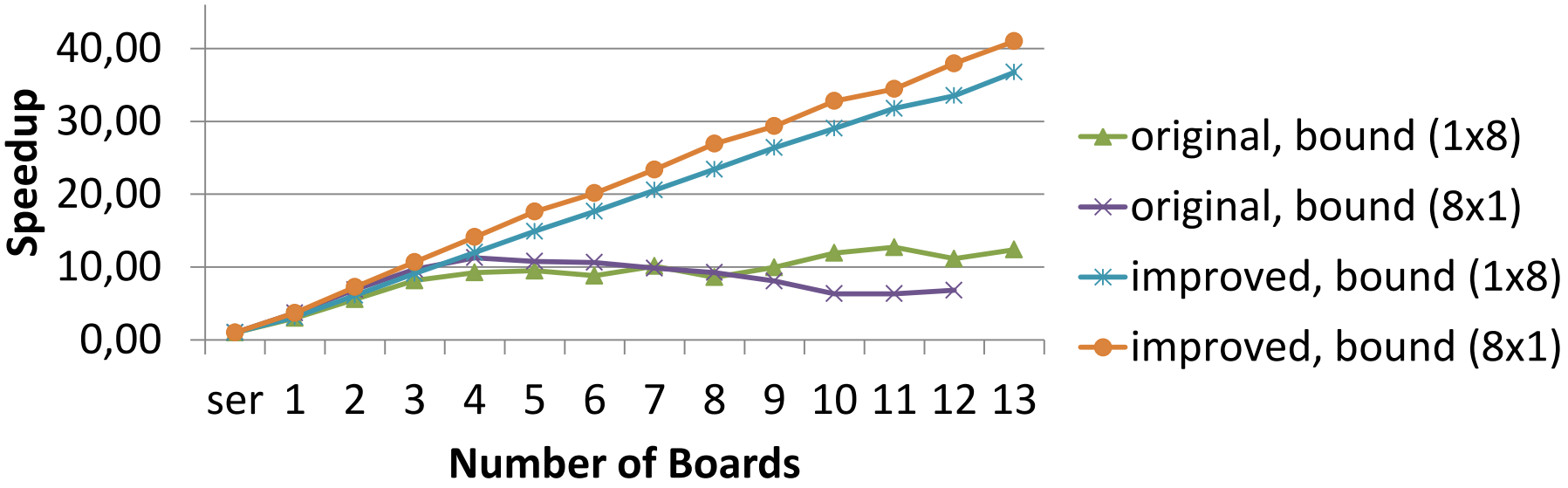


- creation of private arrays turned out to be the performance bottleneck

=> changed data management to use slices of a larger global array

Estimated speedup

number of directional derivatives, 104 Cores used:

First Phase:

8 Threads working per board

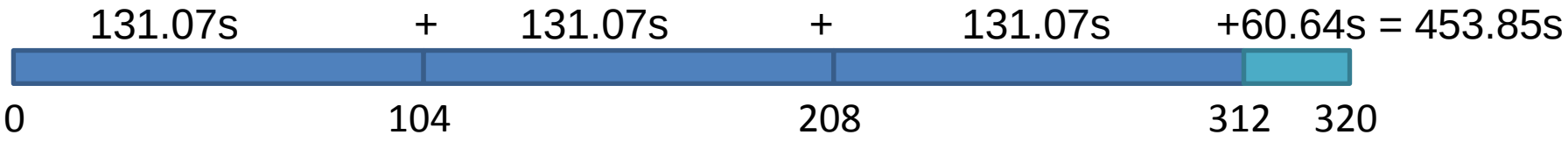
Best result for 8x1 on one board is 5242.67s ≙ 131.07 s/8 derivatives

Second Phase:

1 Threads working per board

Best result for 1x1 on one board is 19404.3s ≙ 60.64 s/derivative

Estimated speedup:



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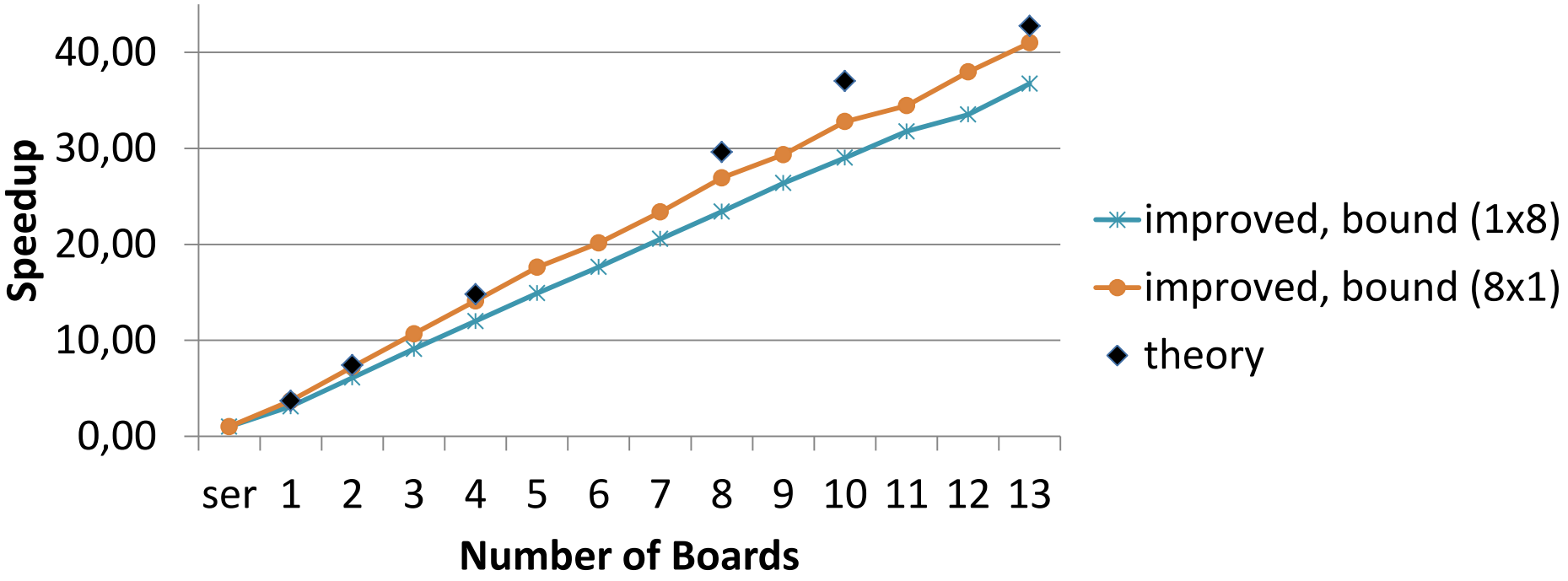
Speedup ≙ 42.76

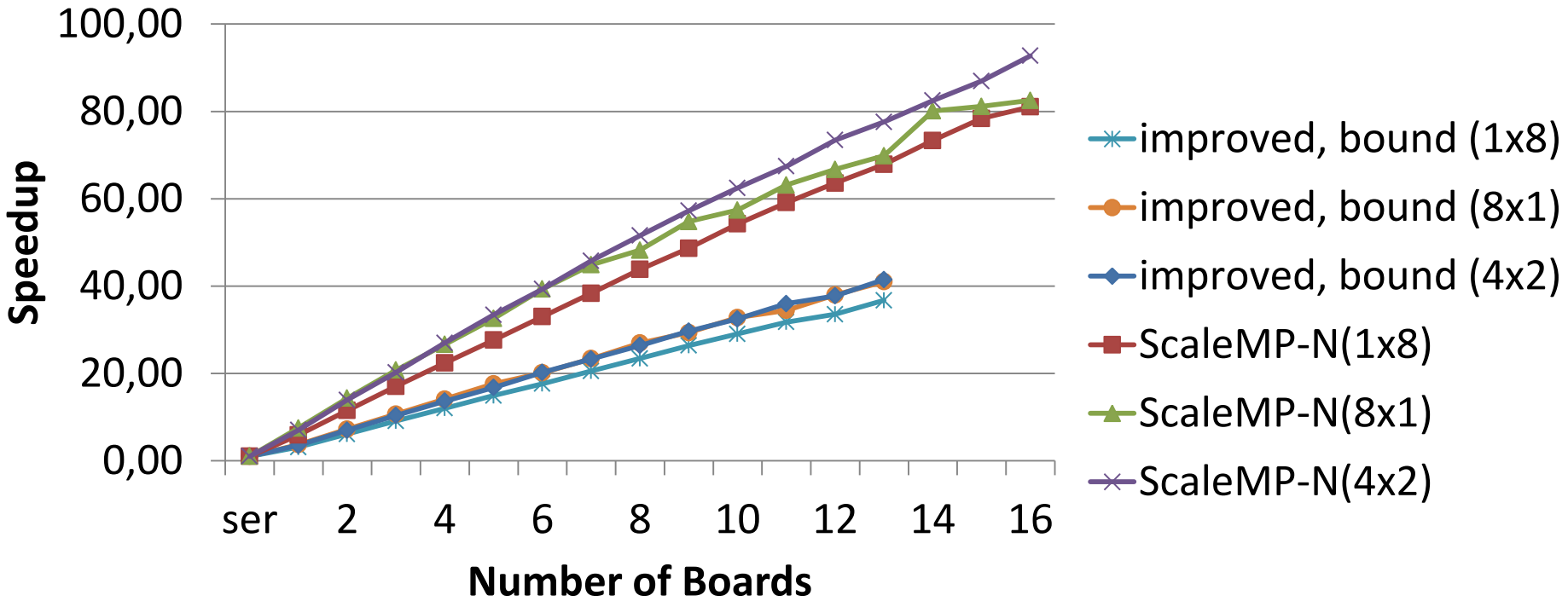
Simulator for Heat and Mass Transport (SHEMAT-Suite)



Best Speedup: 41.48

Estimated theoretical Speedup: 42.76

Simulator for Heat and Mass Transport (SHEMAT-Suite)



ScaleMP-N:

1. 16 boards each 2 x Intel Xeon E5550 @ 2,67 GHz (Nehalem)
2. 320 GB RAM - ~32 GB reserved for vSMP = 288 GB available

Summary

- high remote memory access (20X) and synchronization (150X) time
- high memory bandwidth for dense (~95 GB/s) and sparse matrices (10X)

⇒ distinct cc-NUMA behavior

- FIRE achieved speedup of ~80
- SHEMAT-Suite achieved speedup of 41.5 (theoretical maximum 42.7)

⇒ Real user applications can profit from the ScaleMP architecture.

Conclusion

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Provided that your application …

- **… takes care about thread placement…**
- **… takes care about data placement…**
- **… avoids too many synchronizations…**
- **… reduces the number of memory allocations …**

… than the ScaleMP architecture can deliver a very good performance and a large amount of shared memory at a low price point.

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Thank you for

your attention!

Questions?