Lecture 1:
Why Parallelism?

CMU 15-418: Parallel Computer Architecture and Programming (Spring 2012)

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 in 15-213**

DEMO 1

(15-418 Spring 2012's first parallel program)

Speedup

One major motivation of using parallel processing: achieve a speedup

For a fixed problem size:

$$\text{Speedup(P processors)} = \frac{\text{Time (1 processor)}}{\text{Time (P processors)}}$$

Class observations from demos 1

- Communication limited the maximum speedup achieved
- Minimizing the cost of communication improved speedup
  - Moved students ("processors") closer together (or let them shout)

DEMO 2

(scaling up to four processors)

Class observations from demo 2

- Imbalance in work assignment limited speedup
  - Some processors ran out work to do (went idle), while others were still working

- Improving the distribution of work improved speedup

DEMO 3

(massively parallel execution)

Class observations from demo 3

- The problem I just gave you has a significant amount of communication compared to computation
- Communication costs can dominate a parallel computation, severely limiting speedup

Course theme 1:

Designing and writing parallel programs ... <u>that scale</u>!

- **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 (recall speed of communication issues in class demos)
  - 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.)

Logistics

Logistics

- **Kayvon's office hours**
  - Tues/Thurs 1:30-2:30 PM (right after class)
  - GHC 7005

- **TAs**
  - Michael Papamichael
  - Mike Mu

- **Textbook**
  - Culler and Singh, *Parallel Computer Architecture: A Hardware/Software Approach*
  - Yes, it's old. But many parts are still very good.

Logistics: assignments

- Four programming assignments
  - First assignment individual, the rest are in pairs
  - Each in a different parallel programming environment

Assignment 1: ISPC programming on Intel quad-core CPU

Assignment 2: OpenCL programming on NVIDIA GPUs

Assignment 3: OpenMP programming on Supercomputing cluster

Assignment 4: MPI programming on Supercomputing cluster

Logistics: final project

- 6-week final project
- Done in pairs

- Announcing: the first annual 418 parallelism competition!
  - Non-CMU judges from (Intel, NVIDIA, etc.)
  - Expect non-trivial prizes… (e.g., high end GPUs, tablets)

Logistics: grades

40% assignments

30% exams

25% project

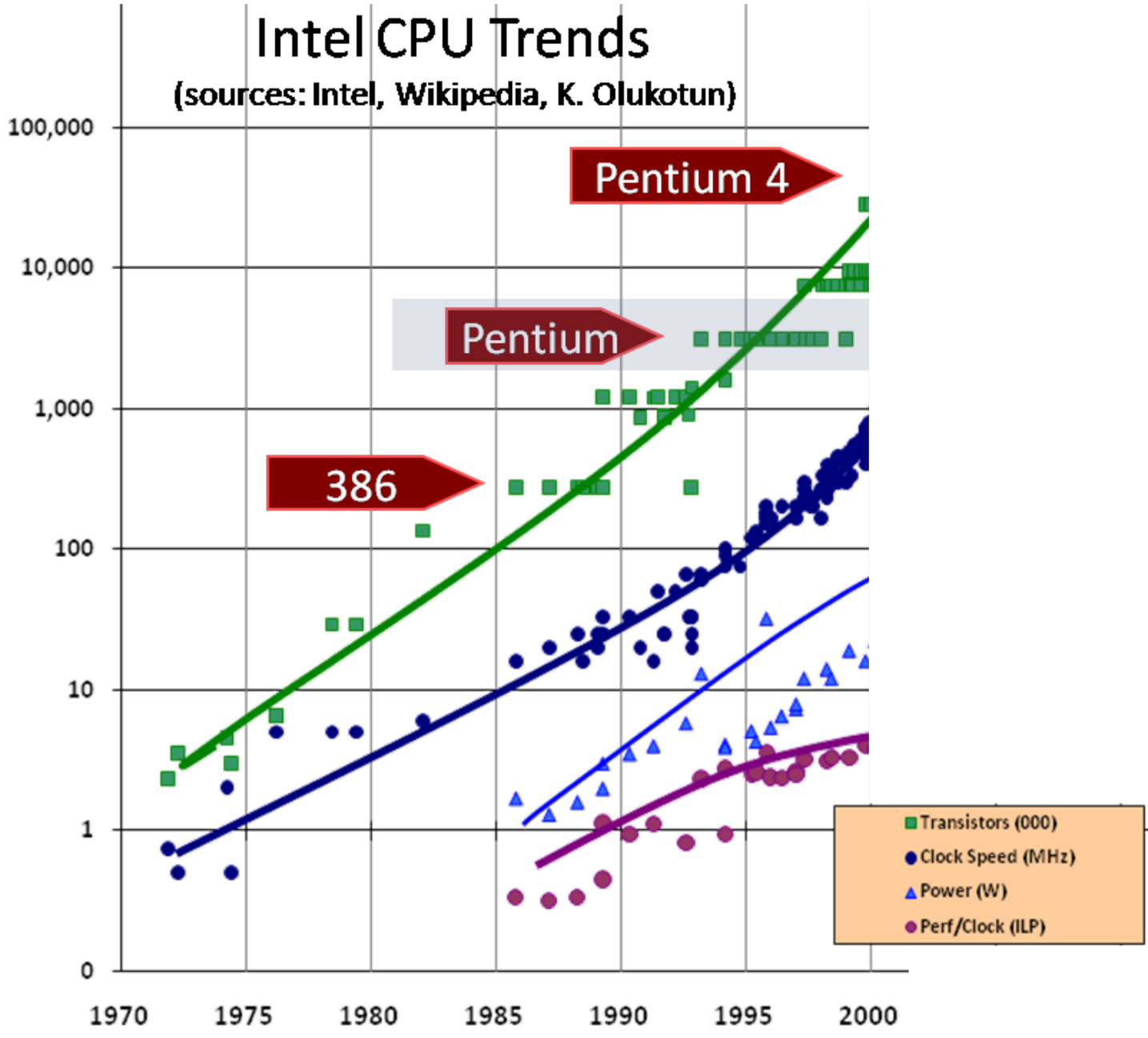
5% class participaction

Why parallelism?

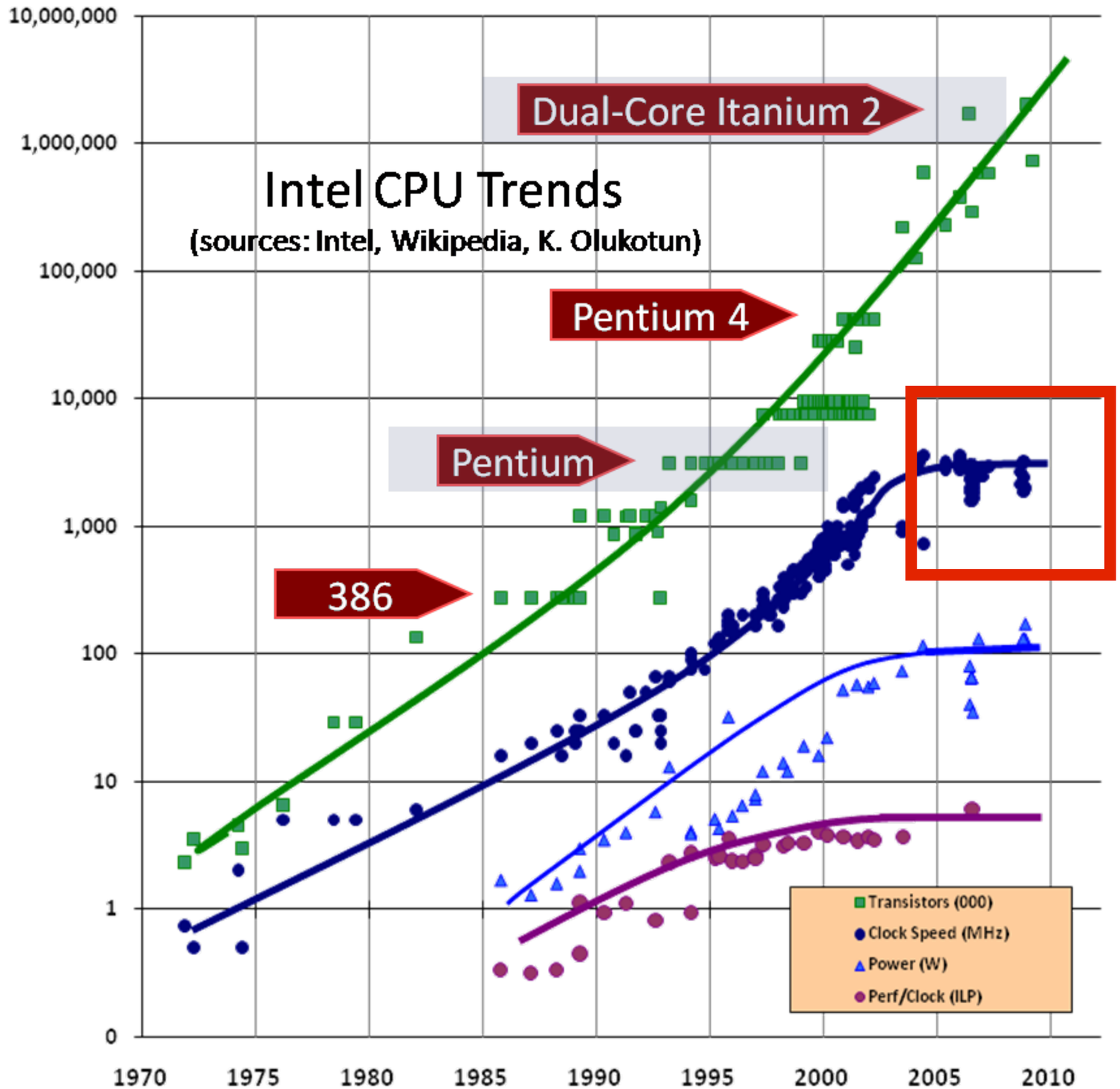
Why parallelism?

- **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

$P = CV^2F$

P: power

C: capacitance

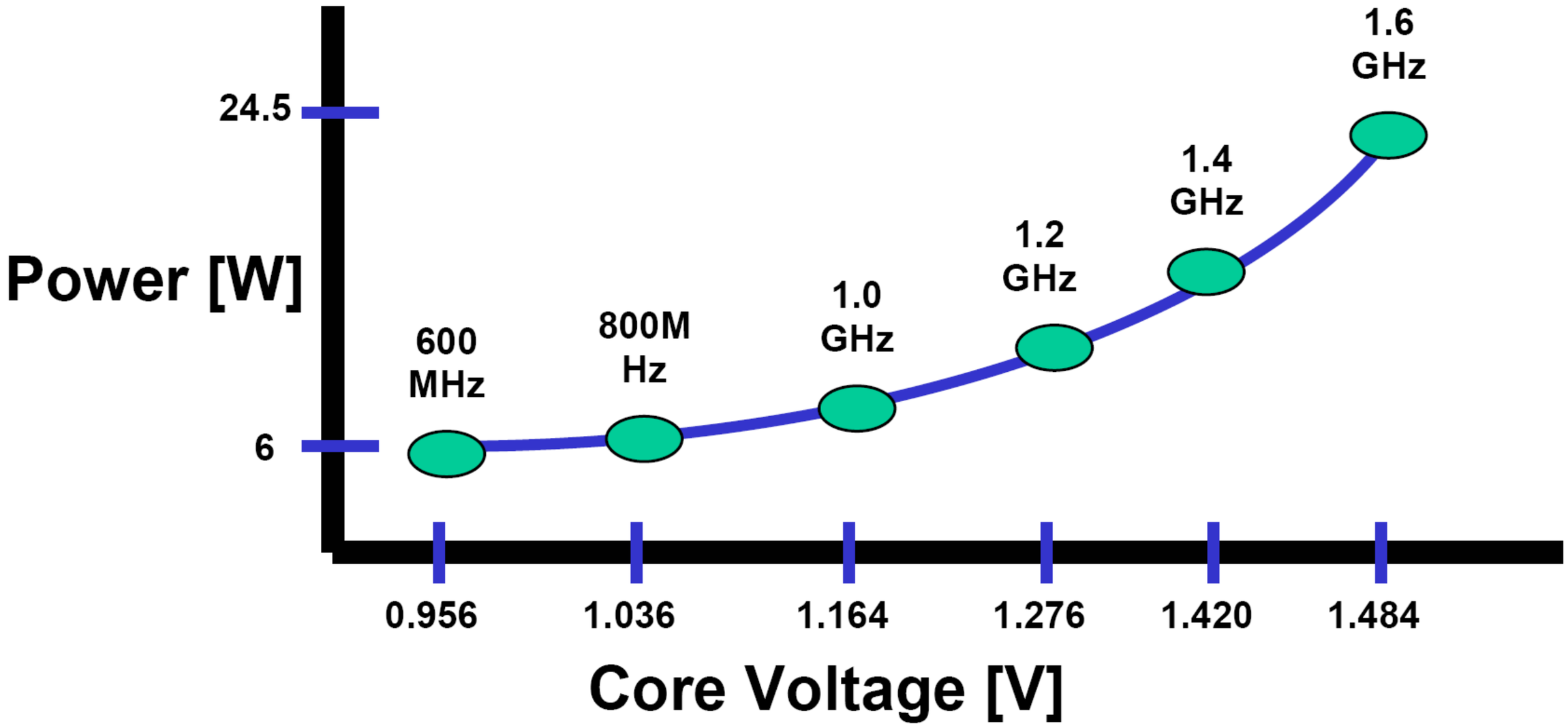
V: voltage

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**

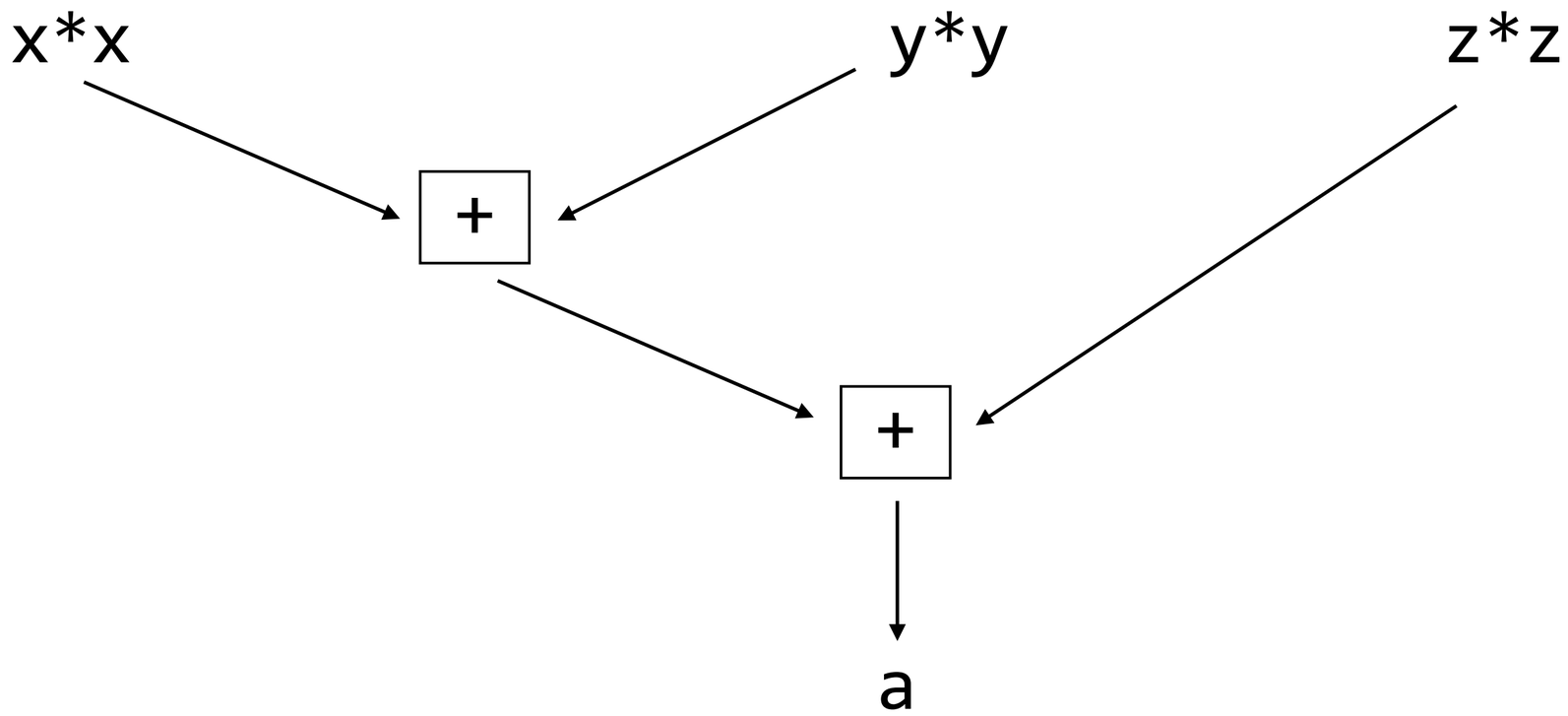
ILP example

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

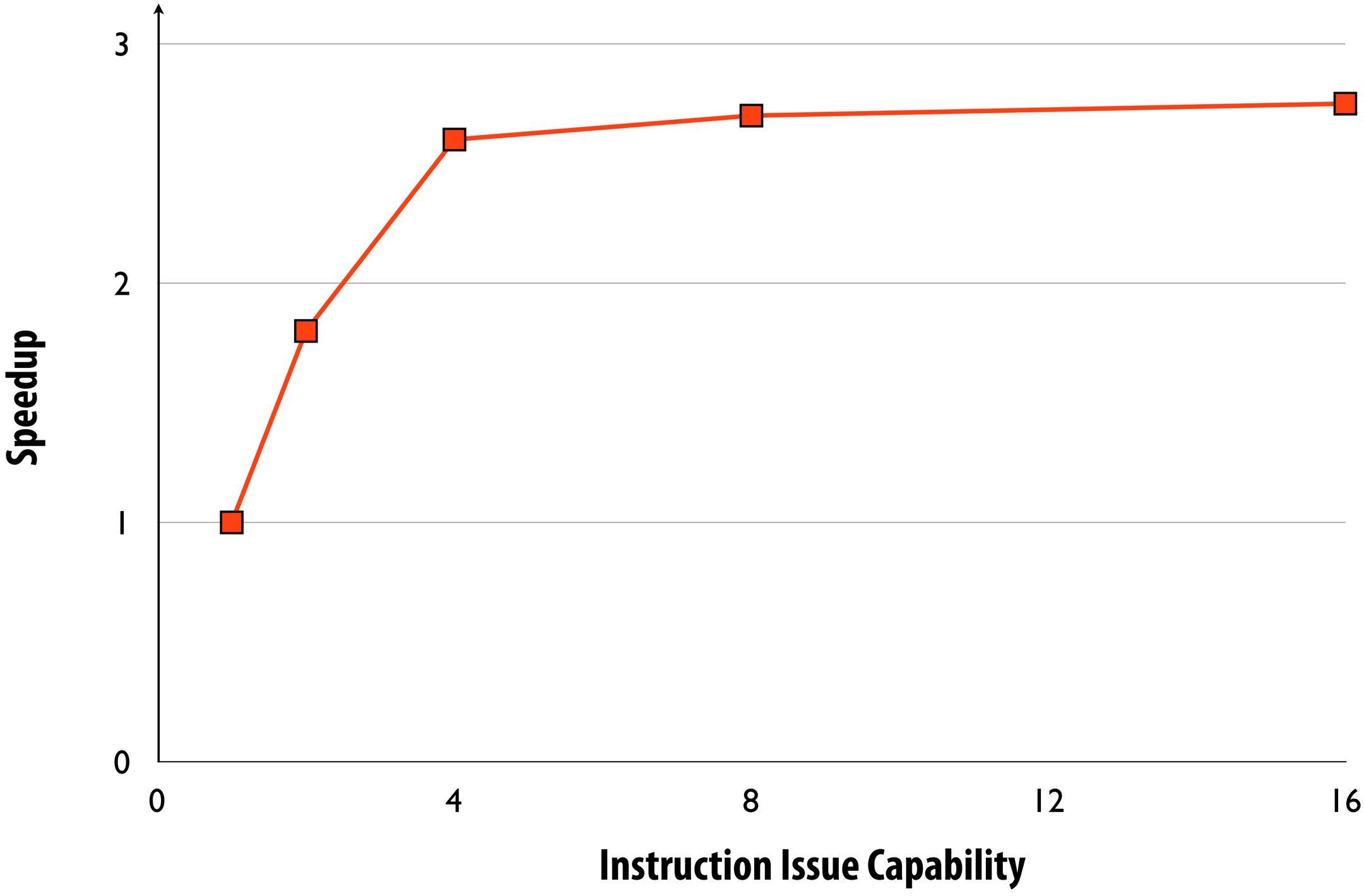
ILP = 3

ILP = 1

ILP = 1



ILP scaling



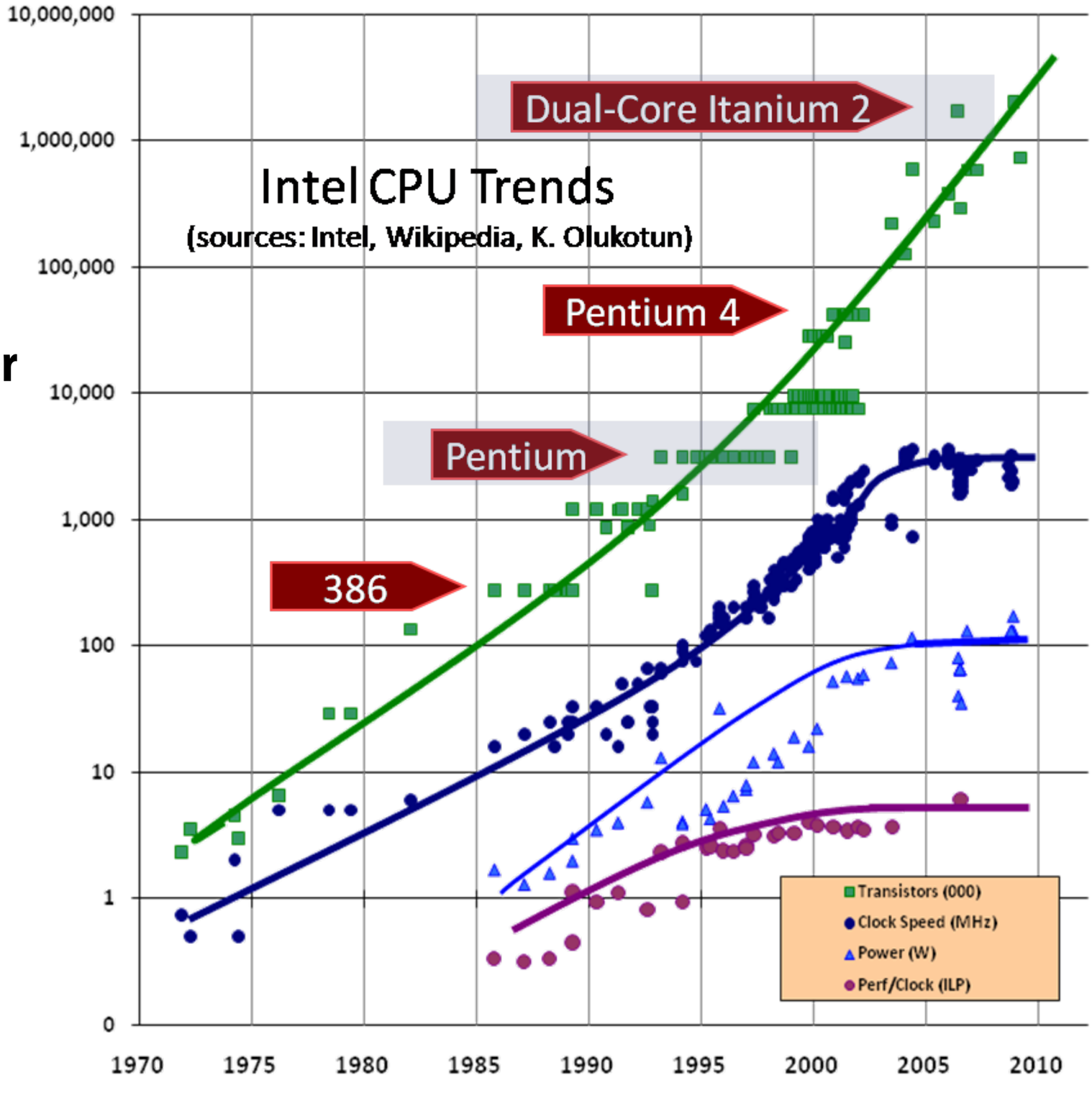
Single core performance scaling

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!



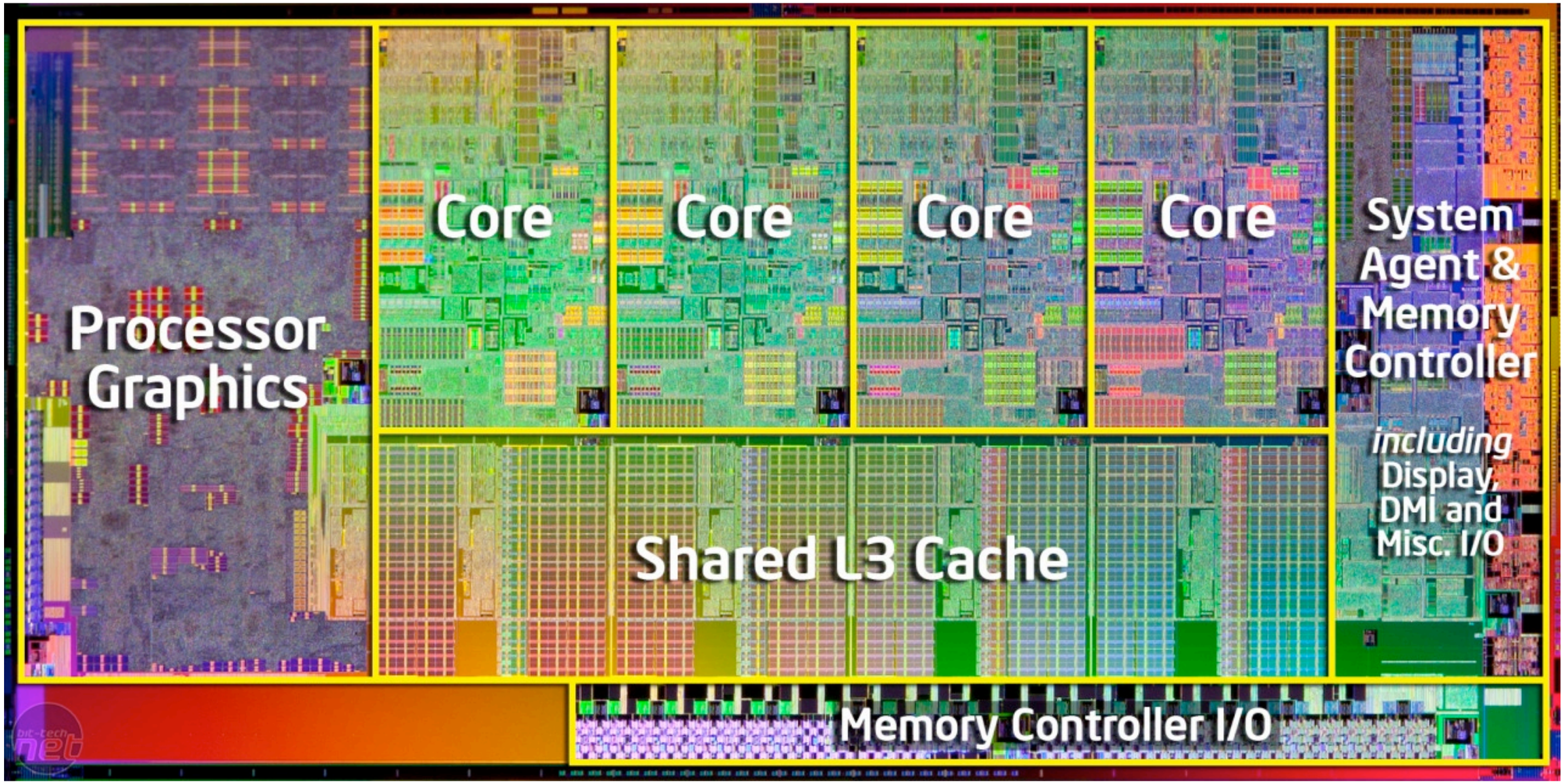
Why parallelism?

- **The answer 10 years ago**
  - 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

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

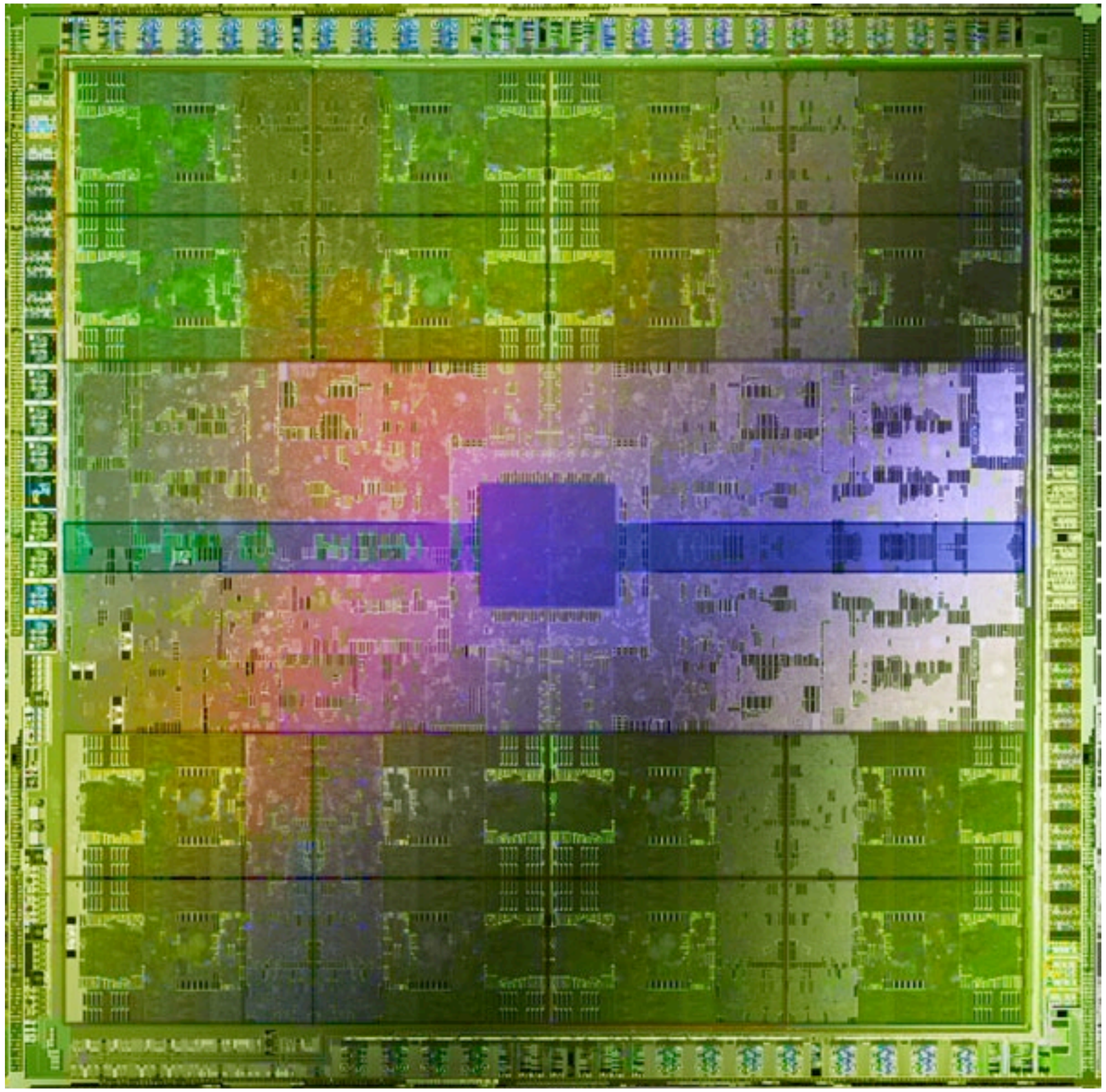
Intel Sandy Bridge (2011)

- Quad core CPU + GPU



NVIDIA Fermi GPU (2009)

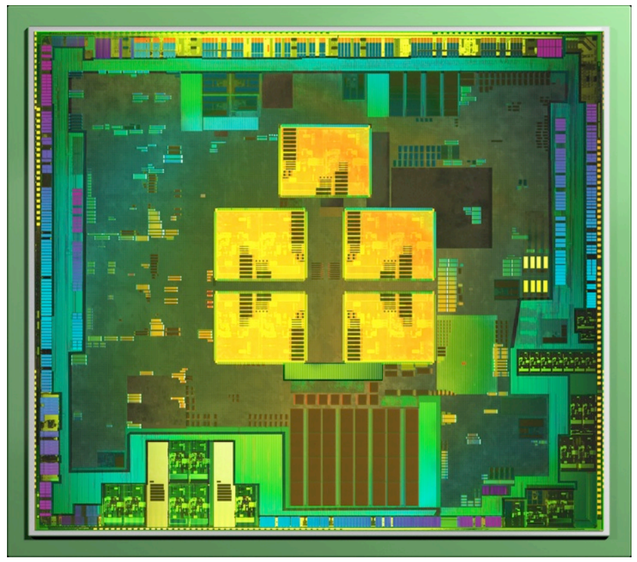
- 16 processing cores



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

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