Thread and Memory Placement on NUMA Systems: Asymmetry Matters

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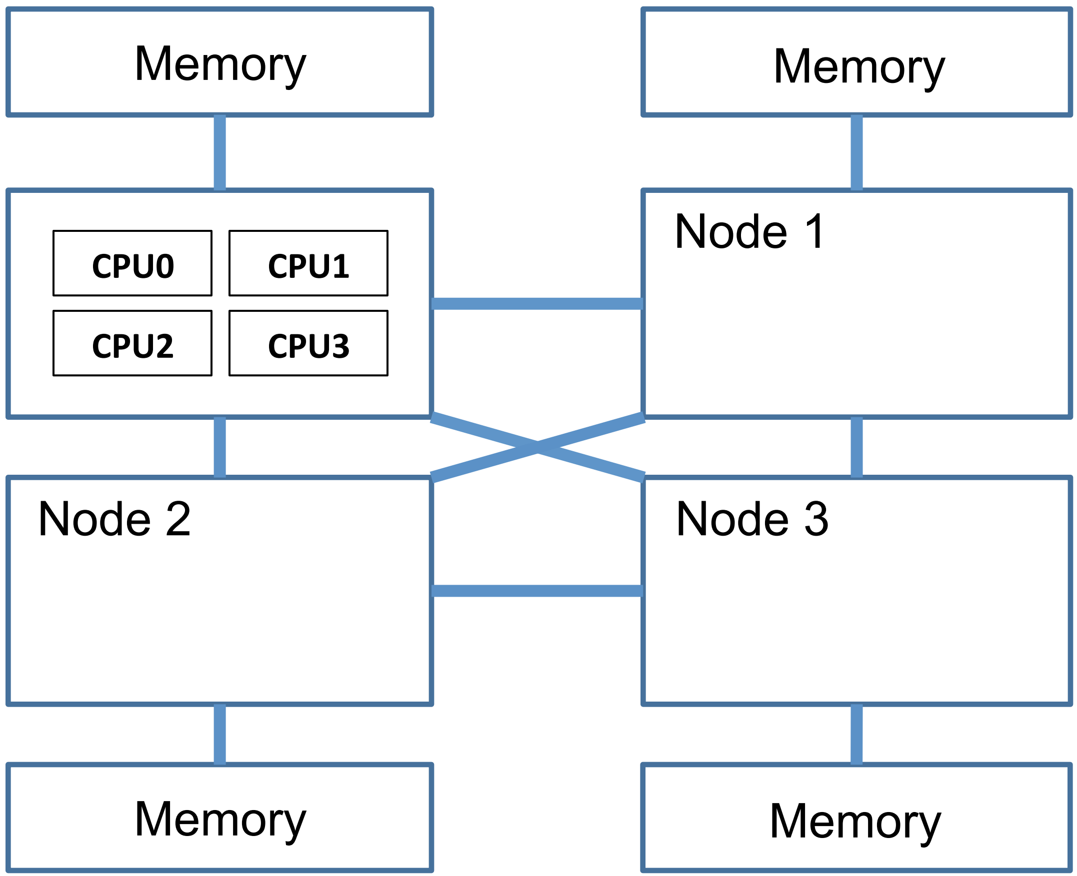
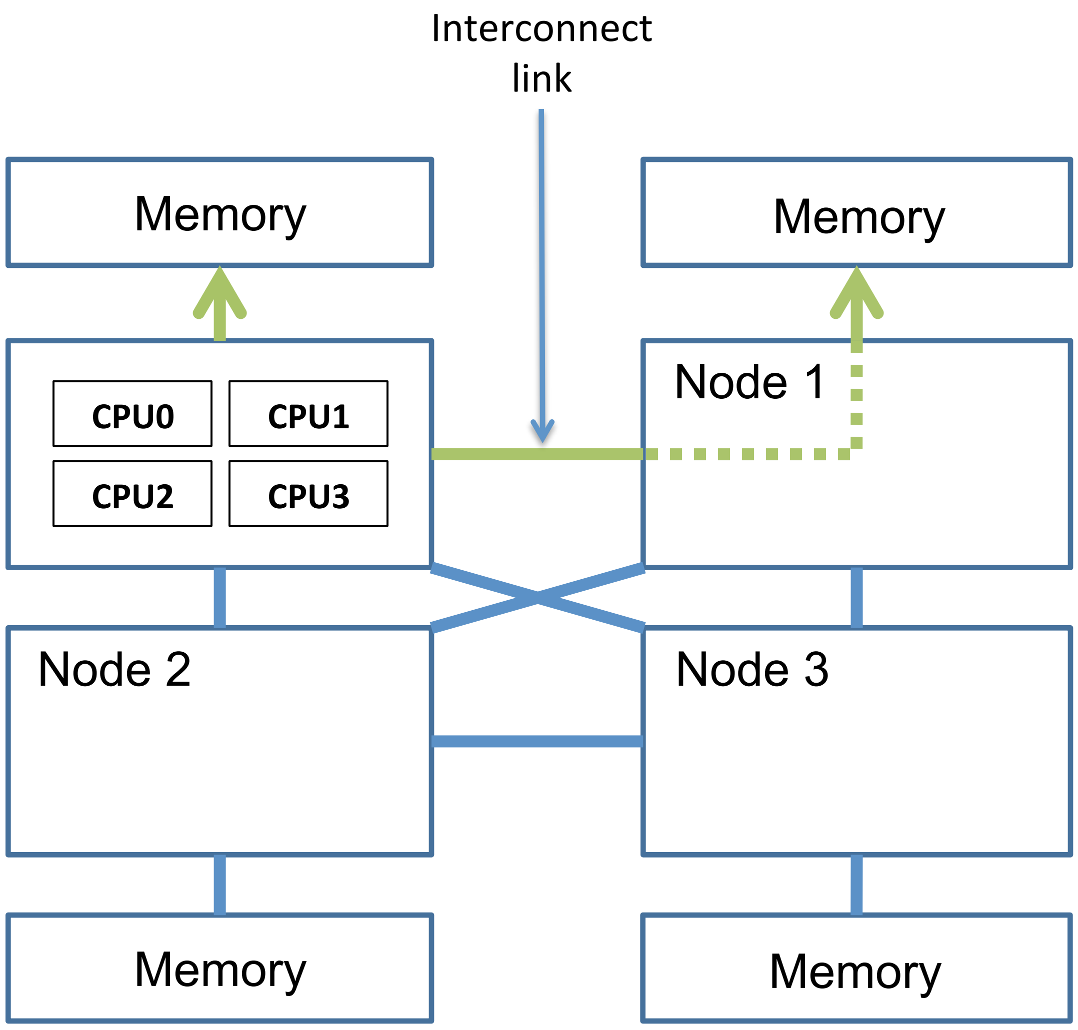
Machines are NUMA



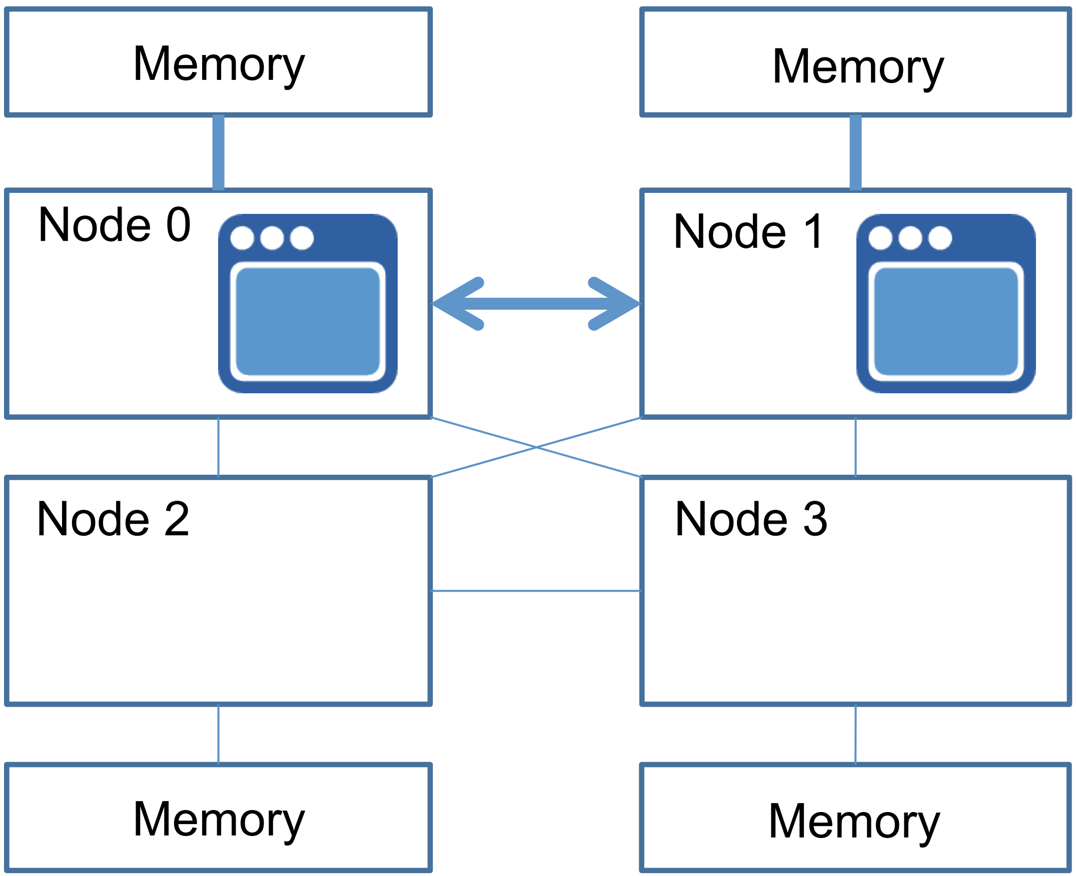
Machines are NUMA



This talk

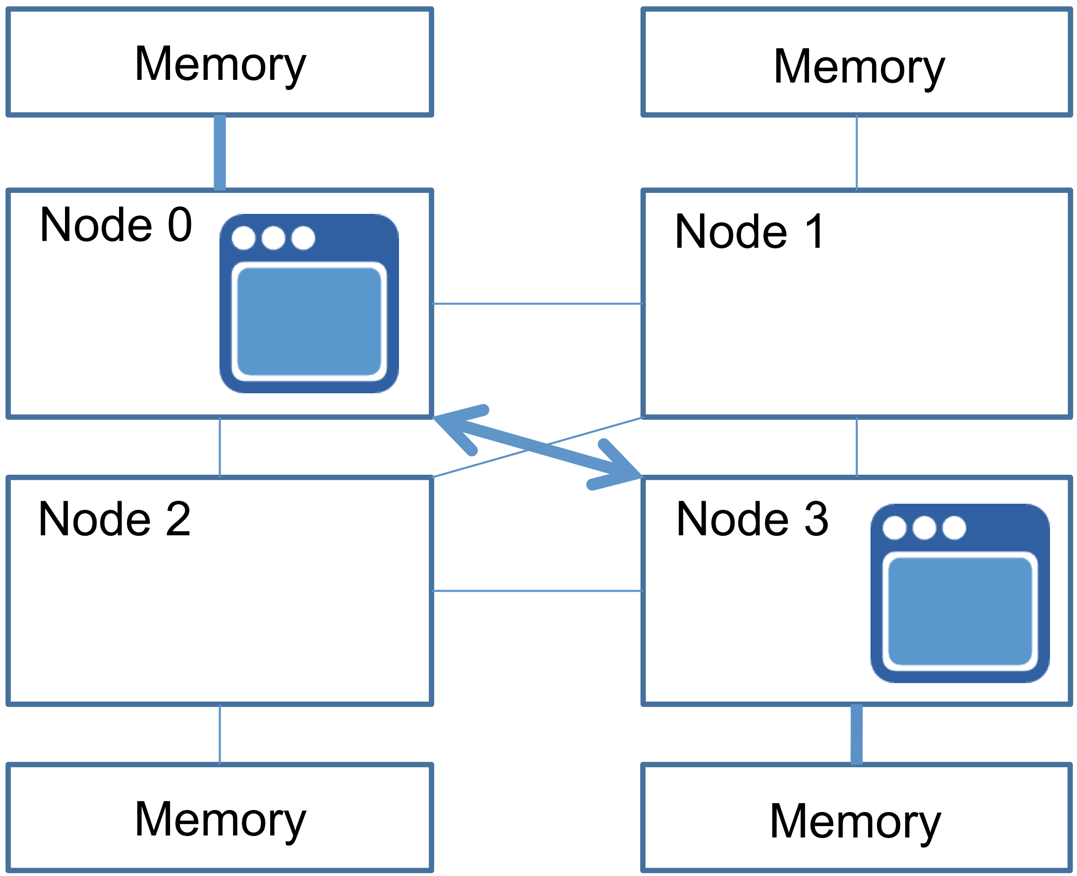
Interconnects.

Let's execute an application...



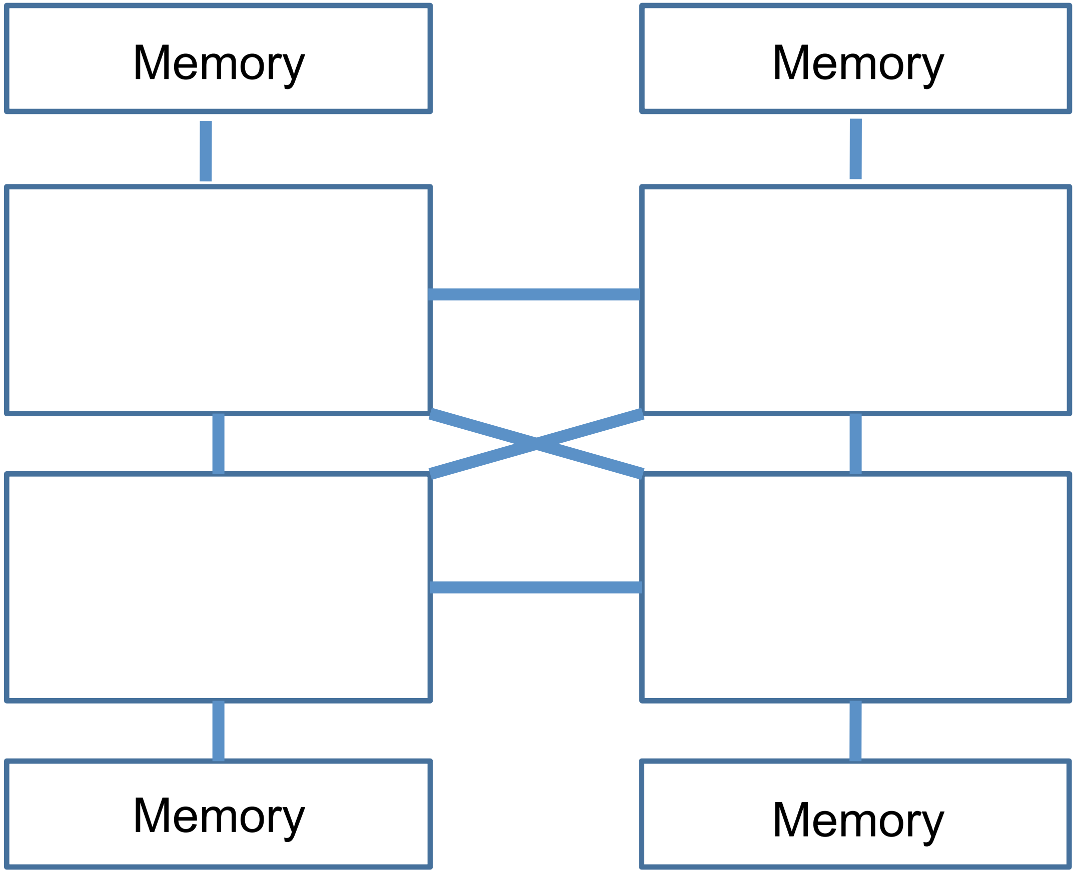
Execution time:
149s

Let's execute the same application again...

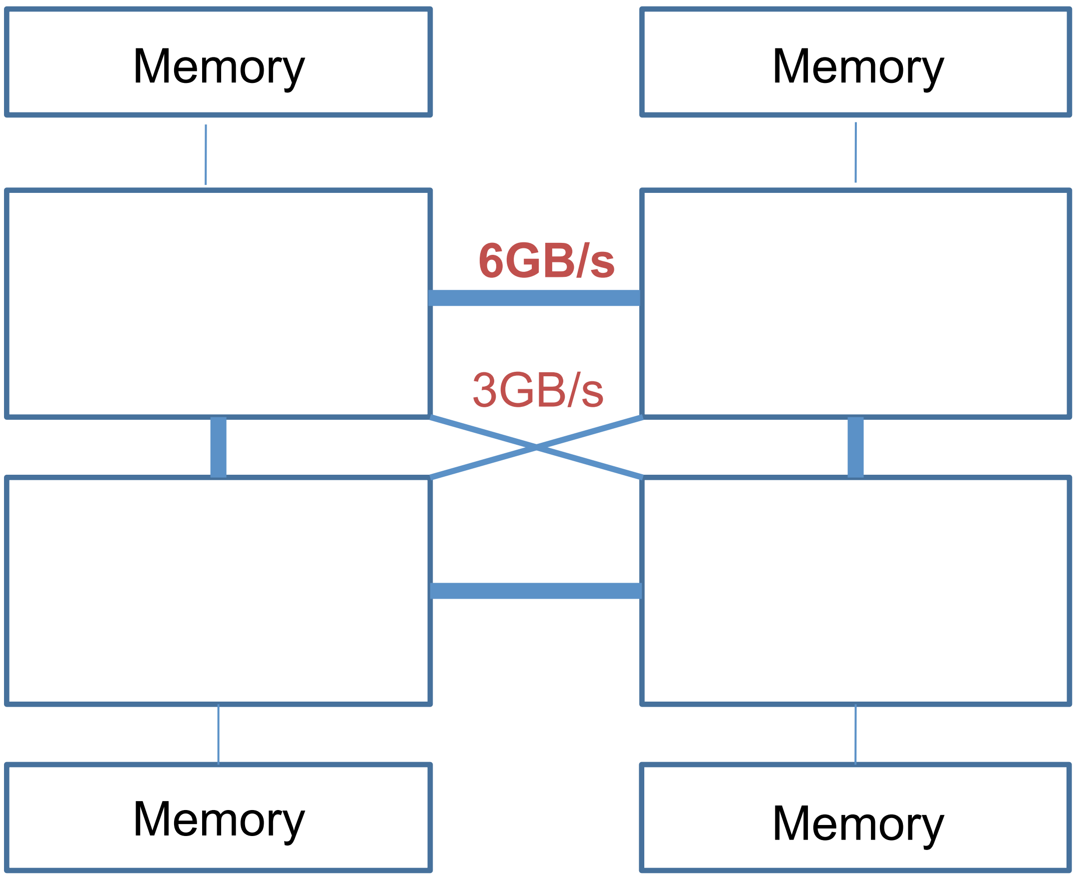


Execution time:
277s!

Why?!



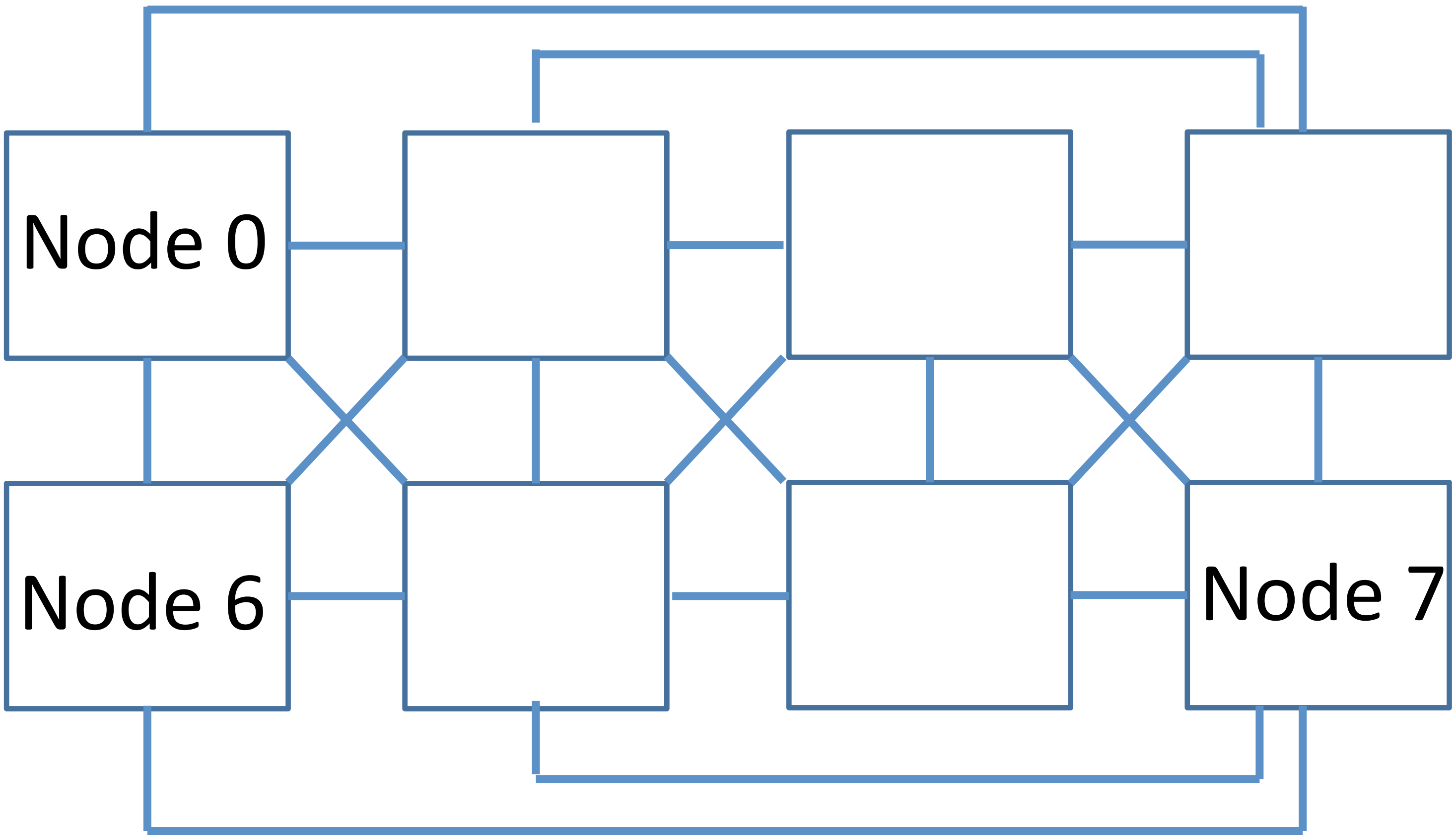
Interconnects have different bandwidths



Some interconnects are fast, some are slow!

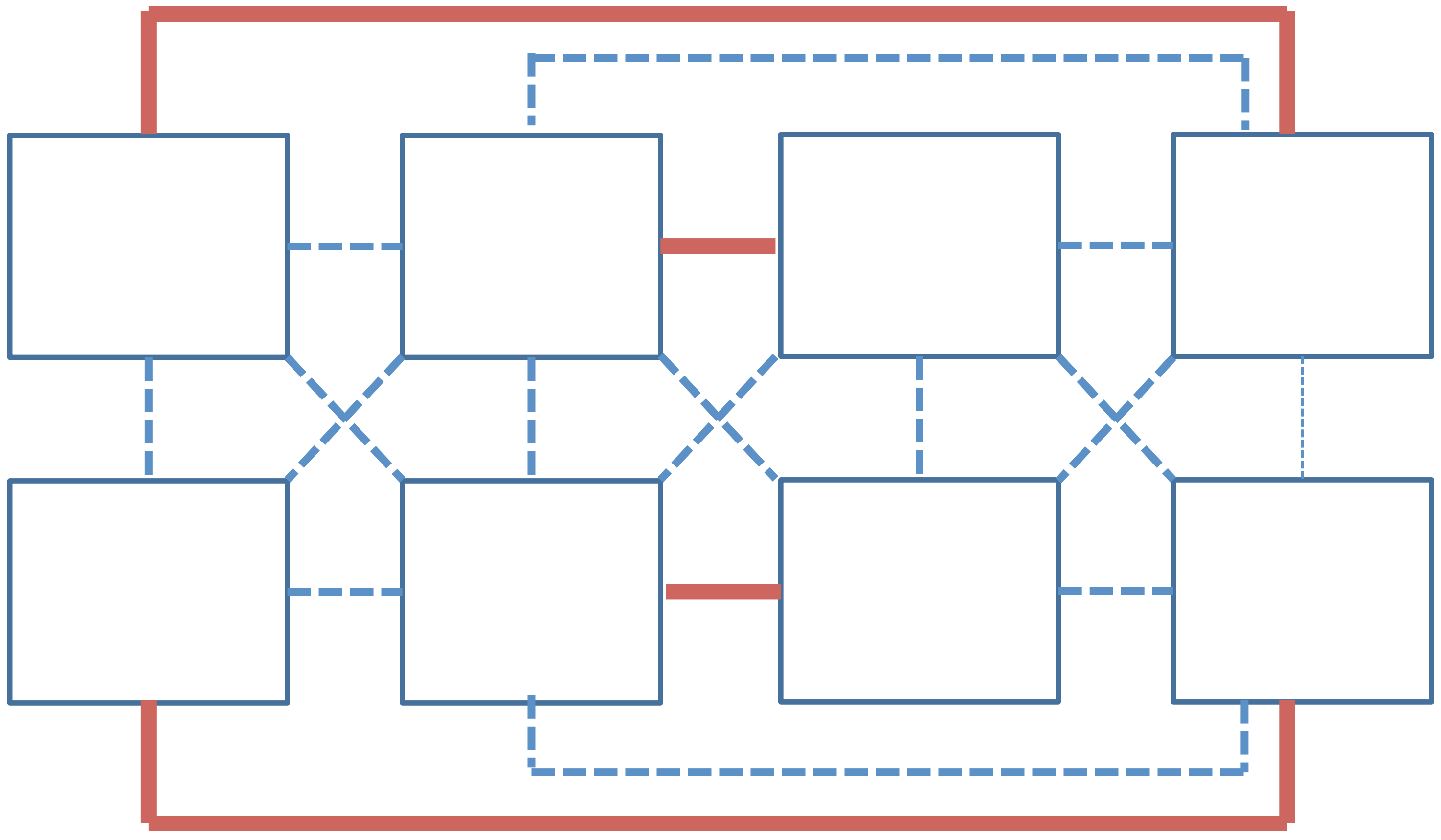
Modern machines are even more complex

Partial interconnect

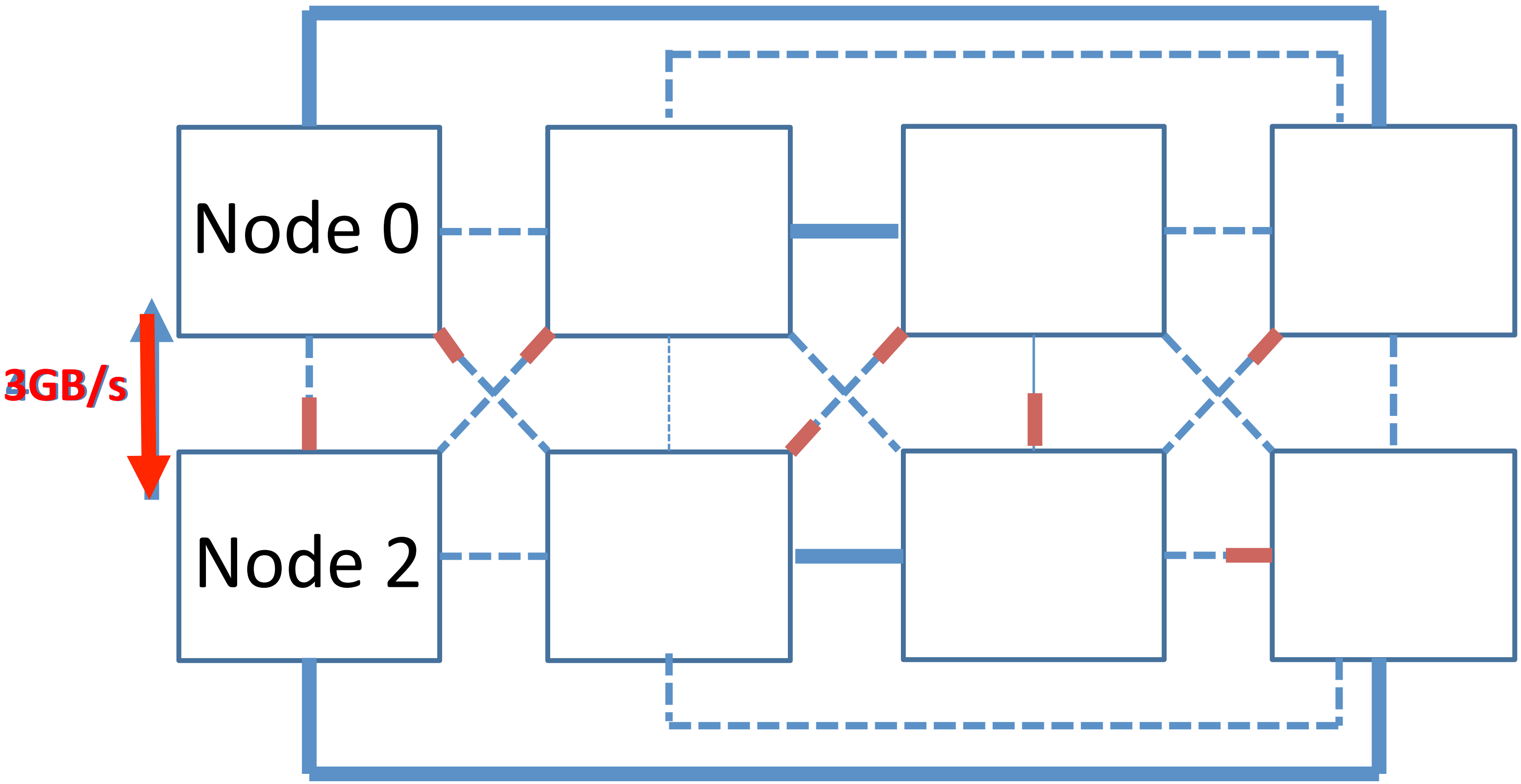


No direct link between node 0 and 7, 0 will do “2-hops” to access 7

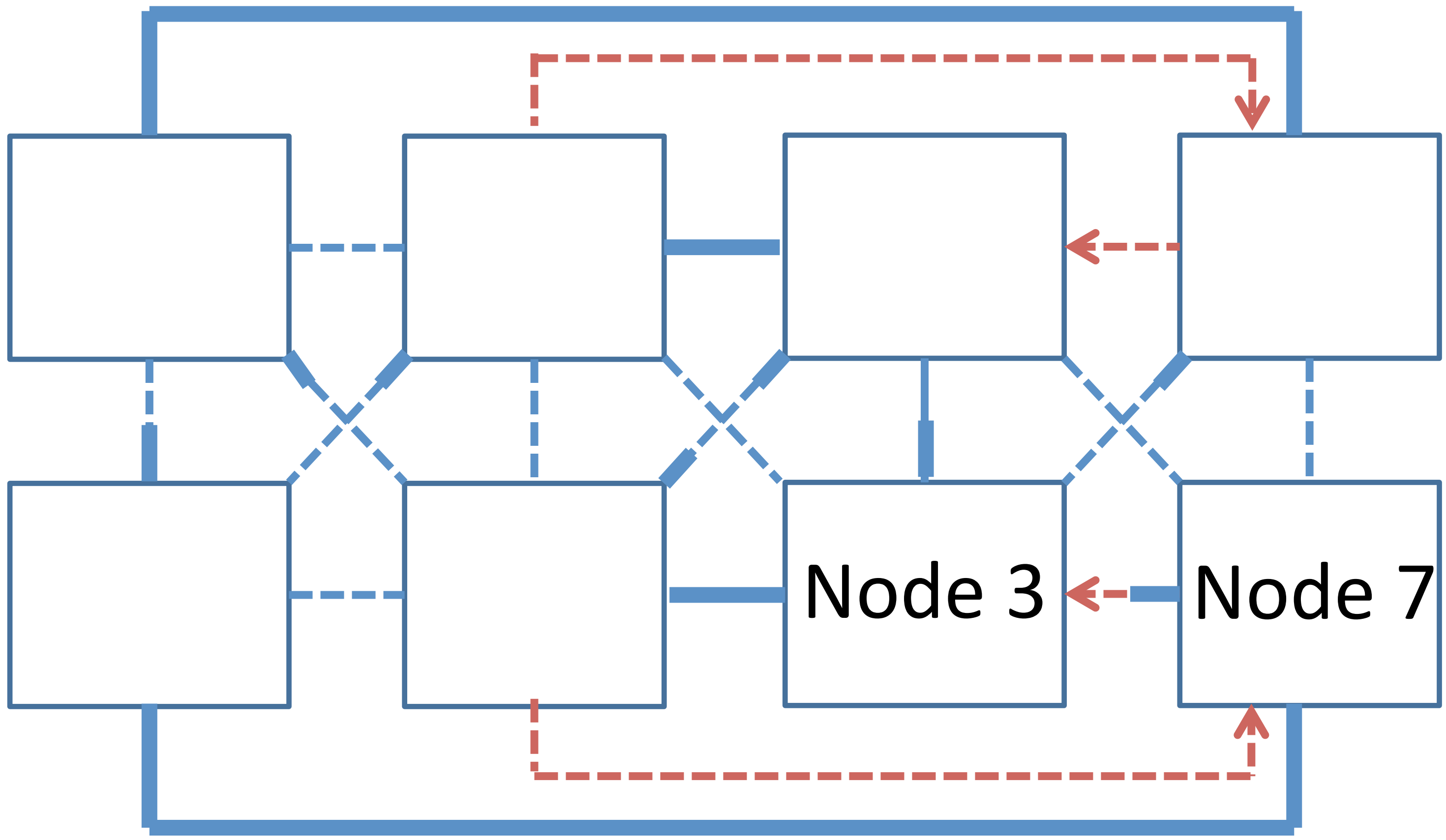
Fast (6GB/s) and slow (3GB/s)



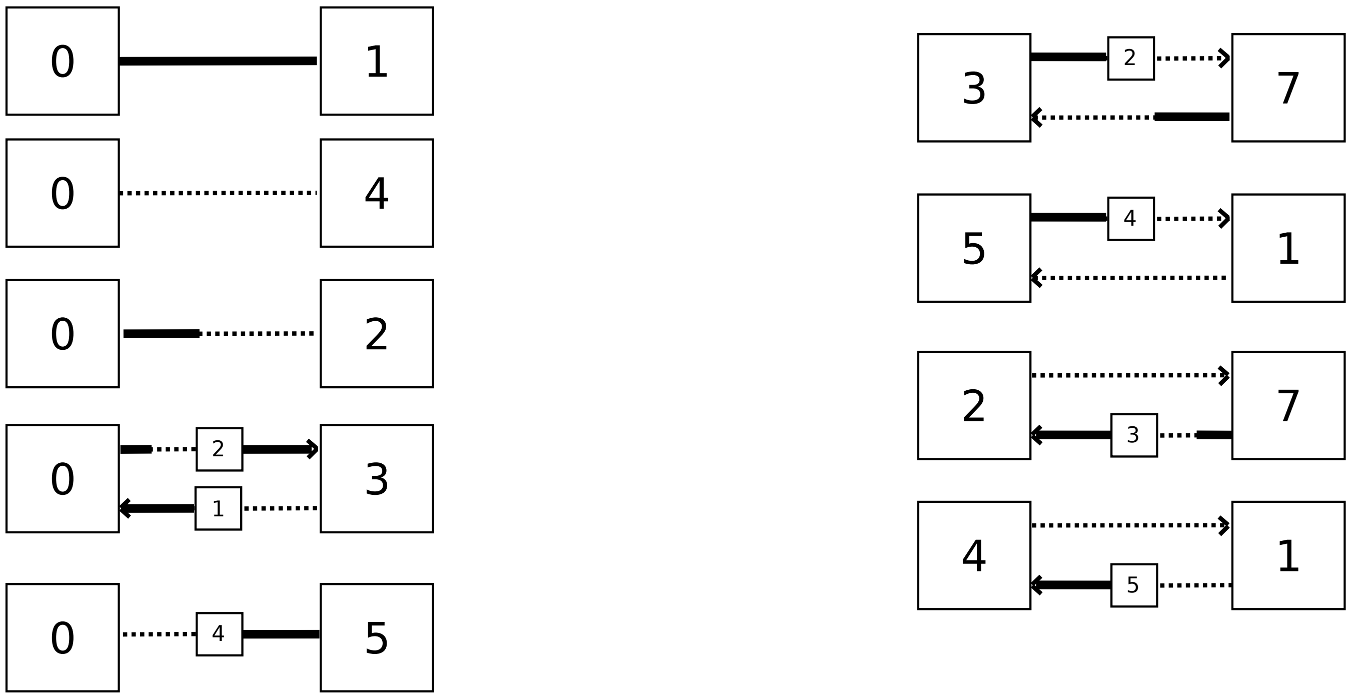
Fast in only one direction (read 4GB/s, write 3GB/s)



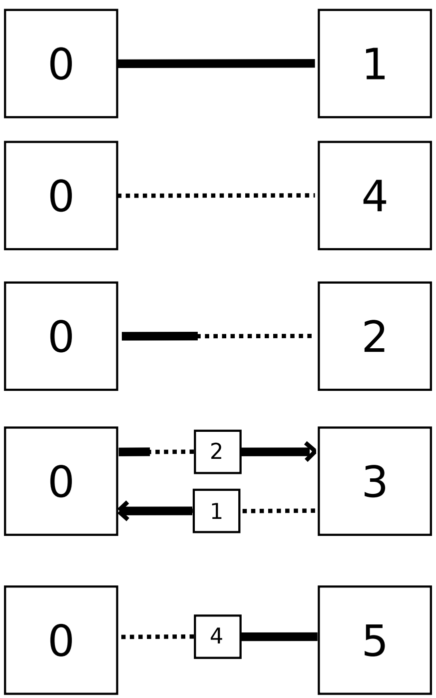
Unidirectional links



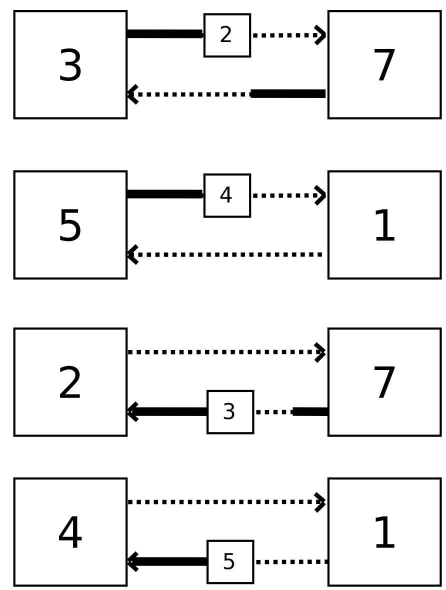
Streamcluster running on 2 nodes



Streamcluster running on 2 nodes



Master thread node	Perf. (s)
-	168
-	**228**
0	**228**
2	168
0	340
3	**185**
0	340
5	**228**



Master thread node	Perf. (s)
3	185
7	338
1	338
5	230
2	**167**
7	225
4	230
1	**226**

Some 2-hops configurations are faster than some 1-hop configurations

Bandwidth is more important than latency

Current optimizations

- Avoid 2-hops (Linux, …)

- Place I/O threads close to I/O nodes

Our solution: AsymSched

Asymmetry aware scheduling
Tries to maximize bandwidth between communicating threads

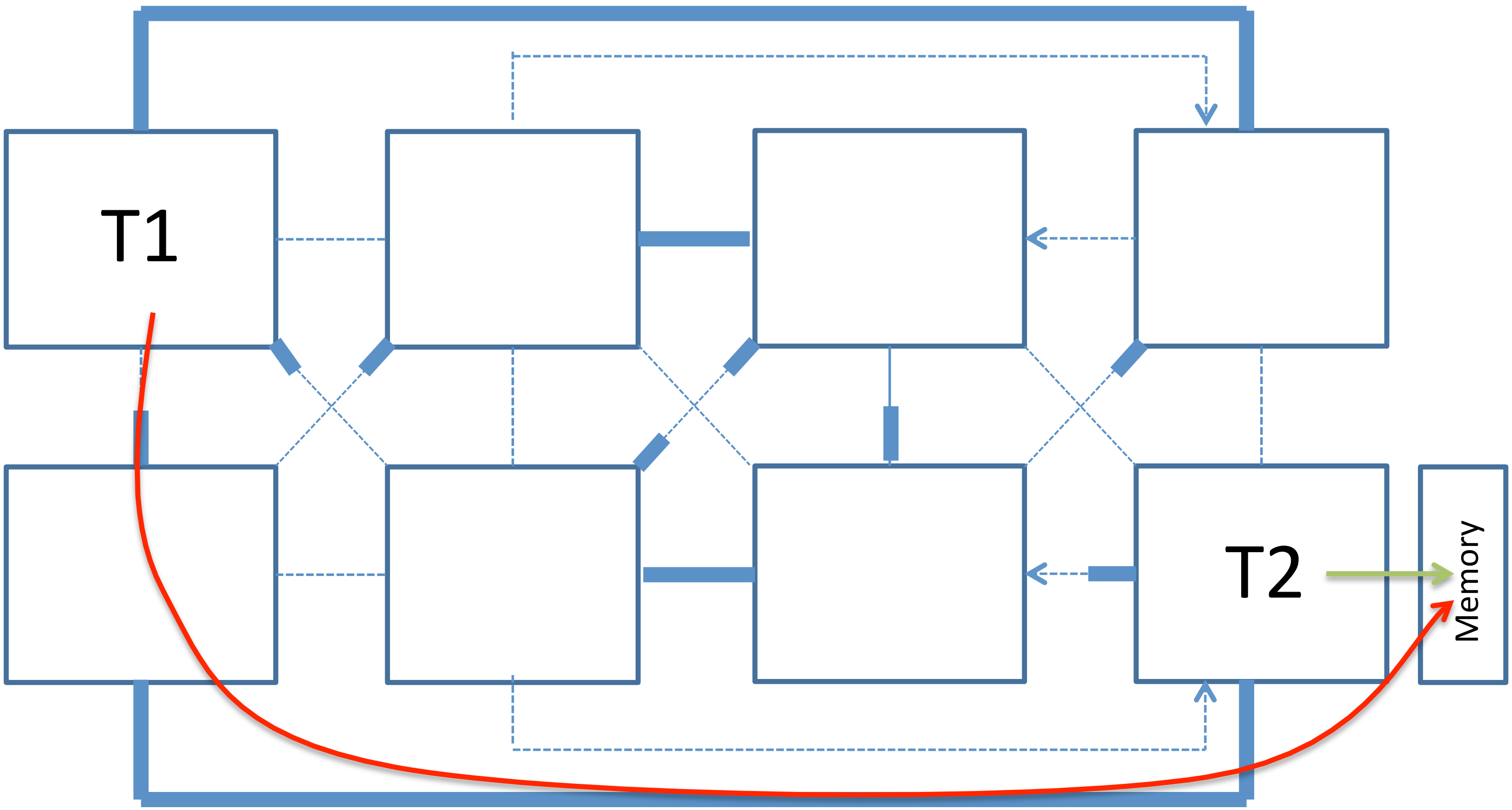
Overview

- Thread migration
  - Place threads on well interconnected nodes

- Memory placement
  - Dynamic memory migration for small working sets
  - Fast bulk memory migration otherwise

- Continuous profiling in background
- Takes decisions every second

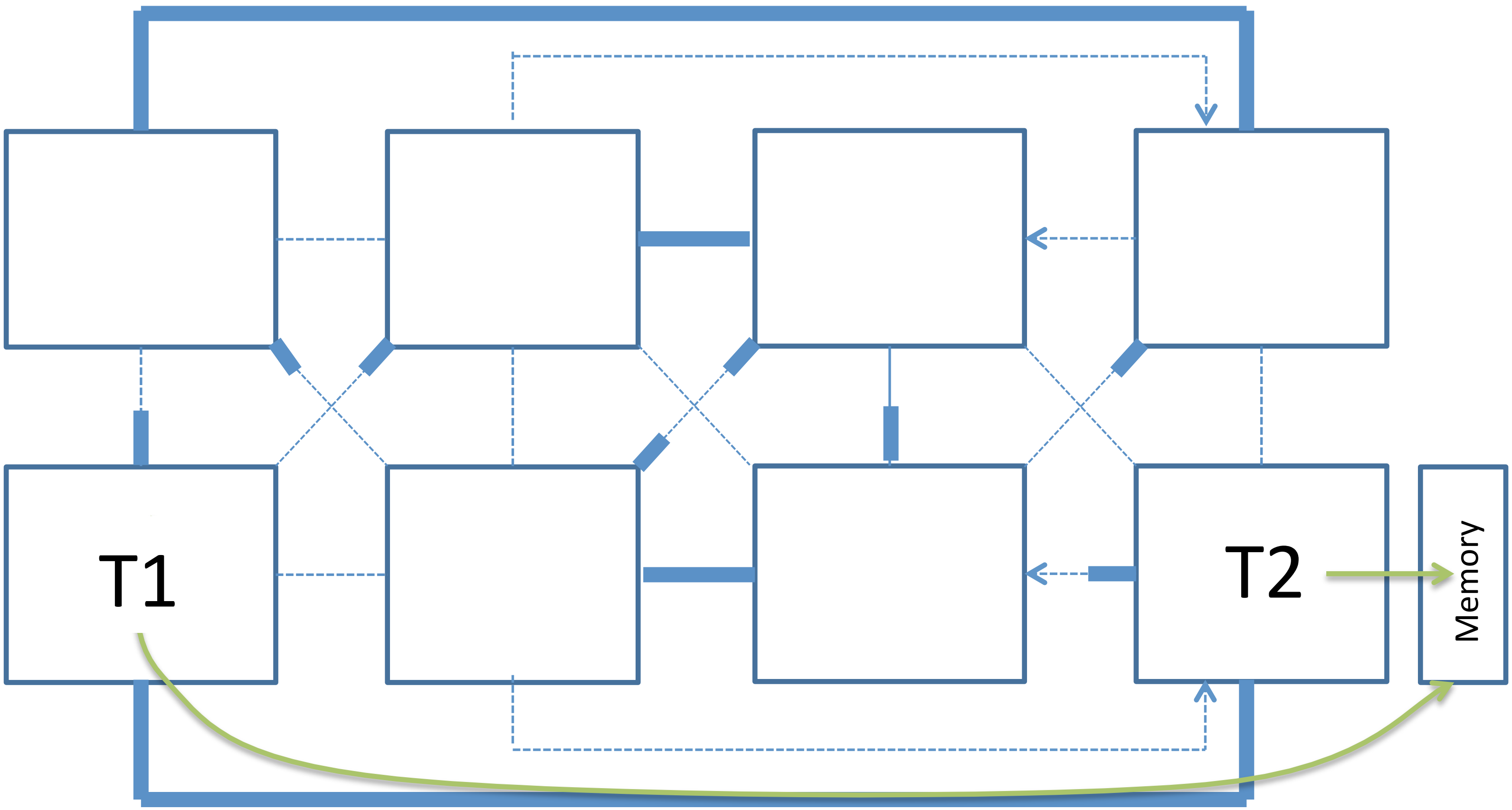
Step one: cluster threads



Limitations

- Hardware counters work at the scale of a node
  - E.g.: Node 0 did an access to node 7
- So we cluster **per node.**
- We only cluster threads that have the same pid.

Step two: migrate threads

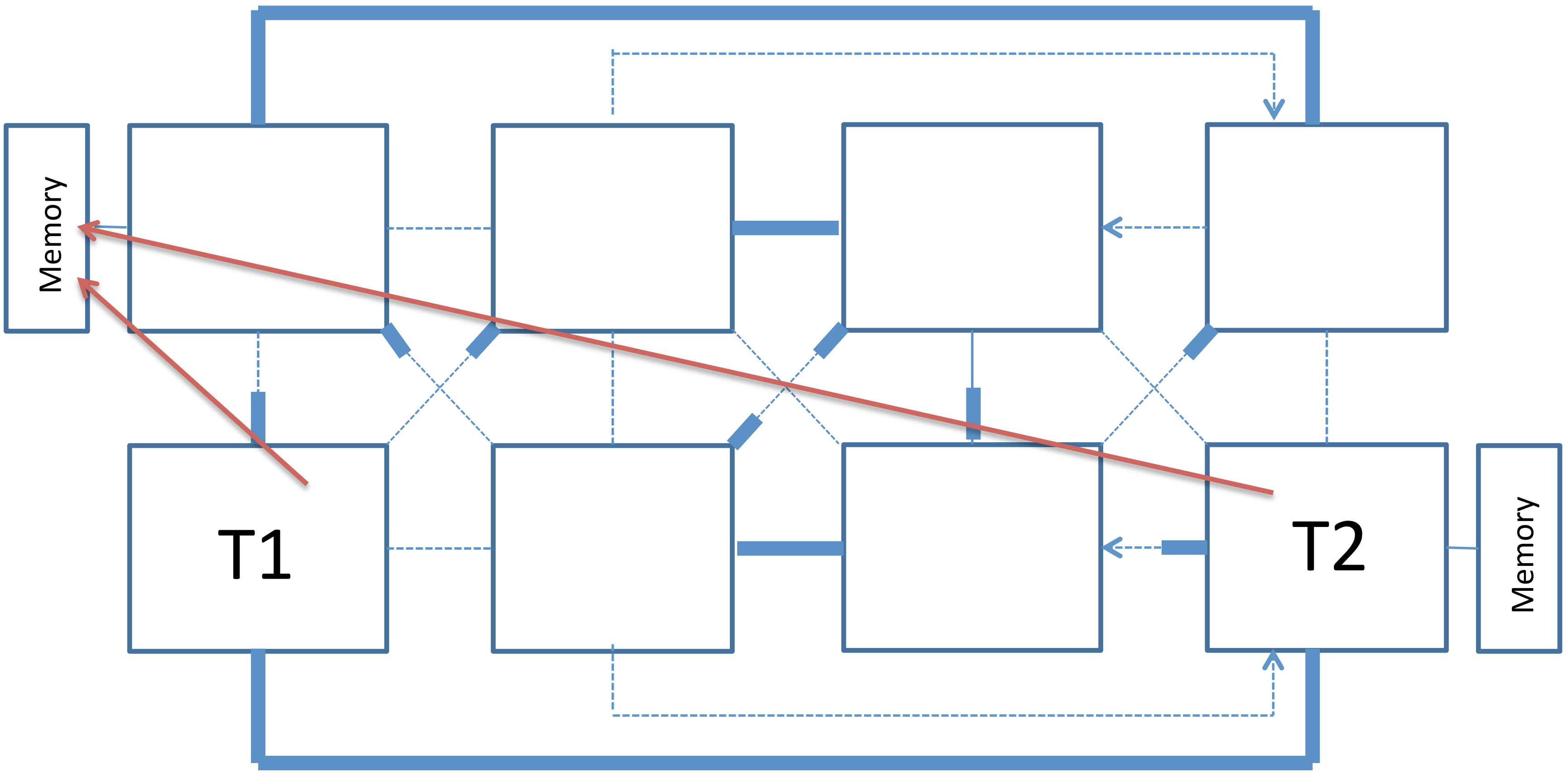


- Migration is done on a node basis
  - We move all threads running on a node to another node.

Challenges

- Find the best placement
  - I.e., the placement that maximizes bandwidth between threads.
- The number of placements is huge
  - Up to factorial(#nodes)
  - We skip "obviously bad" configurations
    - Skip placements that use the "slowest" links
  - We only do computations on non-equivalent configurations.
    - Hash function placement -> generic placement.

Step three: migrate memory



T1 and T2 might continue accessing memory located on the previous node of T1

Implementation

- We use IBS to detect accessed pages
- It is not precise, and might not be sufficient
  - Do full memory migration in that case
- Problem: Linux system call takes 5.1s to migrate 1GB!
  - Our workloads use up to 30GB of RAM.

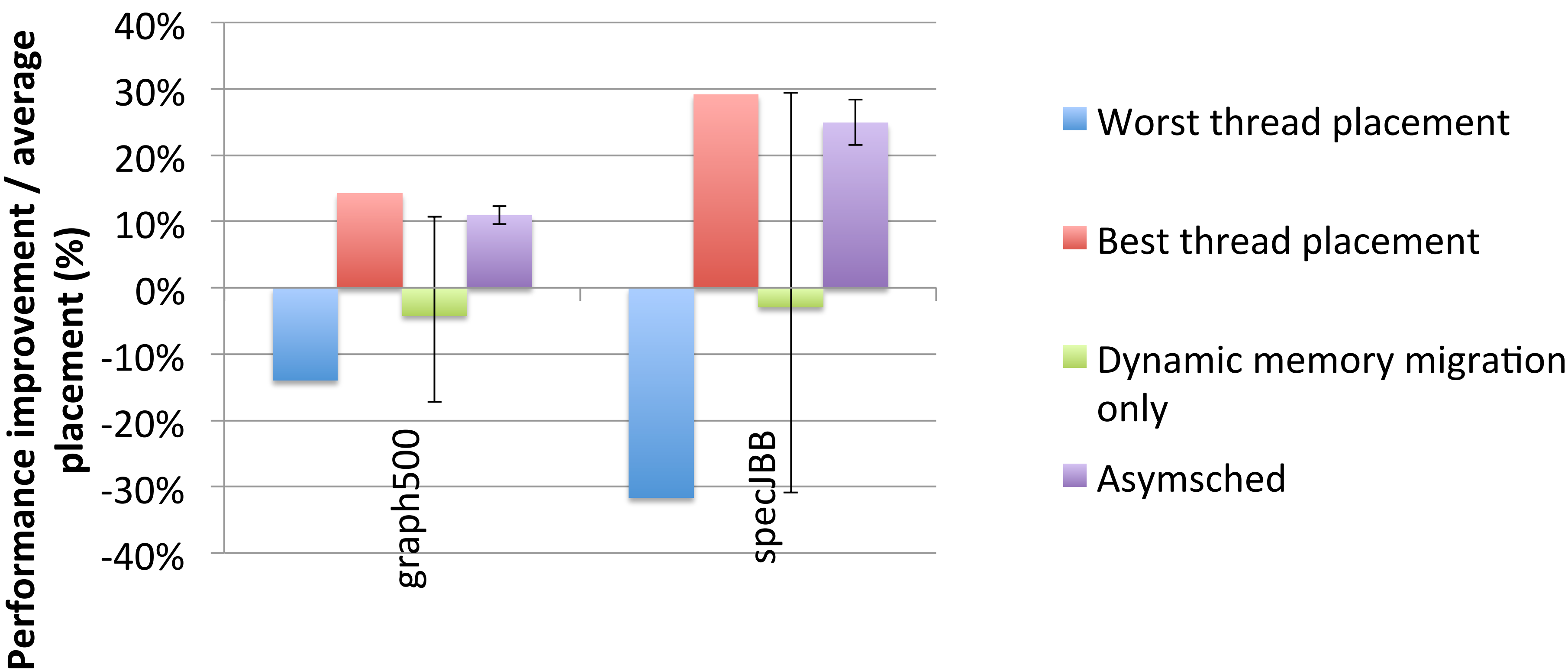
Fast memory migration

- Implementation:
  - Freeze the application (SIGSTOP)
  - Compute a list of all pages to migrate
  - Modify PTEs directly

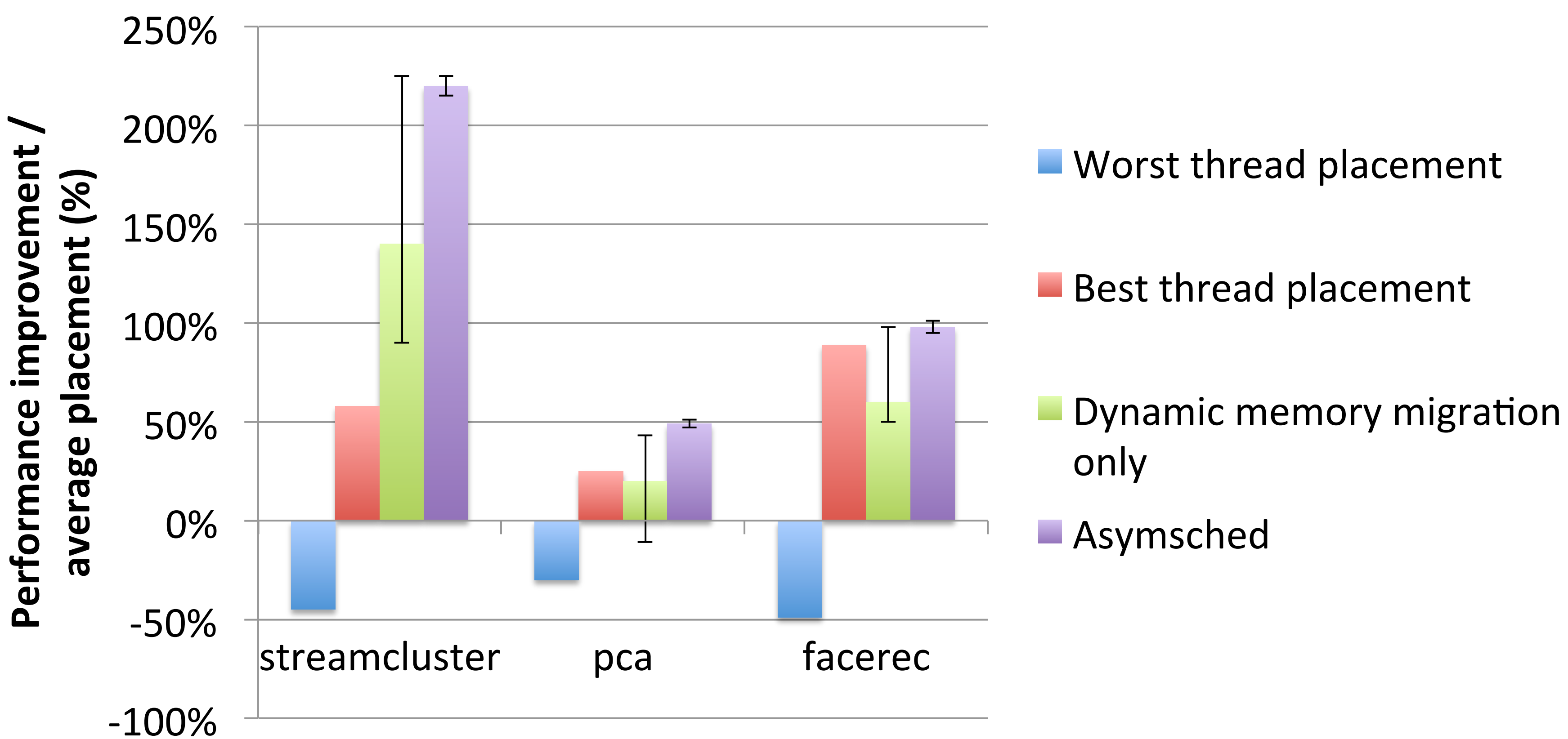
- No lock
- Only **limited by interconnect bandwidth**
- Migrate memory from multiple nodes in parallel

- Migrates 1GB from 1 node in 0.3s (17x faster than Linux)
- Migrates 2GB from 2 nodes in 0.3s (34x)

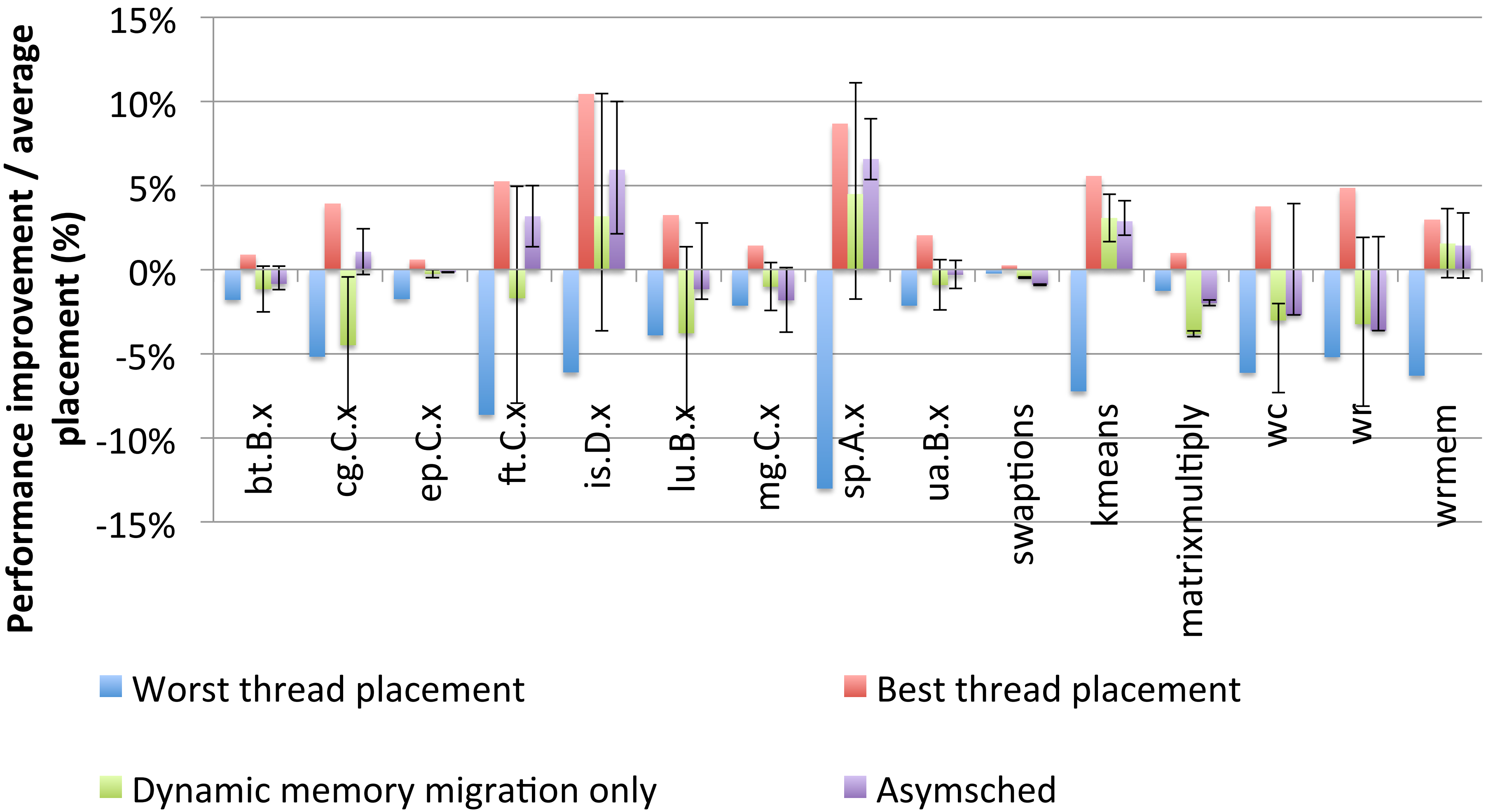
Evaluation (1/4)



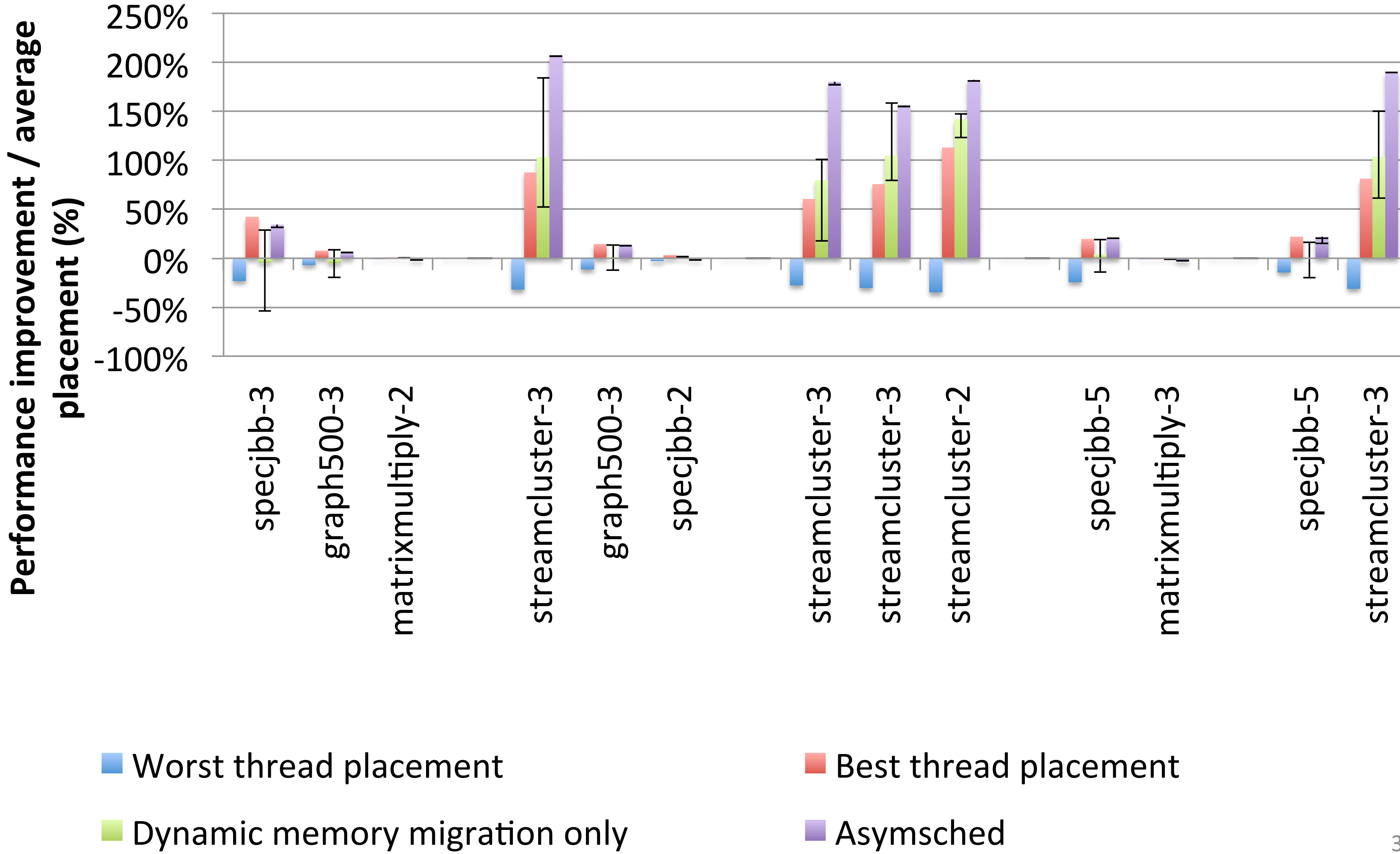
Evaluation (2/4)



Evaluation (3/4)



Evaluation - Multiapp (4/4)



Conclusion

- Systems should maximize bandwidth between threads
- Asymsched
  - Up to **200%** faster than average placement
  - Up to **91%** faster than dynamic memory migration alone

Questions?