Parallel Computing

2012

Slides credit: Kayvon Fatahalian, CMU & James Demmel, UCB.

Why Parallelism?

One common definition

- A parallel computer is a collection of processing elements that cooperate to solve problems fast

We care about performance *

We're going to use multiple processors to get it

Note: different motivation from "concurrent programming" using pthreads that will be done in Network programming lab course.

Parallel Processing, Concurrency & Distributed Computing

- **Parallel processing**

Performance (and capacity) is the main goal
More tightly coupled than distributed computation

- **Concurrency**

Concurrency control: serialize certain computations to ensure correctness, e.g. database transactions
Performance need not be the main goal

- **Distributed computation**

Geographically distributed
Multiple resources computing & communicating unreliably
"Cloud" or "Grid" computing, large amounts of storage
Looser, coarser grained communication and synchronization

- May or may not involve separate physical resources, e.g. multitasking "Virtual Parallelism"

Course theme 1:

Designing and writing parallel programs ... large scale!

Parallel thinking

1. Decomposing work into parallel pieces
2. Assigning work to processors
3. Orchestrating communication/synchronization

Abstractions for performing the above tasks

Writing code in popular parallel programming languages

Course theme 2:

Parallel computer hardware implementation: how parallel computers work

Mechanisms used to implement abstractions efficiently

- - Performance characteristics of implementations
- - Design trade-offs: performance vs. convenience vs. cost

Why do I need to know about HW?

- Because the characteristics of the machine really matter
- Because you care about performance (you are writing parallel programs)

Course theme 3:

Thinking about efficiency

FAST != EFFICIENT

Just because your program runs faster on a parallel computer, it doesn't mean it is using the hardware efficiently

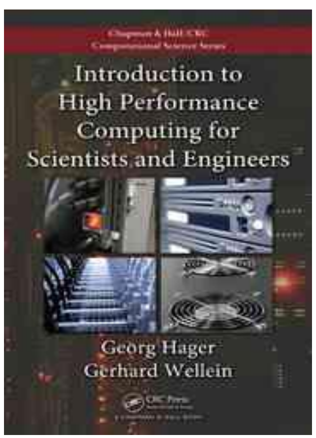
- Is 2x speedup on 10 processors is a good result?

Programmer's perspective: make use of provided machine capabilities

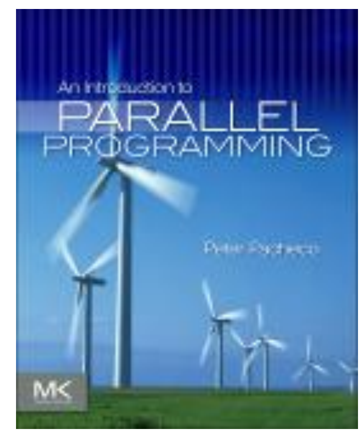
HW designer's perspective: choosing the right capabilities to put in system (performance/cost, cost = silicon area?, power?, etc.)

Course Logistics

Parallel Programming in C with MPI and OpenMP, Quinn (**Quinn book**)



Introduction to High Performance Computing for Computational Scientists and Engineers, by Georg Hager and Gerhard Wellein. (**Hager book**)



"An Introduction to Parallel Programming," Peter Pacheco, Morgan-Kaufmann Publishers, 2011. (**Pacheco book**)

Syllabus

Introduction - Modern Parallel Computers - Types of Concurrency – Programming.

Parallel Architectures – Interconnection Networks – ~~Processor arrays – Multiprocessors – Multi Computers~~ – Flynn's taxonomy.

Parallel Algorithm Design – Foster's Design Methodology – Example Problems. (Parallel Patterns from UIUC and UCB)

Message Passing programming Model – MPI – Point to Point & Collective Calls.

Algorithms for Illustrations – Sieve of Eratosthenes – Floyd's Algorithm.

Performance analysis

- Speed up and Efficiency
- Amdahl's Law
- Gustafson's Barsis Law
- Karp Flatt Metric
- Isoefficiency Metric.

Matrix Vector Multiplication

Monte Carlo Methods

Matrix Multiplication

Solving linear System

finite Difference Methods

sorting algorithm

combinatorial Search.

Shared Memory Programming – Open MP.

Piazza and github links

- Piazza site is up. (soft copies of Hager book and Pacheco book are available)
- Github site will be up soon.
- XSEDE accounts

- (2 or 3) Individual Programming Assignments **(Academic integrity is must)**
- (1 or 2) Group Programming Assignments

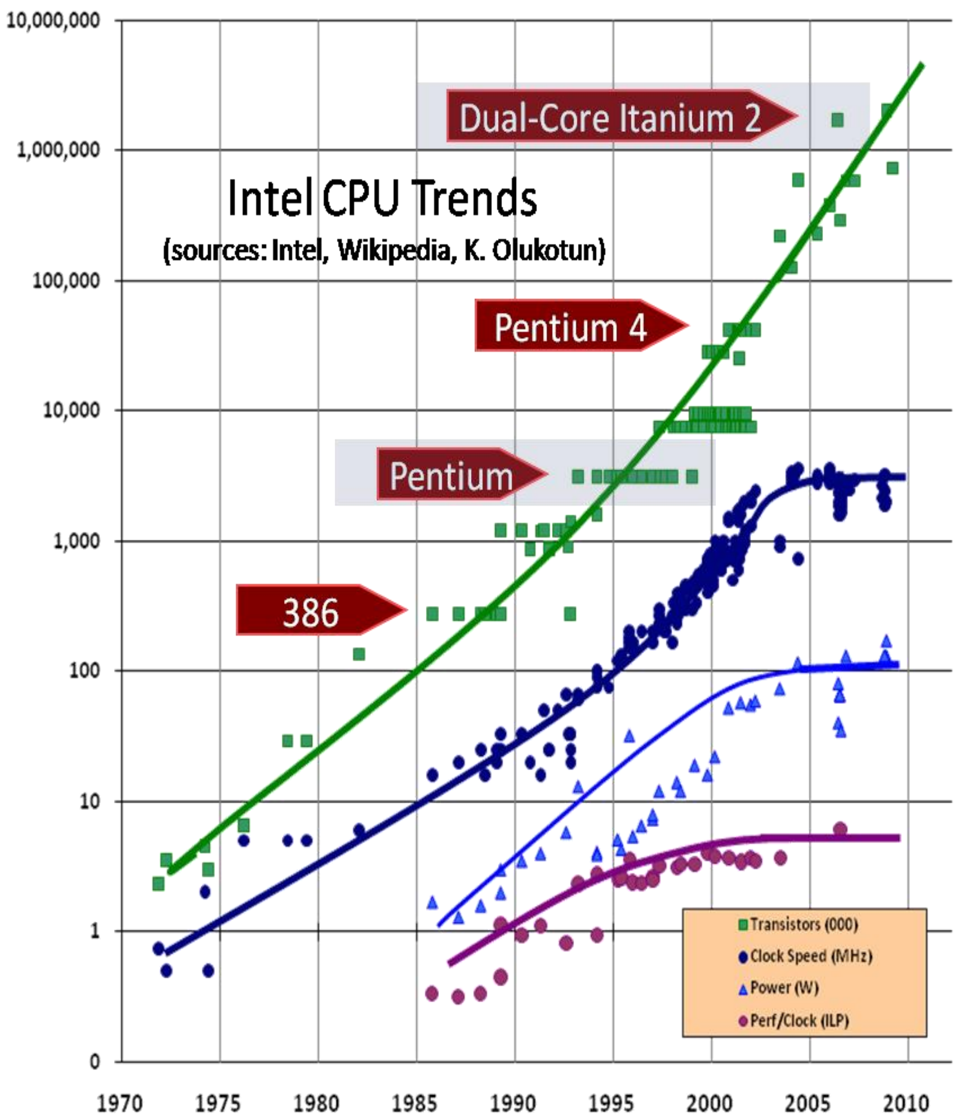
Why parallelism?

The answer 10 years ago

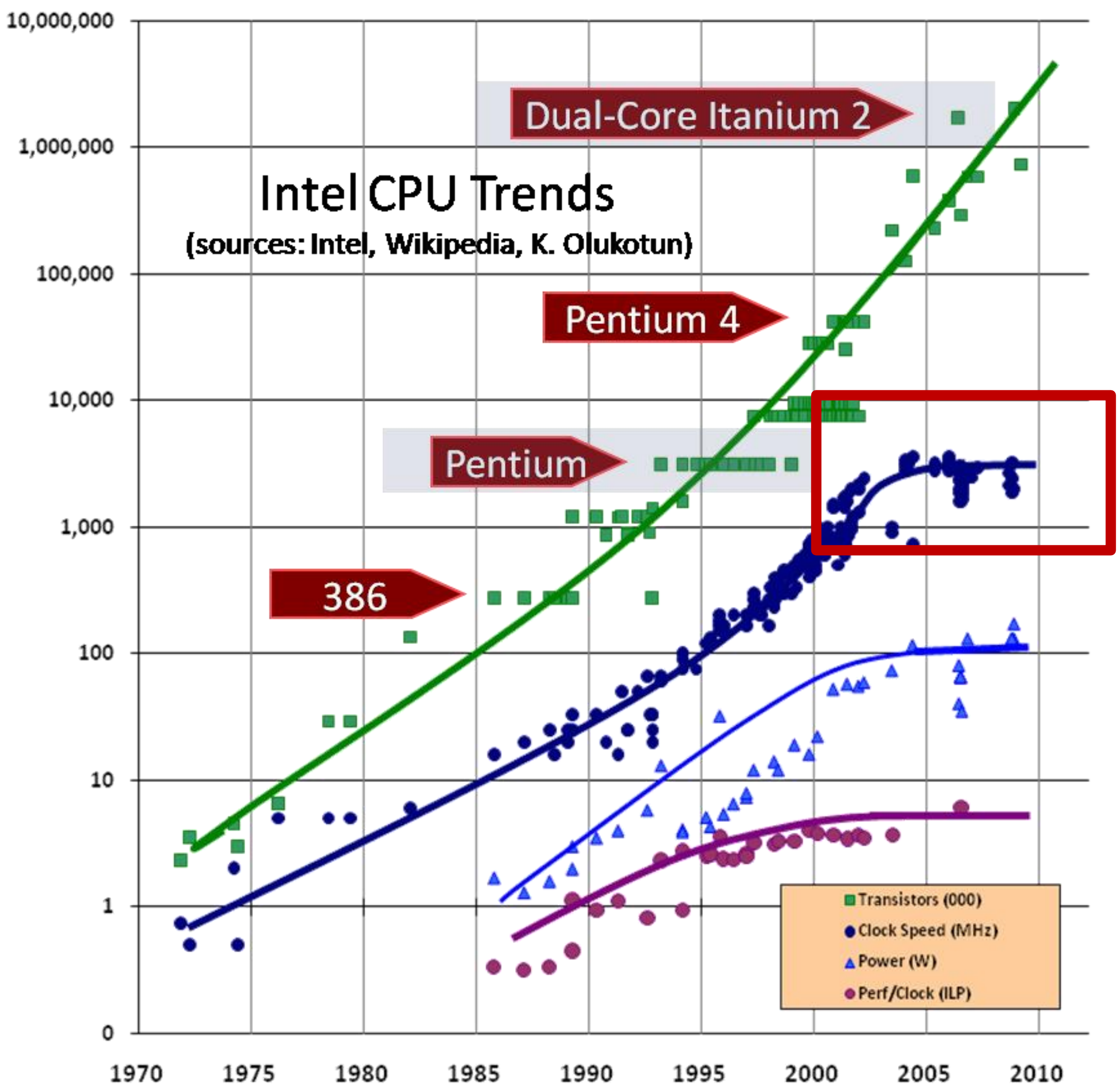
- To get performance that was faster than what clock frequency scaling would provide
- Because if you just waited until next year, your code would run faster on the next generation CPU

Parallelizing your code not always worth the time

- Do nothing: performance doubling ~ every 18 months



End of frequency scaling



Power Wall

P = CV2F

P: power

C: capacitance

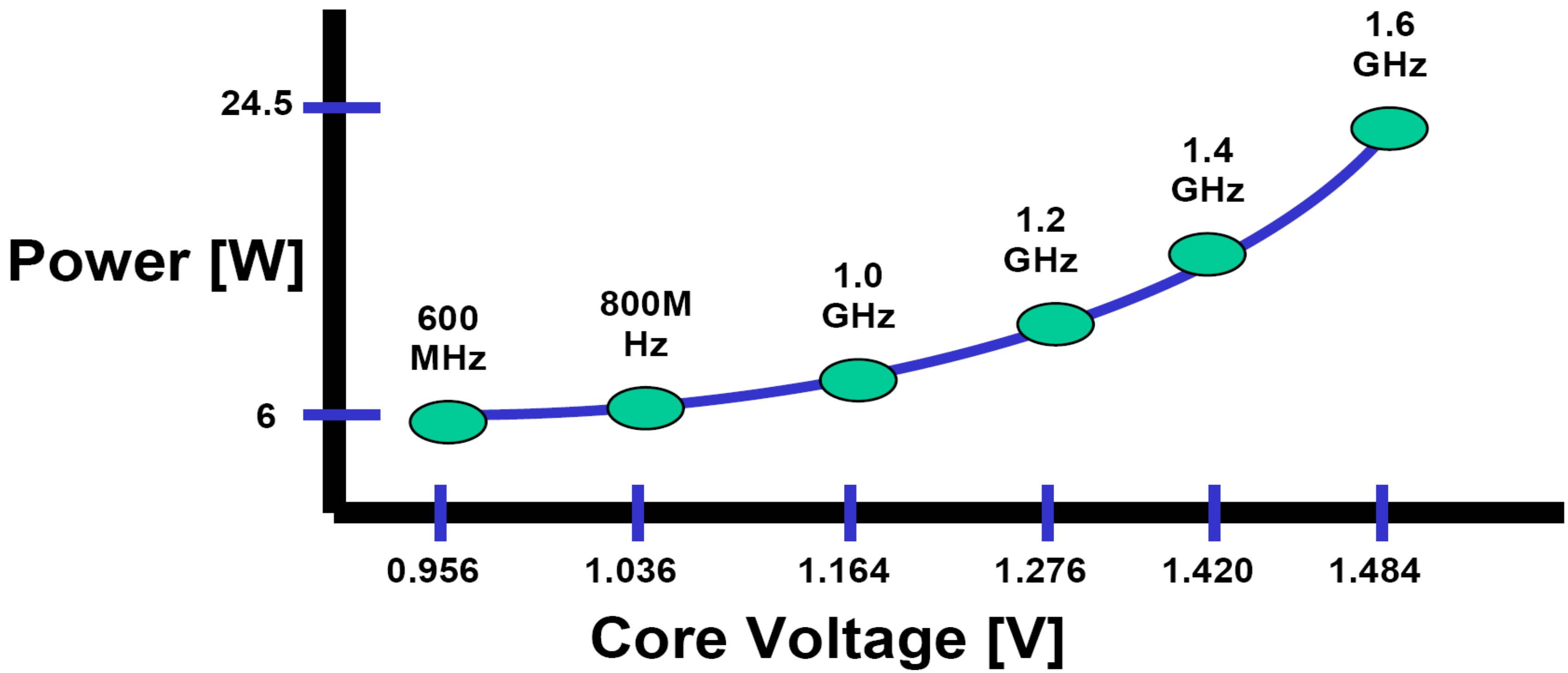
V: voltage

F: frequency

Higher frequencies typically require higher voltages

Power vs. core voltage

Pentium M



Credit: Shimin Chin

Programmable invisible parallelism

Bit level parallelism

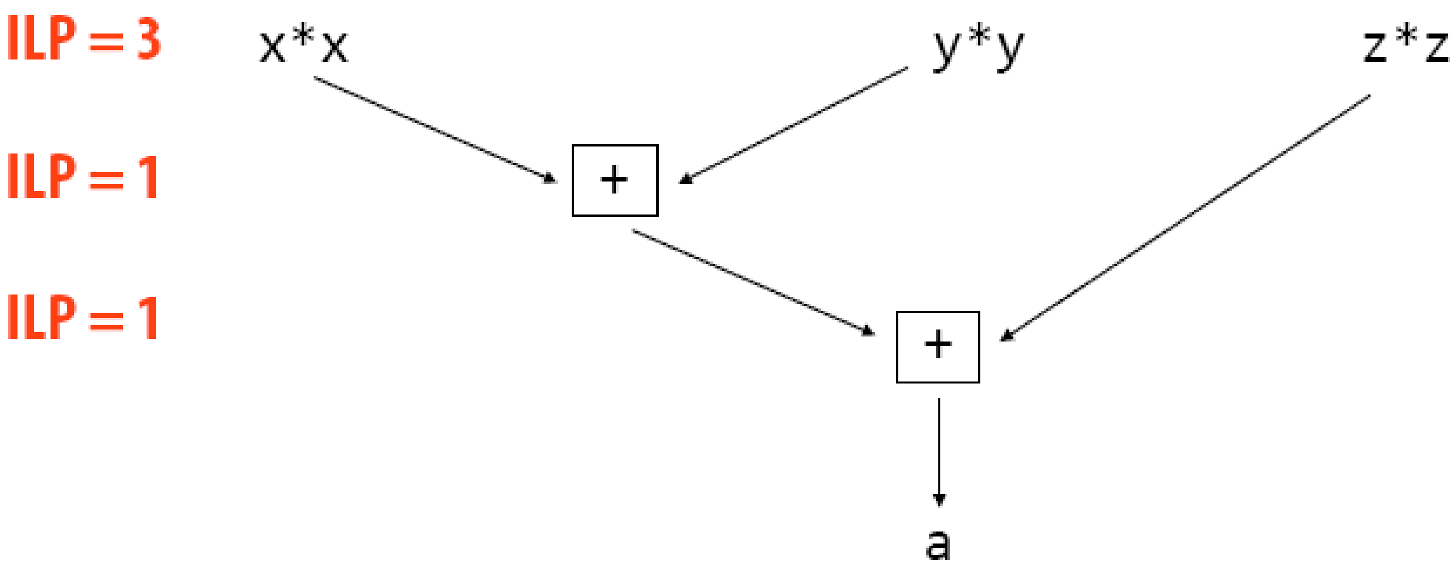
- 16 bit   32 bit   64 bit

Instruction level parallelism (ILP)

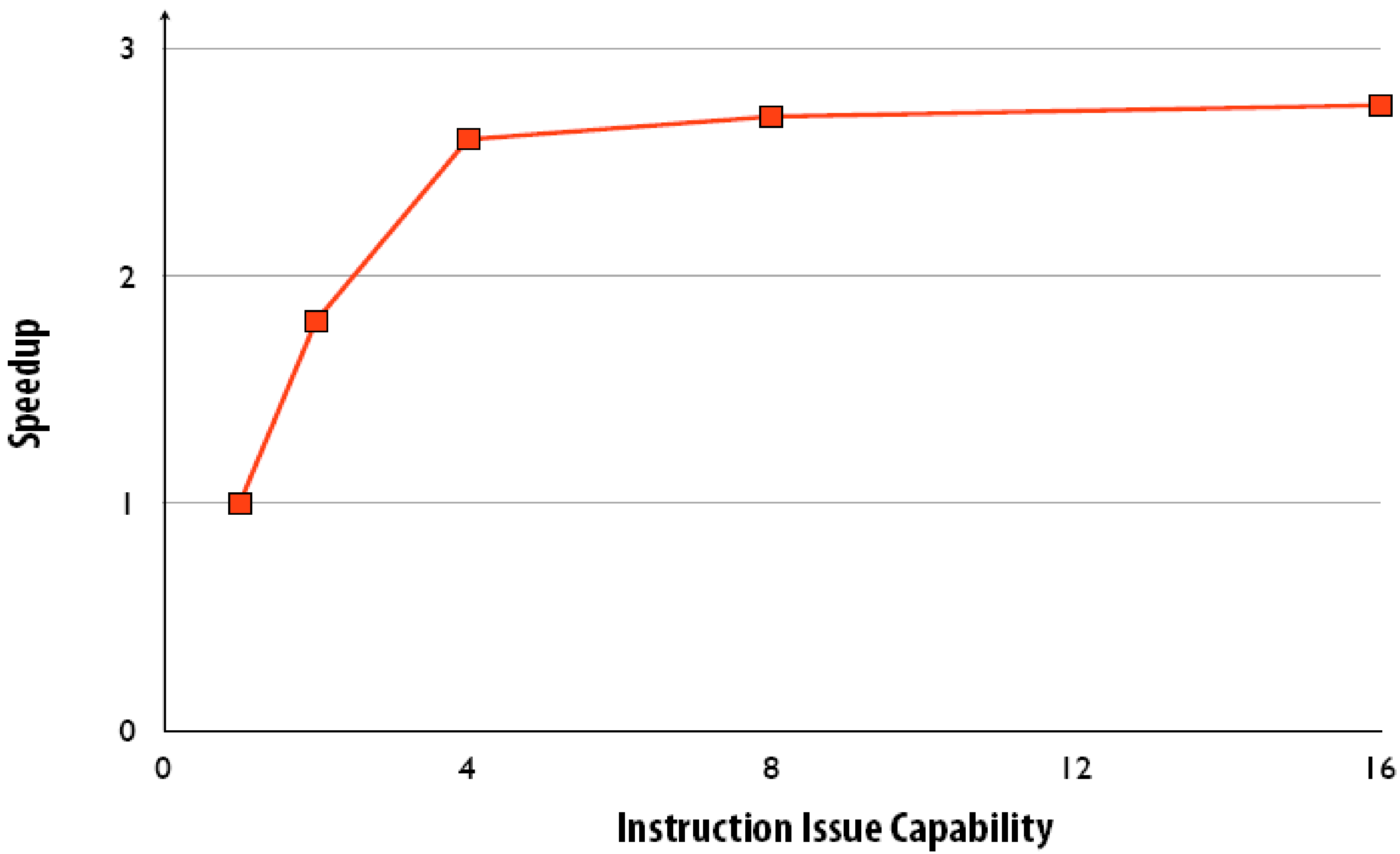
- Two instructions that are independent can be executed simultaneously
- “Superscalar” execution

ILP example

$$a = (x*x + y*y + z*z)$$



ILP scaling

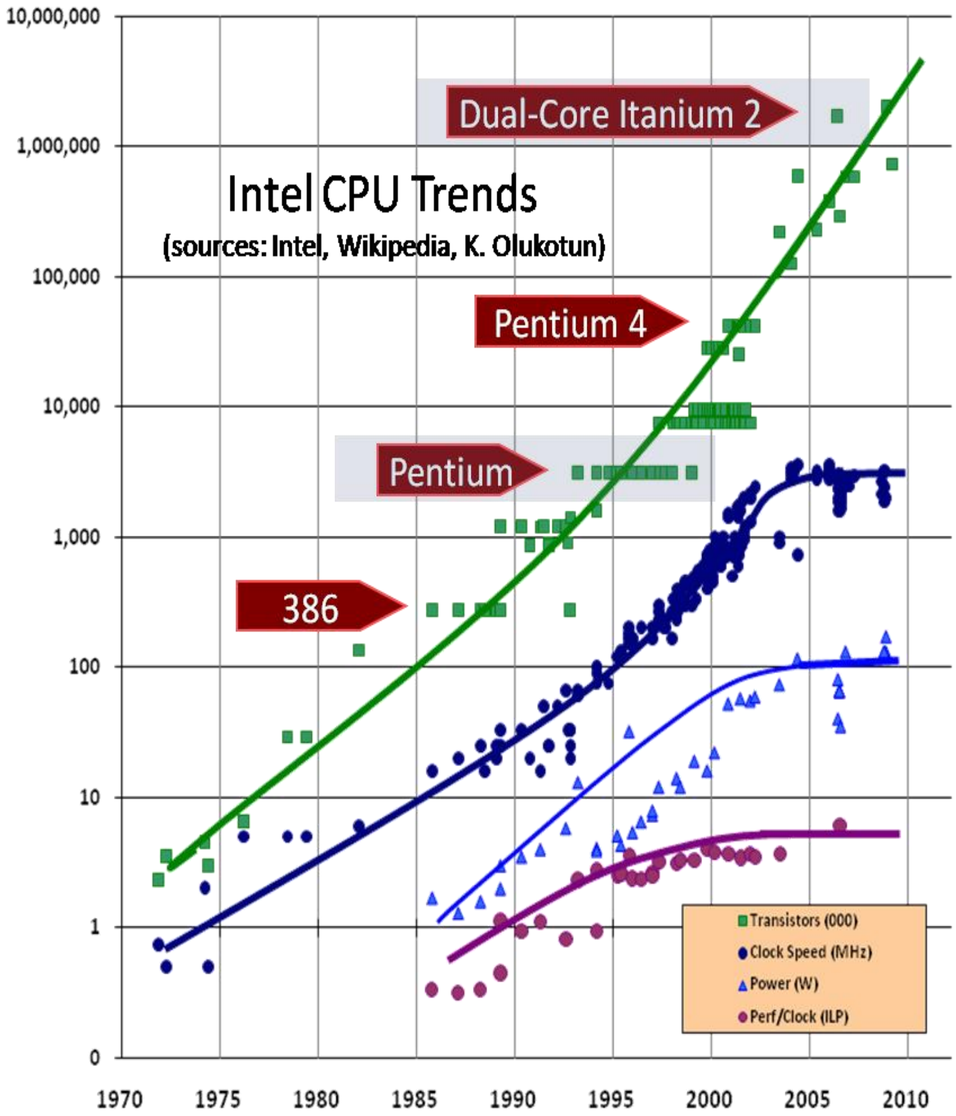


Single core performance scaling

- The rate of single thread performance scaling has decreased (essentially to 0)

  1. Frequency scaling limited by power
  2. ILP scaling tapped out

- No more free lunch for software developers!



Why parallelism?

The answer 10 years ago

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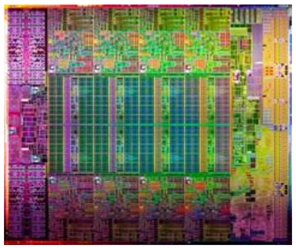
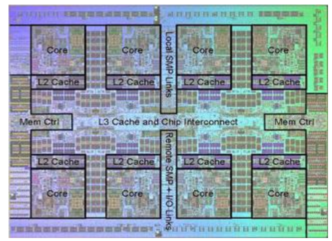
The answer today:

- **Because it is <u>the only way</u> to achieve significantly higher application performance for the foreseeable future**

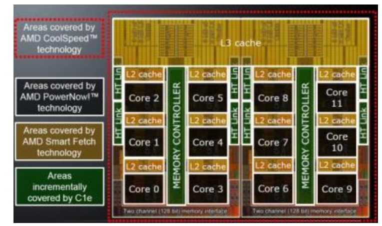
Multi-cores



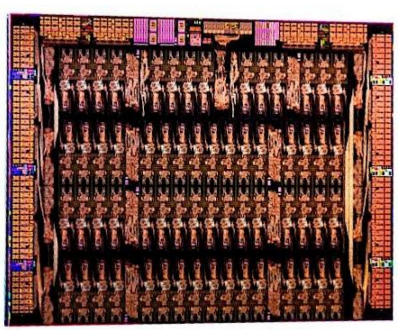
Intel Sandy Bridge
8 cores



IBM Power 7
8 cores



AMD MAGNY-COURS
12 cores



The 62-core Xeon Phi coprocessor

The PCI card housing a Xeon Phi coprocessor

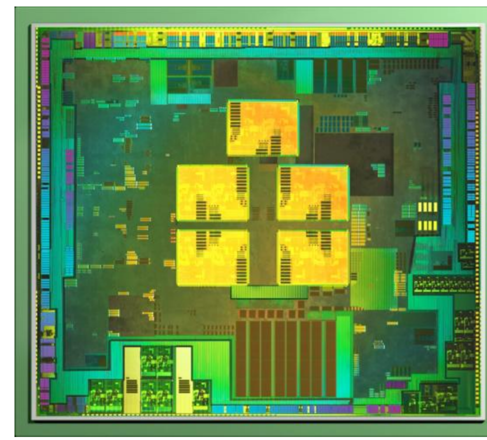
NVIDIA Kepler (2012)

The Tesla K20 GPU coprocessor card
With 2496 CUDA cores, 1.17 Tflops DP

Mobile processing

Power limits heavily influencing designs

Apple A5: (in iPhone 4s and iPad 2)
Dual Core CPU + GPU + image processor and more



NVIDIA Tegra:
Quad core CPU + GPU + image processor...

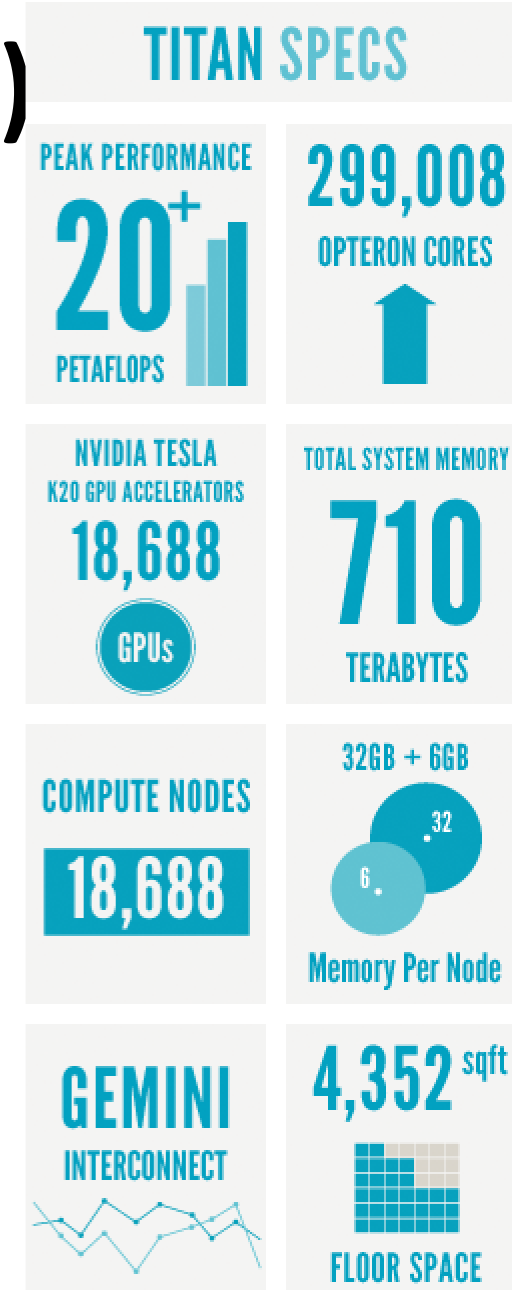
Supercomputing

- **Today: clusters of CPUs + GPUs**
- **Pittsburgh Supercomputing Center: Backlight**
- **512 eight core Intel Xeon processors**

  - 4096 total cores

ORNL Titan (#1,Nov 2012)

- http://www.olcf.ornl.gov/titan/



Some more relevant info from Top500

Summary (what we learned)

Single thread performance scaling has ended

- To run faster, you will need to use multiple processing elements
- Which means you need to know how to write parallel code

Writing parallel programs can be challenging

- Problem partitioning, communication, synchronization
- Knowledge of machine characteristics is important

What you should get out of the course

In depth understanding of:

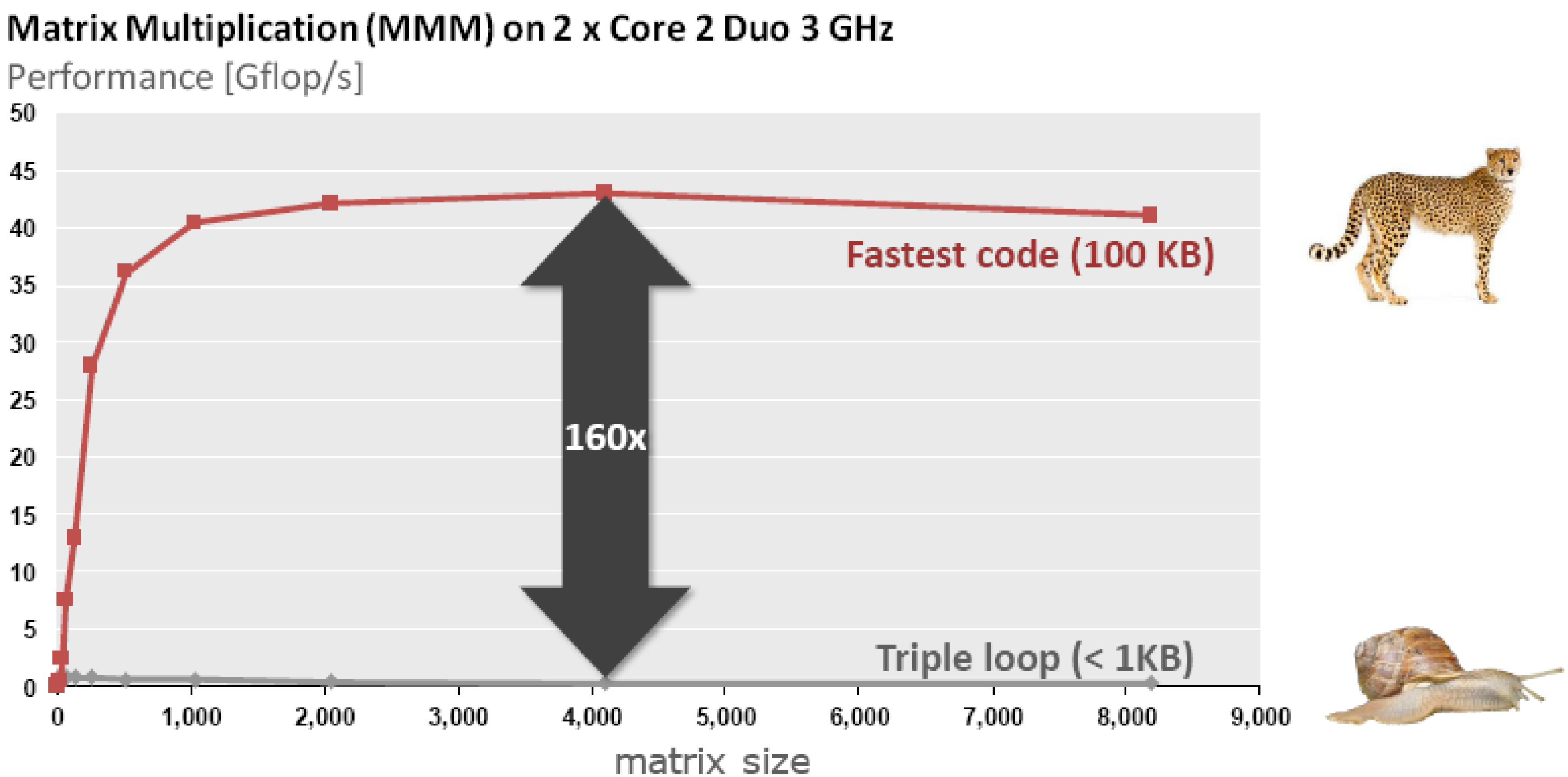
- When is parallel computing useful?
- Understanding of parallel computing hardware options.
- Overview of programming models (software) and tools, and experience using some of them
- Some important parallel applications and the algorithms
- Performance analysis and tuning
- Exposure to various open research questions

Programming for performance

Motivation

- Most applications run at < 10% of the "peak" performance of a system
  - Peak is the maximum the hardware can physically execute
- Much of this performance is lost on a single processor, i.e., the code running on one processor often runs at only 10-20% of the processor peak
- Most of the single processor performance loss is in the memory system
  - Moving data takes much longer than arithmetic and logic
- To understand this, we need to look under the hood of modern processors
  - For today, we will look at only a single "core" processor
  - These issues will exist on processors within any parallel computer

Matrix Multiplication



- Vendor compiler, best flags
- Exact same operations count ($2n^3$)

Possible lessons to learn from these courses

- “Computer architectures are fascinating, and I really want to understand why apparently simple programs can behave in such complex ways!”
- “I want to learn how to design algorithms that run really fast no matter how complicated the underlying computer architecture.”
- “I hope that most of the time I can use fast software that someone else has written and hidden all these details from me so I don’t have to worry about them!”
- All of the above, at different points in time