Parallel Algorithm Engineering

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Based on slides by
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Outline

- Background
- Current multicore architectures
- UMA vs NUMA
- The openMP framework and numa control
- Examples

Software crisis

> “The major cause of the software crisis is that the machines have become several orders of magnitude more powerful! To put it quite bluntly: as long as there were no machines, programming was no problem at all; when we had a few weak computers, programming became a mild problem, and now we have gigantic computers, programming has become an equally gigantic problem.”

-- E. Dijkstra, 1972 Turing Award Lecture

Before

- The 1st Software Crisis
  - When: around '60 and 70'
  - Problem: large programs written in assembly
  - Solution: abstraction and portability via high-level languages like C and FORTRAN
- The 2nd Software Crisis
  - When: around '80 and '90
  - Problem: building and maintaining large programs written by hundreds of programmers
  - Solution: software as a process (OOP, testing, code reviews, design patterns)
    - Also better tools: IDEs, version control, component libraries, etc.

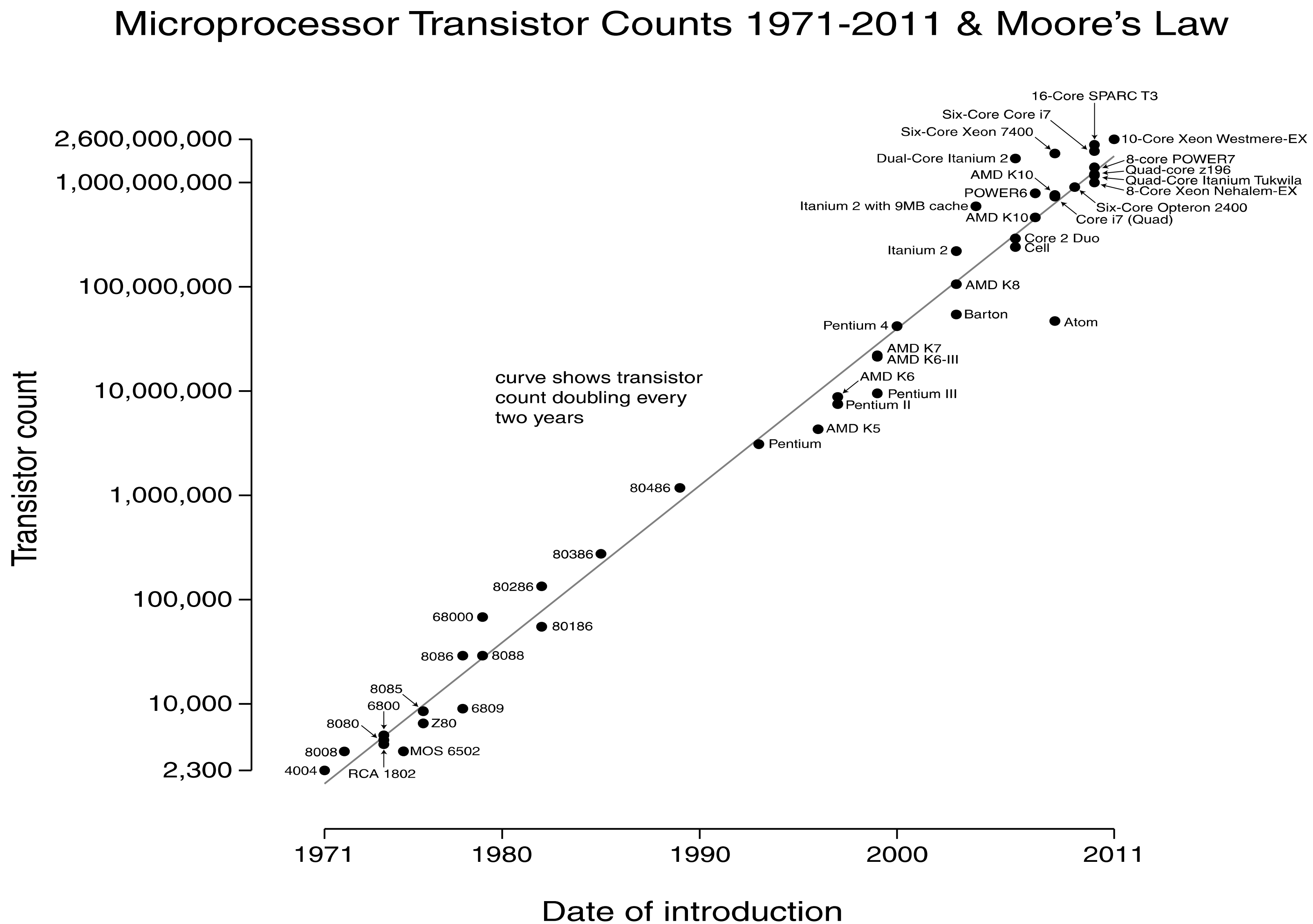
Recently..

- Processor-oblivious programmers
  - A Java program written on PC works on your phone
  - A C program written in '70 still works today and is faster
  - Moore’s law takes care of good speedups

Currently..

- Software crisis again?
  - When: 2005 and ...
  - Problem: sequential performance is stuck
  - Required solution: continuous and reasonable performance improvements
    - To process large datasets (BIG Data!)
    - To support new features
    - Without loosing portability and maintainability

Moore's law



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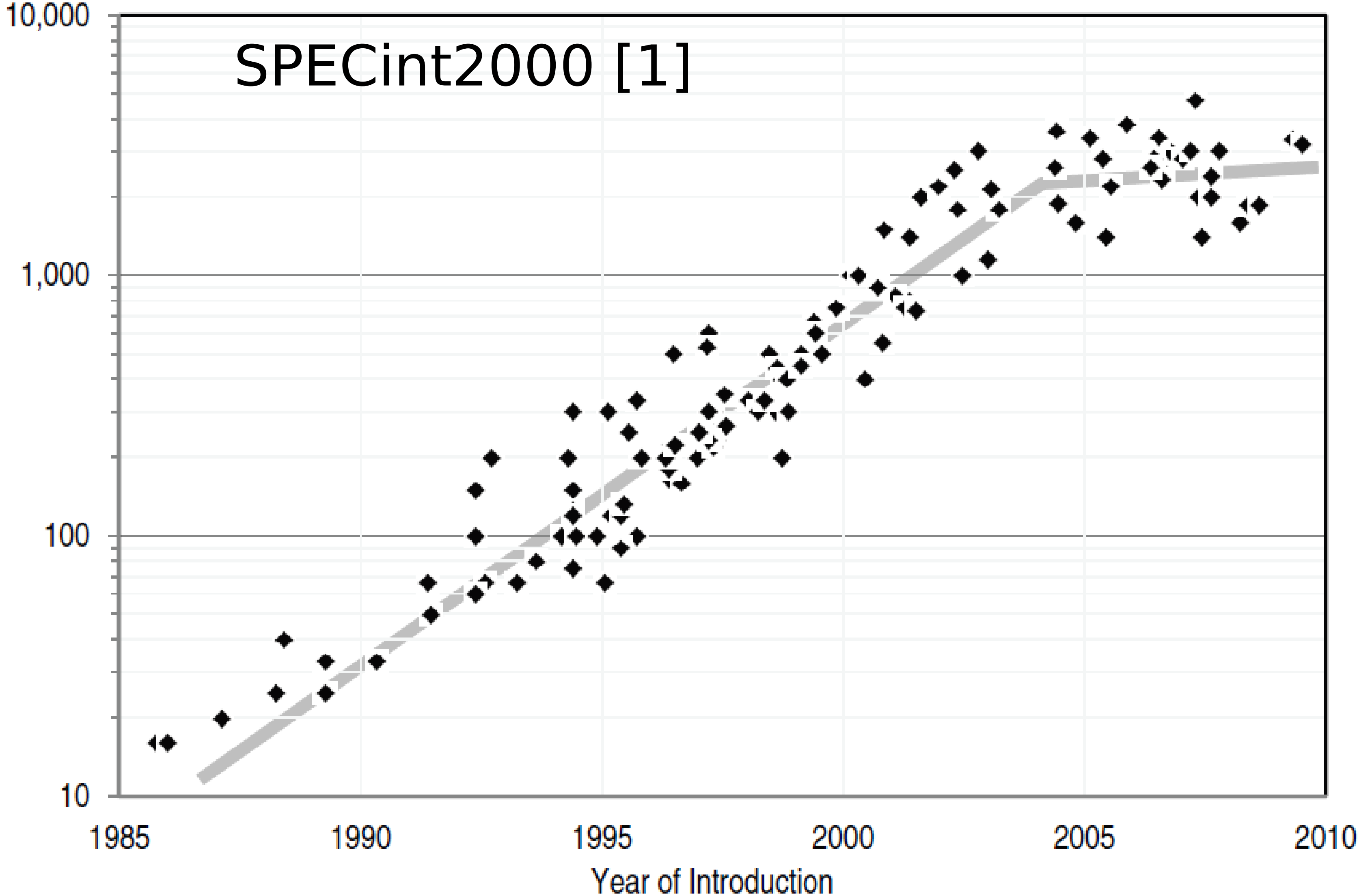
Uniprocessor performance



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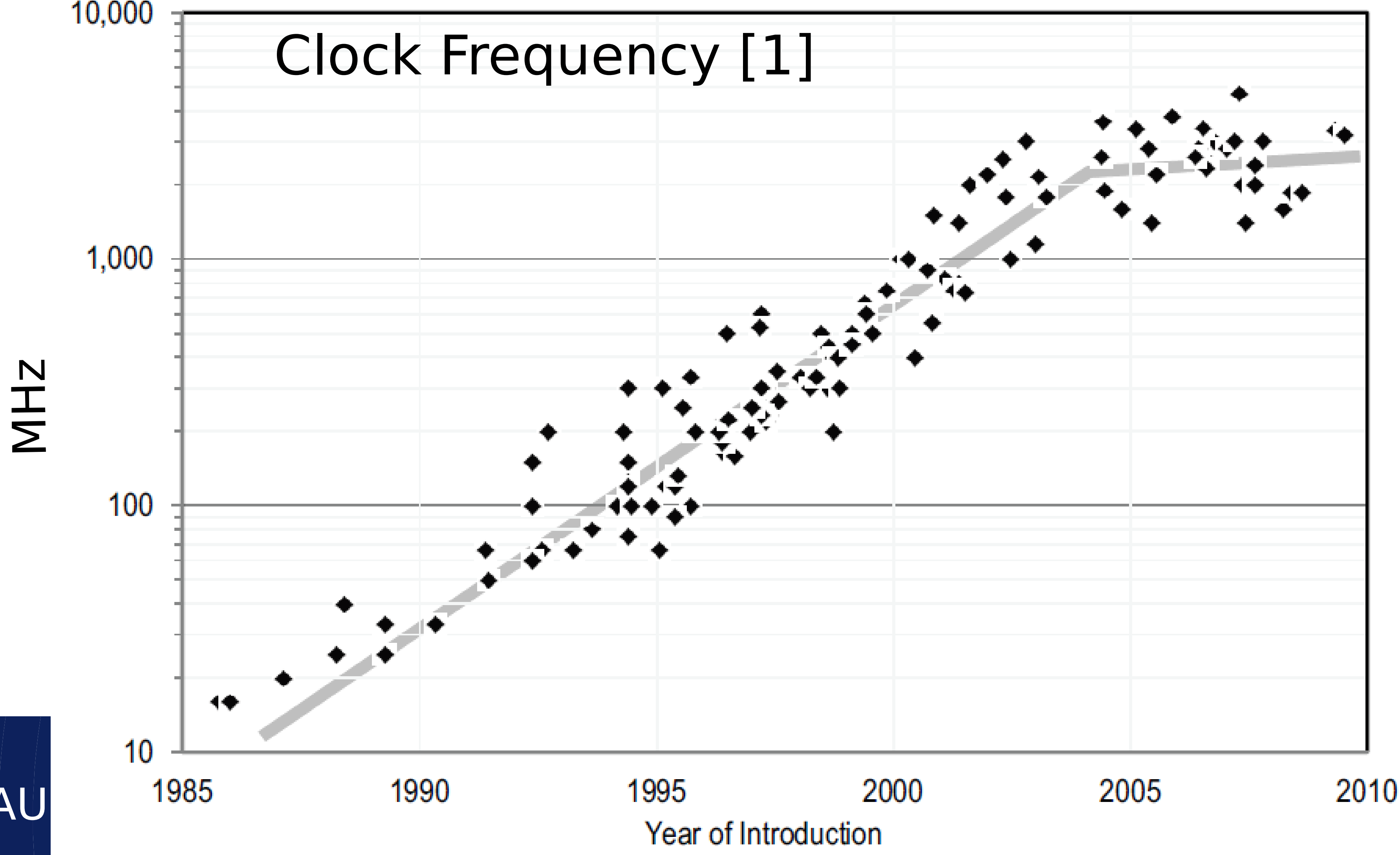
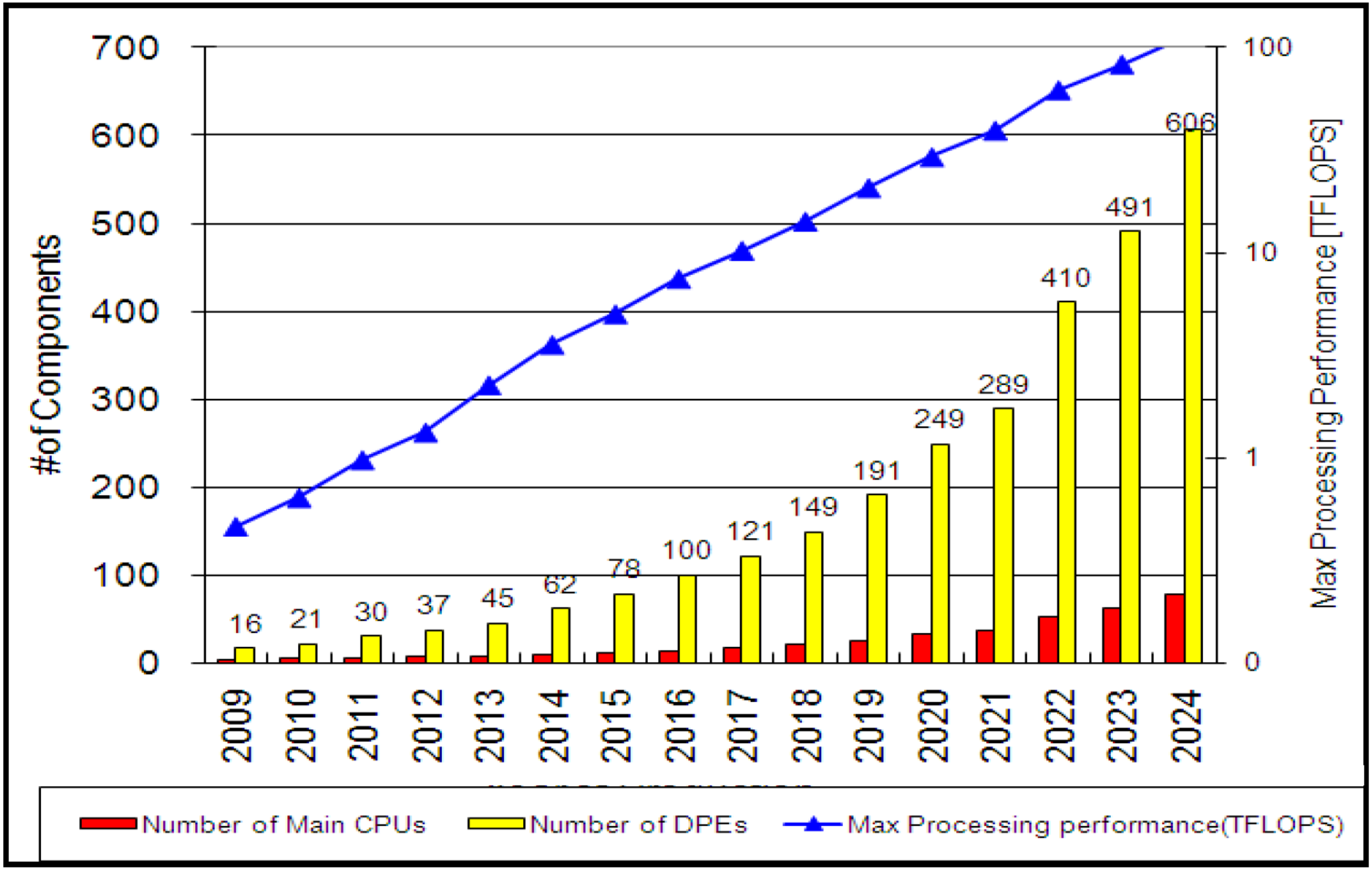
Uniprocessor performance (cont.)



Parallel processing: Predicted # of cores for stationary systems, according to ITRS



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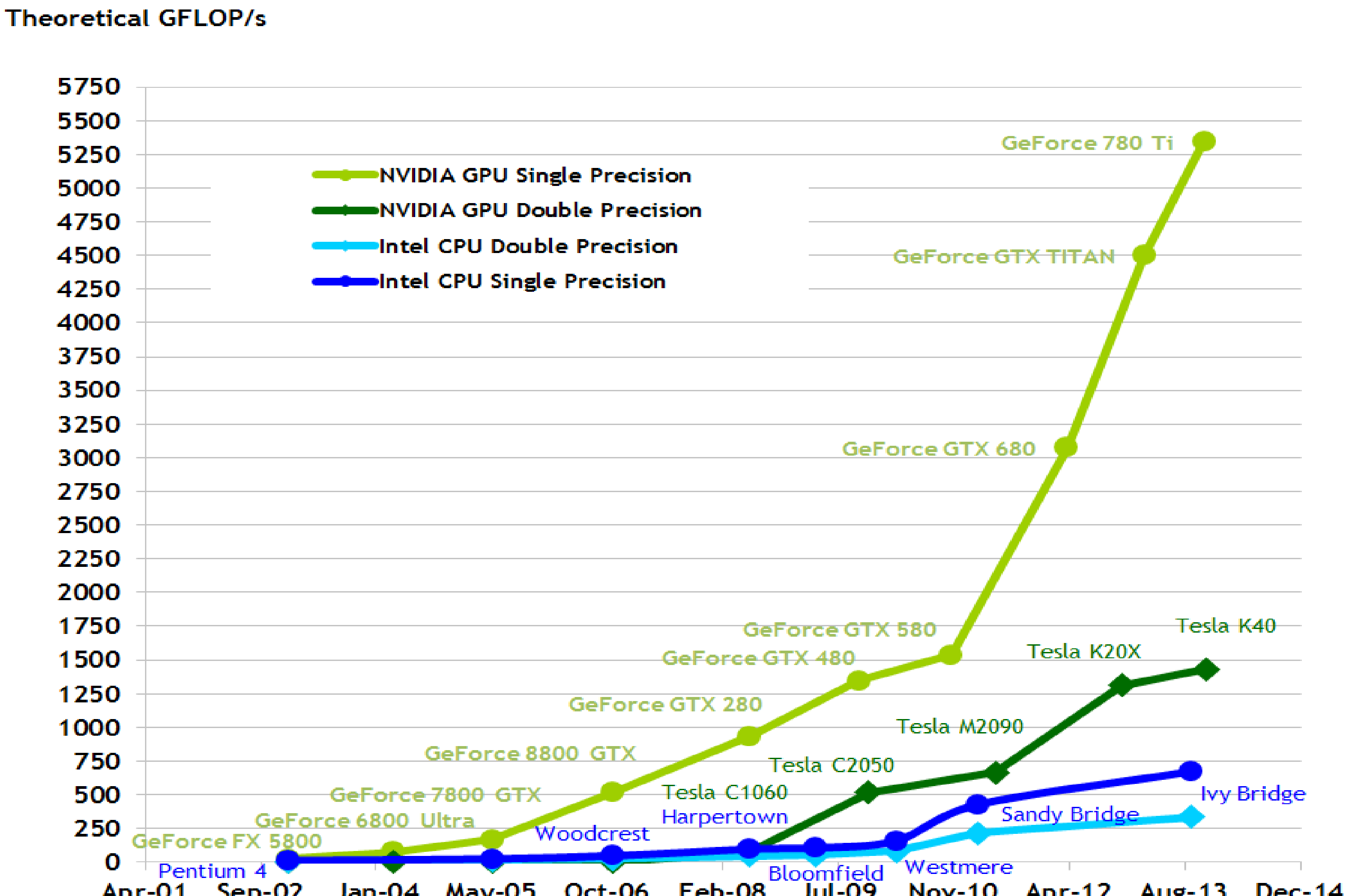
Even “worse” for GPUs

- GTX 780 Ti have 2880 cores @ 0.9Ghz



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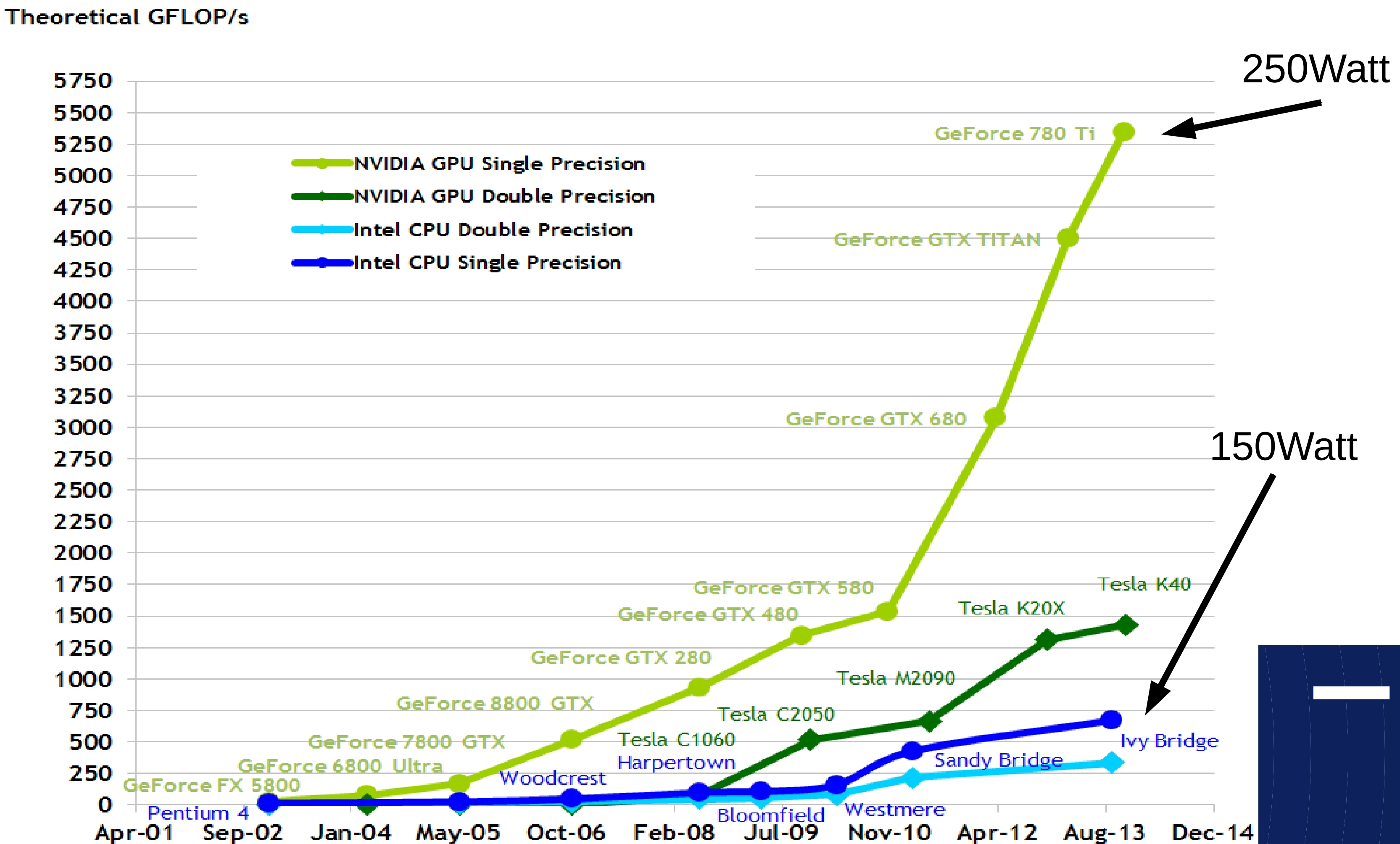
Why

- Power considerations
  - Consumption
  - Cooling
  - Efficiency
- DRAM access latency
  - Memory wall
- Wire delays
  - Range of wire in one clock cycle
- Diminishing returns of more instruction-level parallelism
  - Out-of-order execution, branch prediction, etc.

Power consumptions

- GTX 780 Ti have 2880 cores @ 0.9Ghz

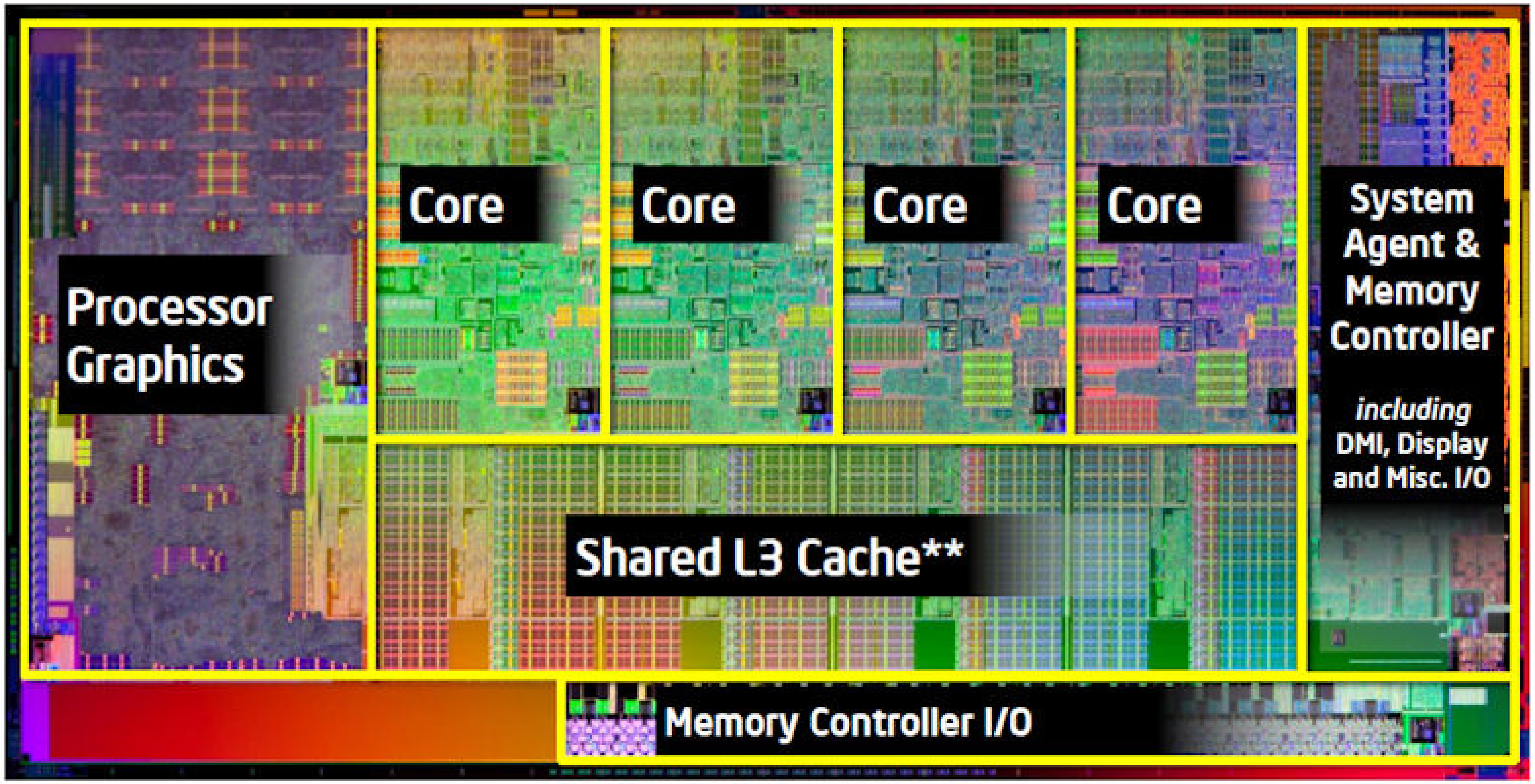


Overclocking

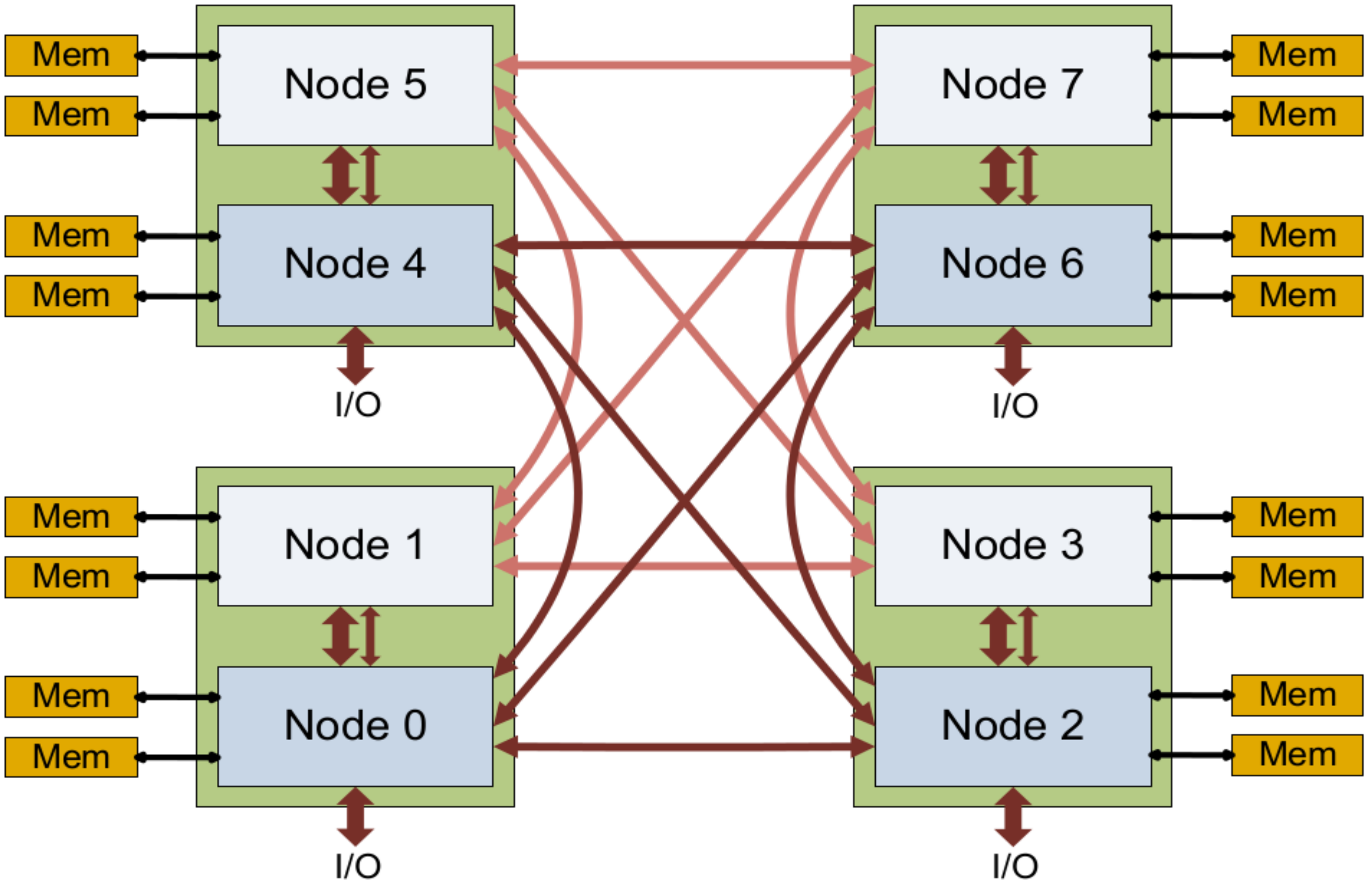
- Air-water: ~5.0 GHz
  - Possible at home
- Phase change: ~6.0 GHz
- Liquid helium: 8.794 GHz
  - Current world record
  - Reached with AMD FX-8350

Towards parallel setups

- Instead of going faster --> go more parallel!
  - Transistors are now used for multiple cores

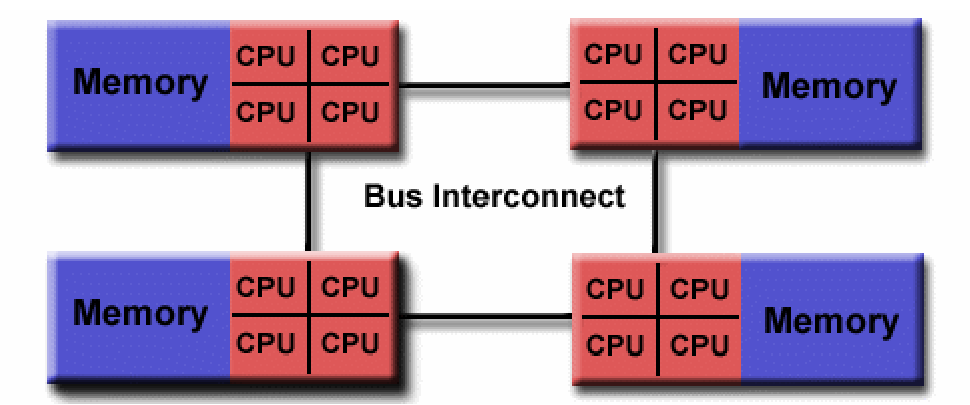


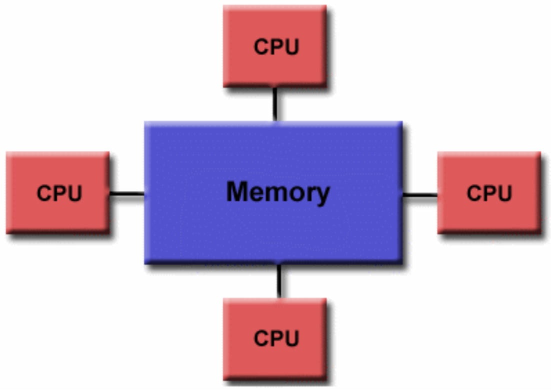
4 sockets – 8 CPU setup



UMA vs NUMA

- All laptops and most desktops are UMA
- Most modern servers are NUMA
- Important to know which you target!





Current commercial MC CPUs

- Intel
  - Intel® Core™ i7-5960X: 8-core (16 threads), 20 MB Cache, max 3.5 GHz

    Intel® Xeon® Processor E5-2699 v3: 18-core (36 threads), 45 MB Cache, max 3.6 GHz (x 8-socket configuration)
  - Phi 7120P: 61 cores (244 threads), 30.5 MB Cache, max 1.33 GHz, max memory BW 352 GB/s
- AMD
  - FX-9590: 8-core, 8 MB Cache, 4.7 GHz
  - A10-7850K: 12-core (4 CPU 4 GHz + 8 GPU 0.72 GHz), 4 MB C
  - Opteron 6386 SE: 16-core, 16 MB Cache, 3.5 GHz (x 4-socket conf.)
- Oracle
  - SPARC M6: 12-core (96 threads), 48 MB Cache, 3.6 GHz (x 32-socket configuration)

Concurrency vs Parallelism

- Parallelism
  - A condition that arises when at least two threads are executing simultaneously
  - A specific case of concurrency
- Concurrency:
  - A condition that exists when at least two threads are making progress.
  - A more generalized form of parallelism
  - E.g., concurrent execution via time-slicing in uniprocessors (virtual parallelism)
- Distribution:
  - As above but running simultaneously on different machines (e.g., cloud computing)

Amdahls law

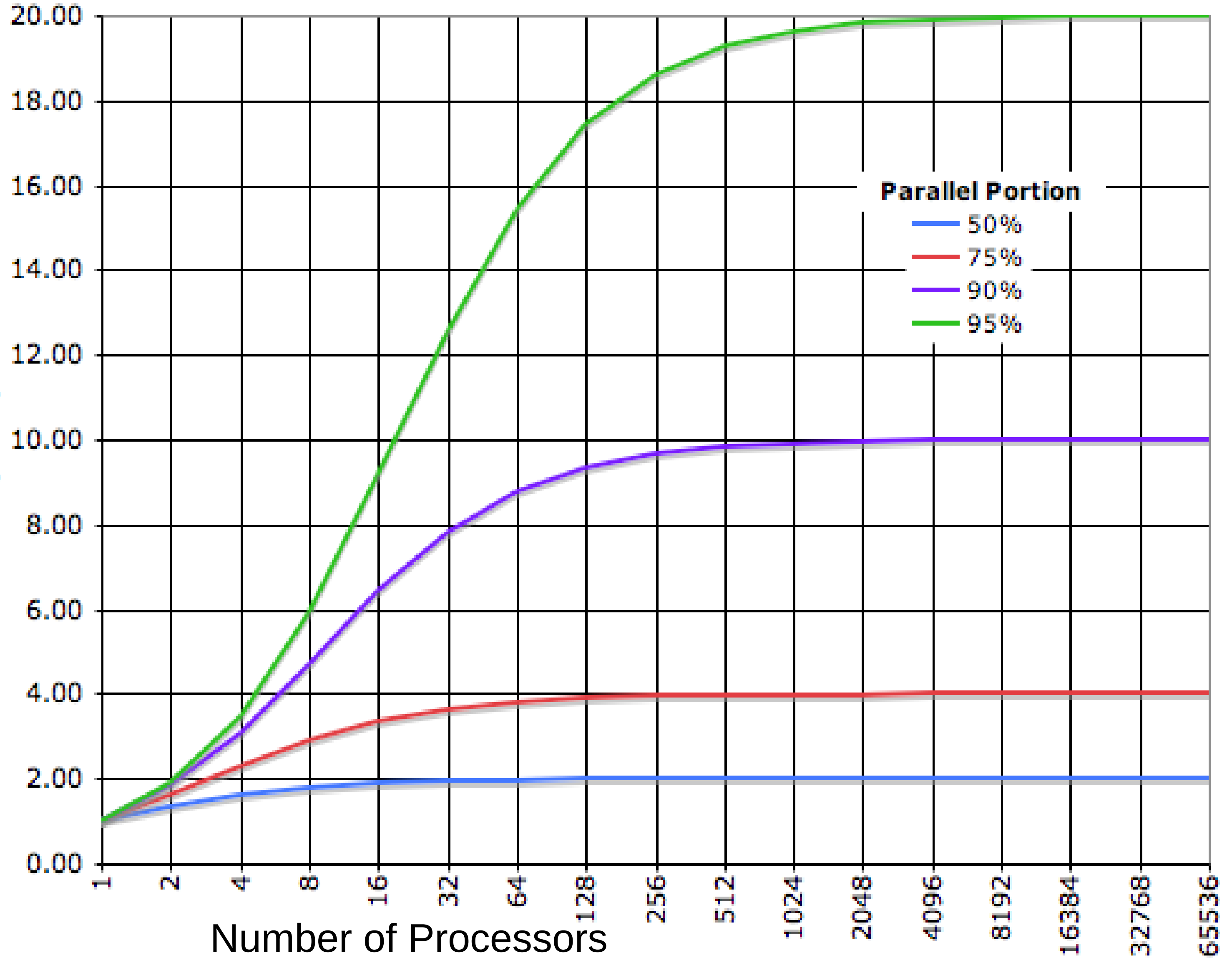
- Potential program speedup is defined by the fraction of code that can be parallelized
- Serial components rapidly become performance limiters as thread count increases
  - *p* – fraction of work that can parallelized
  - *n* – the number of processors

$$= \frac{1}{(1-p) + \frac{p}{n}}$$

fraction of time to complete sequential work

fraction of time to complete parallel work

Amdahls law



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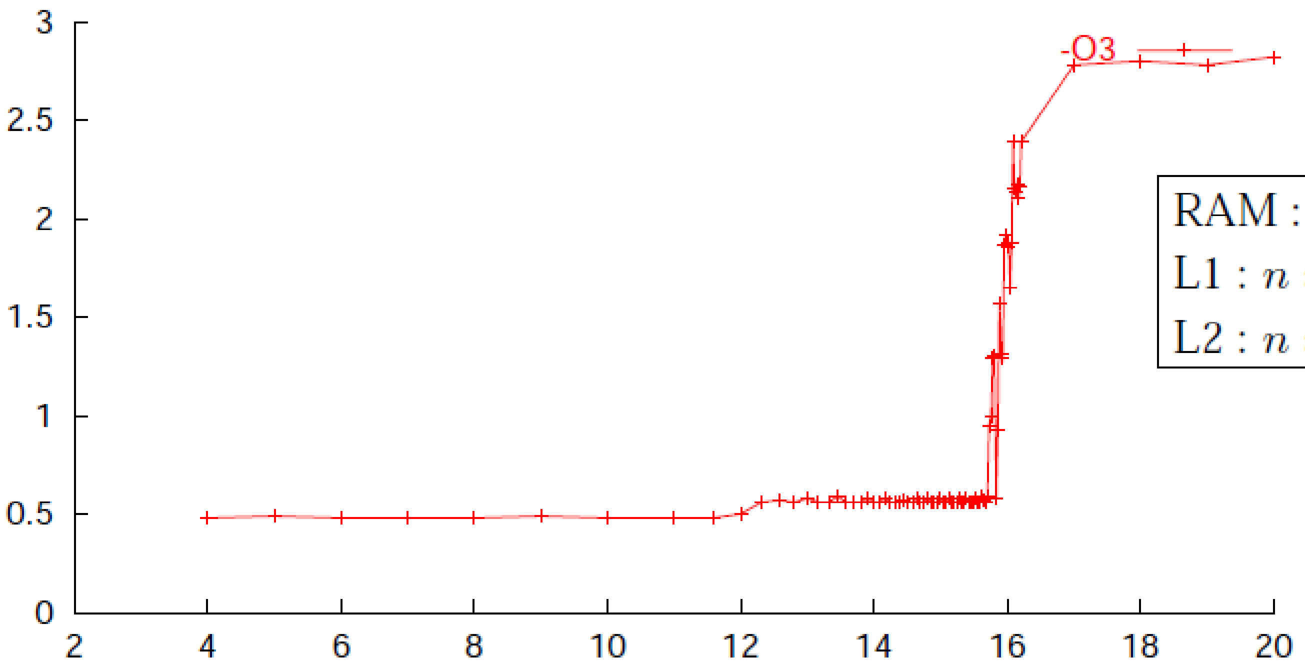
When to parallelize

- When you have independent units of work
- When your code is compute bound
- Or your code is not utilizing the memory bandwidth
- When you see performance gains in tests :-)

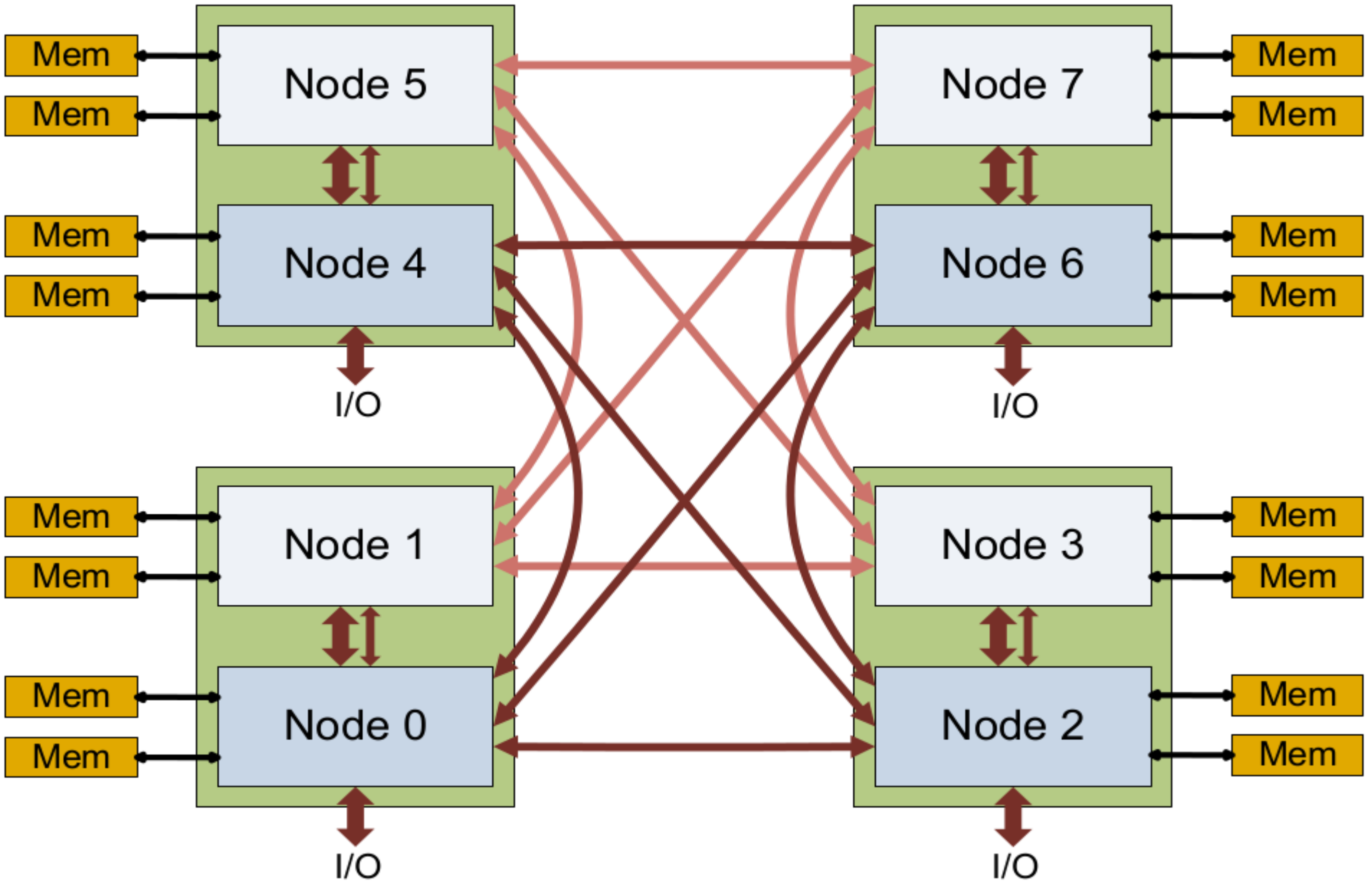
We have seen this previously

- L1 and L2 cache sizes

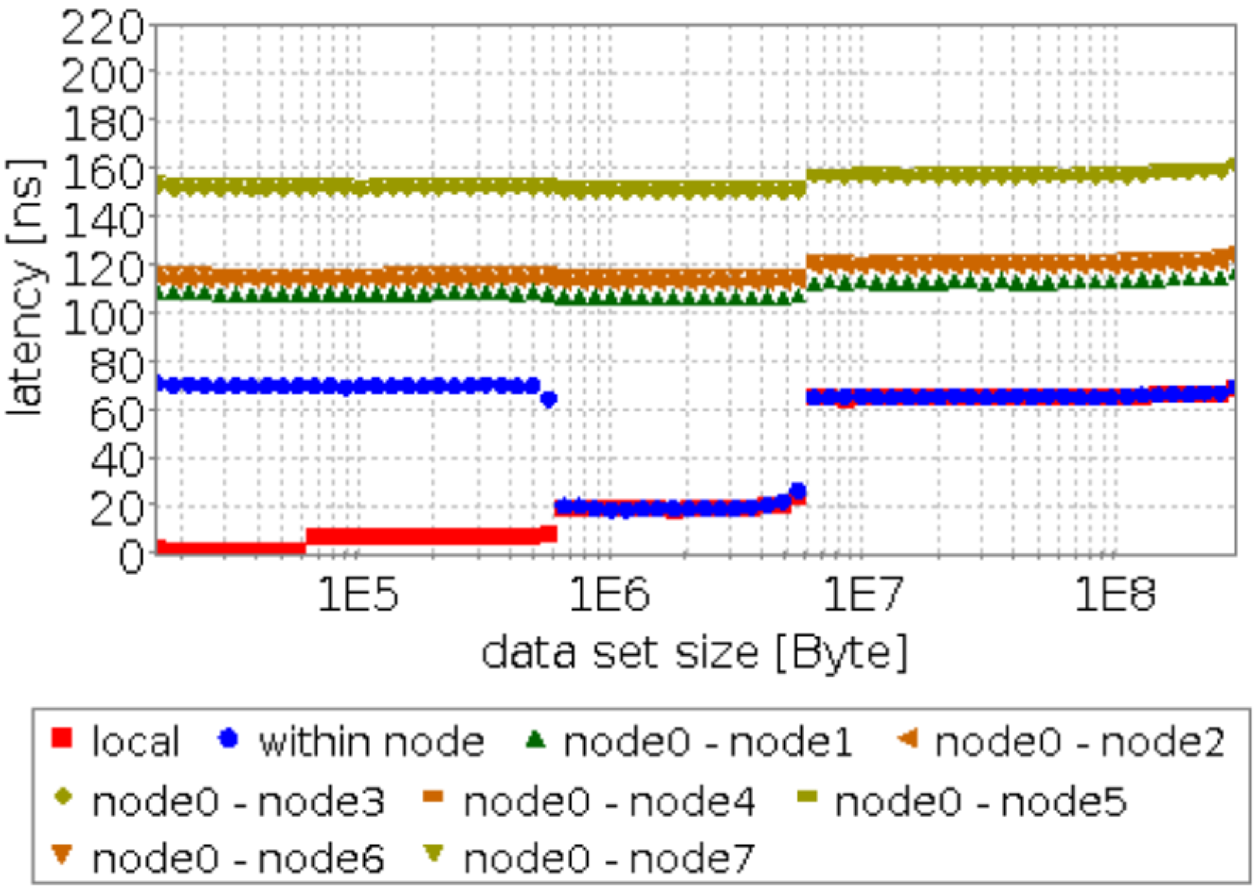


$\mathrm{RAM}: n \approx 2^{25} \equiv 128\,MB$
$\mathrm{L1}: n \approx 2^{12} \equiv 16\,KB$
$\mathrm{L2}: n \approx 2^{16} \equiv 256\,KB$

Remember from previously

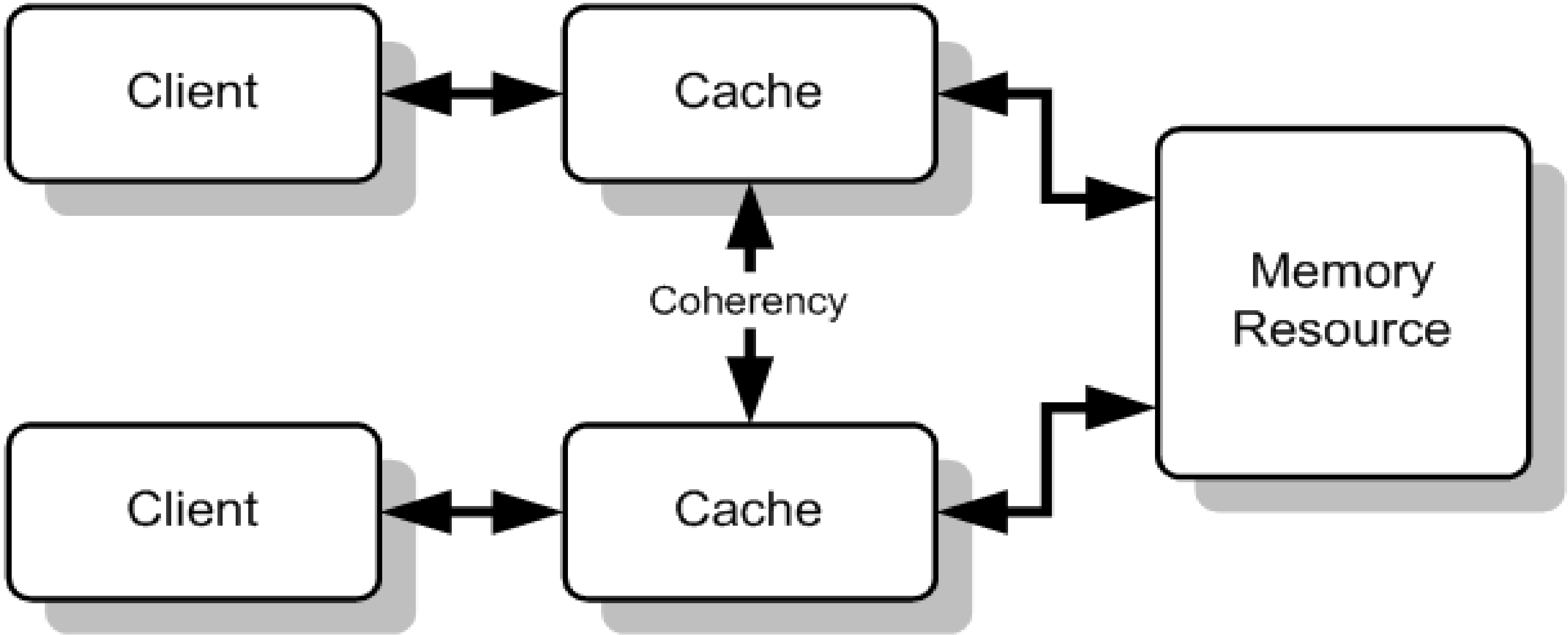


Numa effects



Cache coherence

- Ensures the consistency between all the caches.

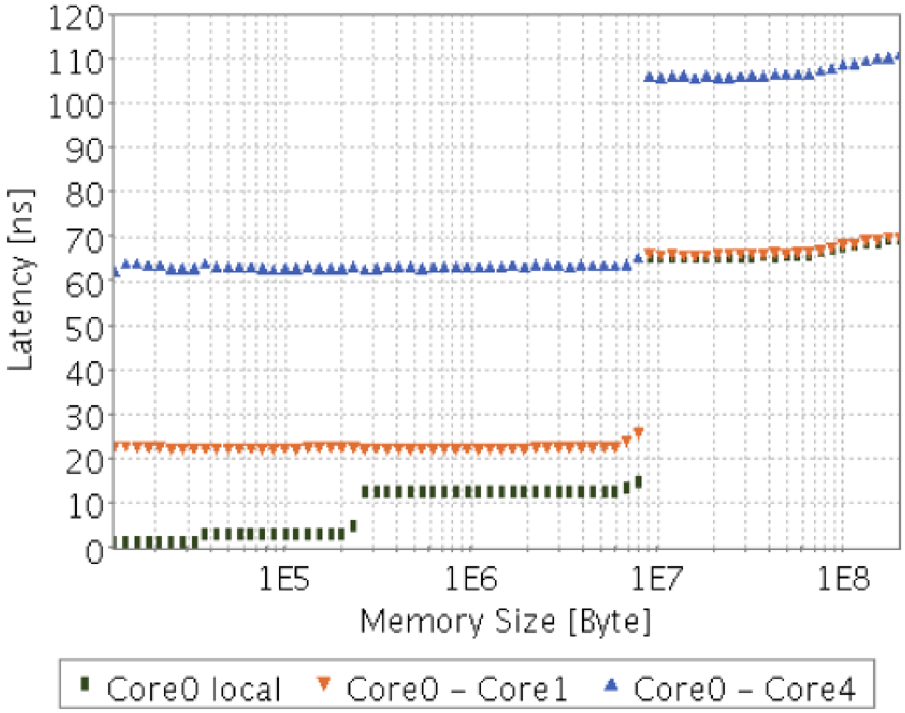


MESIF protocol

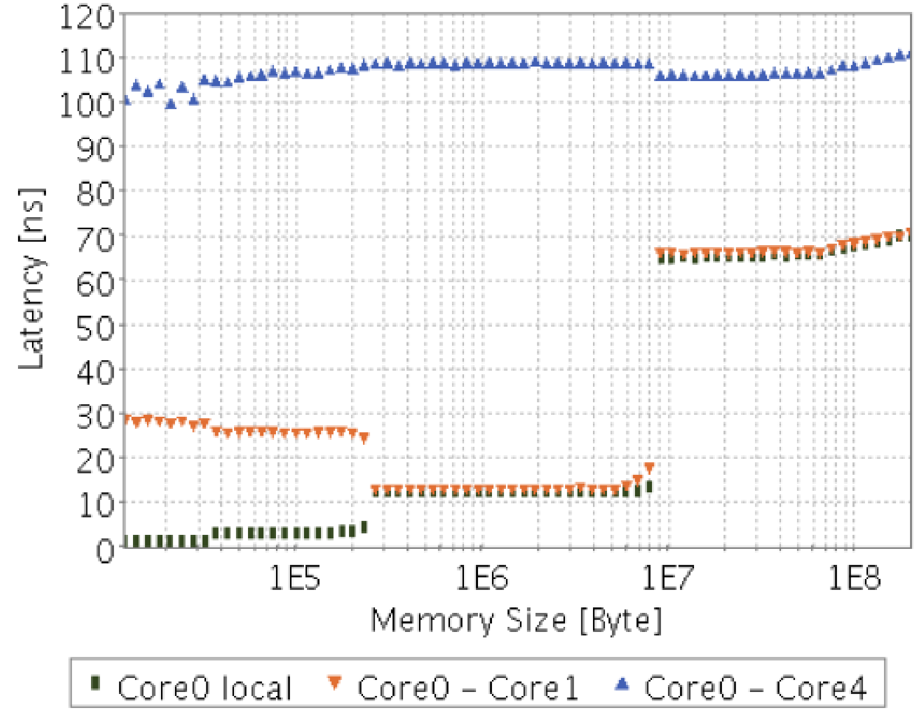
- Modified (M): present only in the current cache and *dirty*. A write-back to main memory will make it (E).
- Exclusive (E): present only in the current cache and *clean*. A read request will make it (S), a write-request will make it (M).
- Shared (S): may be stored in other caches and *clean*. May be changed to (I) at any time.
- Invalid (I): unusable
- Forward (F): a specialized form of the S state

Cache coherency effects

Exclusive cache lines



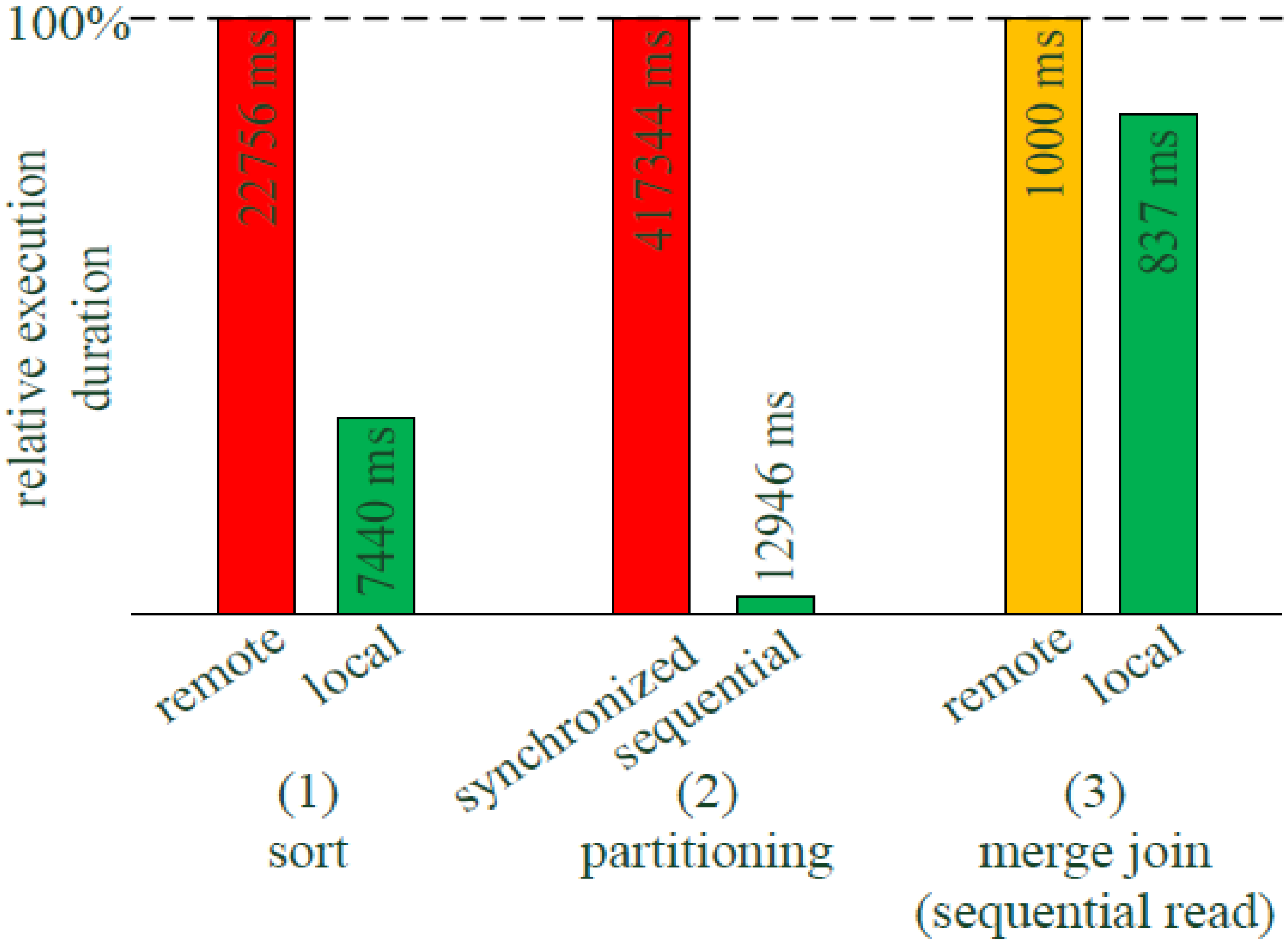
Modified cache lines



Latency in nsec on 2-socket Intel Nehalem

Does it matter?

- Processing 1600M tuples on 32-core machine



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Commandments

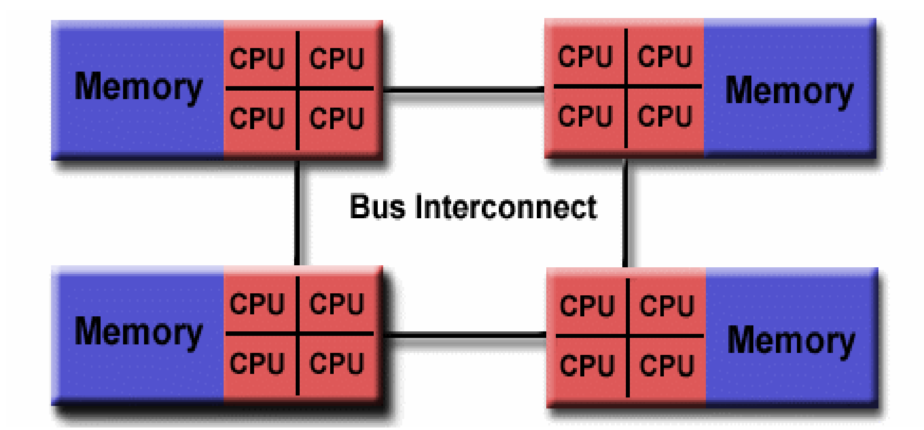
- C1: *Thou shalt not write thy neighbor's memory randomly* – chunk the data, redistribute, and then sort/work on your data locally.
- C2: *Thou shalt read thy neighbor's memory only sequentially* – let the prefetcher hide the remote access latency.
- C3: *Thou shalt not wait for thy neighbors* – don't use fine grained latching or locking and avoid synchronization points of parallel threads.

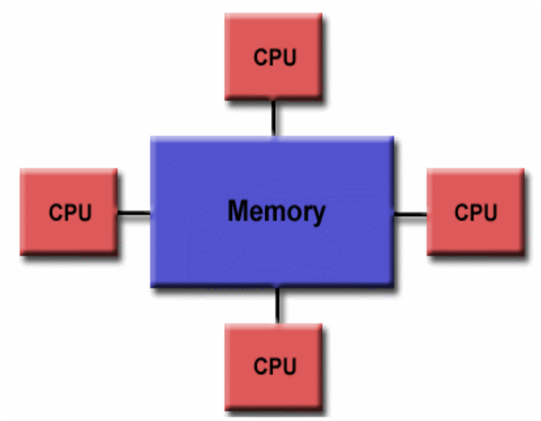
The openMP framework

- API for multiprocessing
- Easily applied to parallelize code
- Built for shared memory processors
- Works cross platform
- http://openmp.org

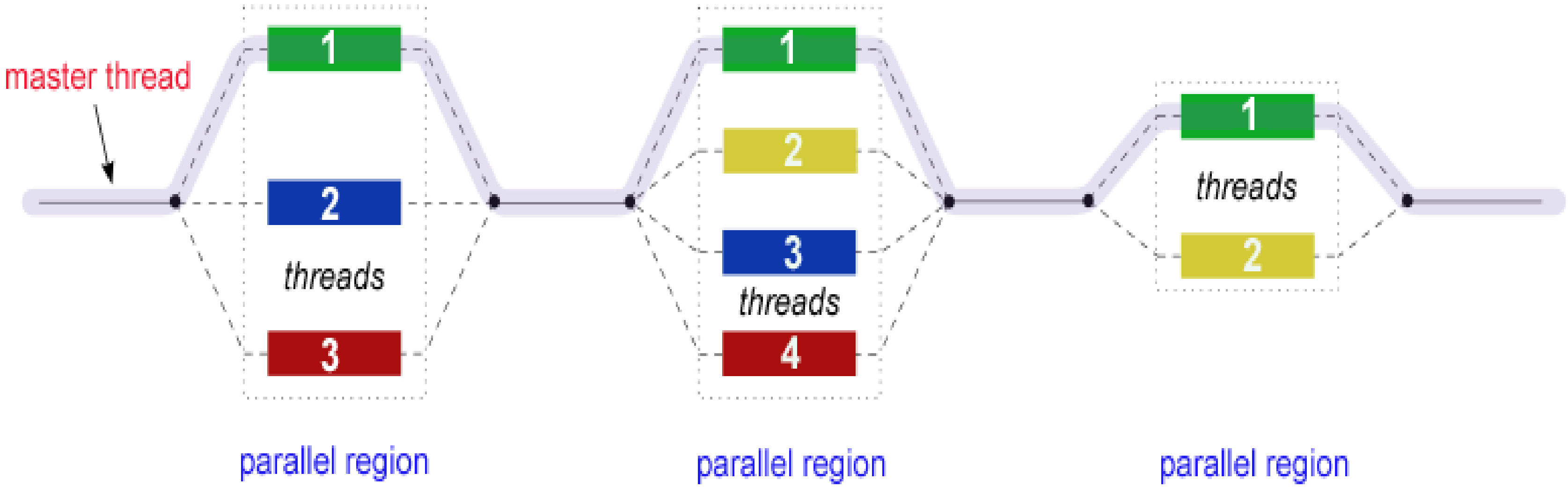
Shared memory processors

- Recall the UMA and NUMA architetures
- Both are shared memory processor architetures





General control flow



Compiling openMP

- #include <omp.h>
- Compile with the openmp flag
  - Gcc -fopenmp test.cpp
- Environment variables
  - setenv OMP_NUM_THREADS 12
  - export OMP_NUM_THREADS=12

Useful functions

- Thread-ID
  - omp_get_thread_num();
- Amount of threads
  - omp_get_num_threads();
- Set amount of active threads
  - omp_set_num_threads(4);
  - export OMP_NUM_THREADS=12

Directives

- Used to communicate with the compiler
- #pragma directives used to instruct the compiler to use pragmatic or implementation-dependent features
- One such feature is openMP
- #pragma omp parallel

Problems with NUMA

- We do not know where the data is allocated
- We do not know on which NUMA node the thread is running
- So, no openMP on really parallel machines?

New libraries to the rescue

- We can pin threads to processors
- We can control memory allocations
- Tools
  - Numactl
  - libnuma

libnuma

- Provides c++ header files
- Can be used to create numa awareness in the code
- A bit like openMP but instead provides methods for getting numa node and allocating memory on specific numa nodes

Numactl

- Like libnuma, but controlled from the shell
- Can be used to control existing software without changing the code
- Very useful when running experiments

Numactl (continued)

Socket affinity	-N --cpunodebind=	{0,1}	Execute process on cores of these sockets only
Memory policy	-l --localalloc	No argument	Allocate on current socket; fallback to any other if full
Memory policy	-i --interleave=	{0,1}	Allocate round robin (interleave) on these sockets. No fallback
Memory policy	--preferred=	{0,1} select one	Allocate on this socket; fallback to any other if full.
Memory policy	-m --membind=	{0,1}	Allocate only on this (these} socket(s). No fallback.
Core affinity	-C --physcpubind=	{1,2,3,4,5,6,7,8,9,10,11,12}	Execute process on this (these) core(s) only

Examples

Questions?

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