NYU
New York University

CSCI-UA.0480-003

Parallel Computing

Lecture 1: Why Parallel Computing?

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Who Am I?

- Mohamed Zahran (aka Z)
- Computer architecture/OS/Compilers Interaction
- http://www.mzahran.com
- Office hours: Tuesdays 2-4 pm
  - or by appointment
- Room: WWH 320

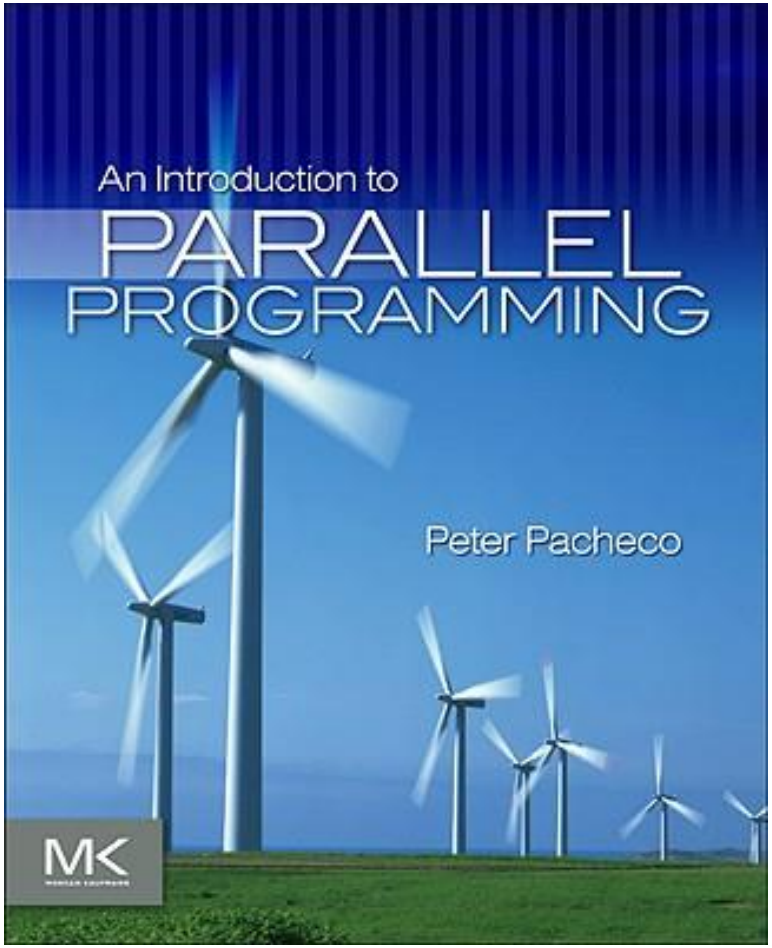
Main Goals of this Course

- Why parallel computing is the current and next big thing?
- How does the parallel hardware look like?
- What are the challenges of parallel computing?
- How to write parallel programs and make the best use of the underlying hardware?

My wish list for this course:

- Learn to think in parallel
- Make the best choice of hardware configuration and software tools/languages
- Be ready for the competitive market or for your next step in the academic/research ladder
- Learn how to progress way beyond the final exam!
- Enjoy the course!

Textbook



- Author : Peter Pacheco
- Release Date: 2011
- Publisher: Morgan Kaufmann
- Print Book ISBN :
  9780123742605

Course Components

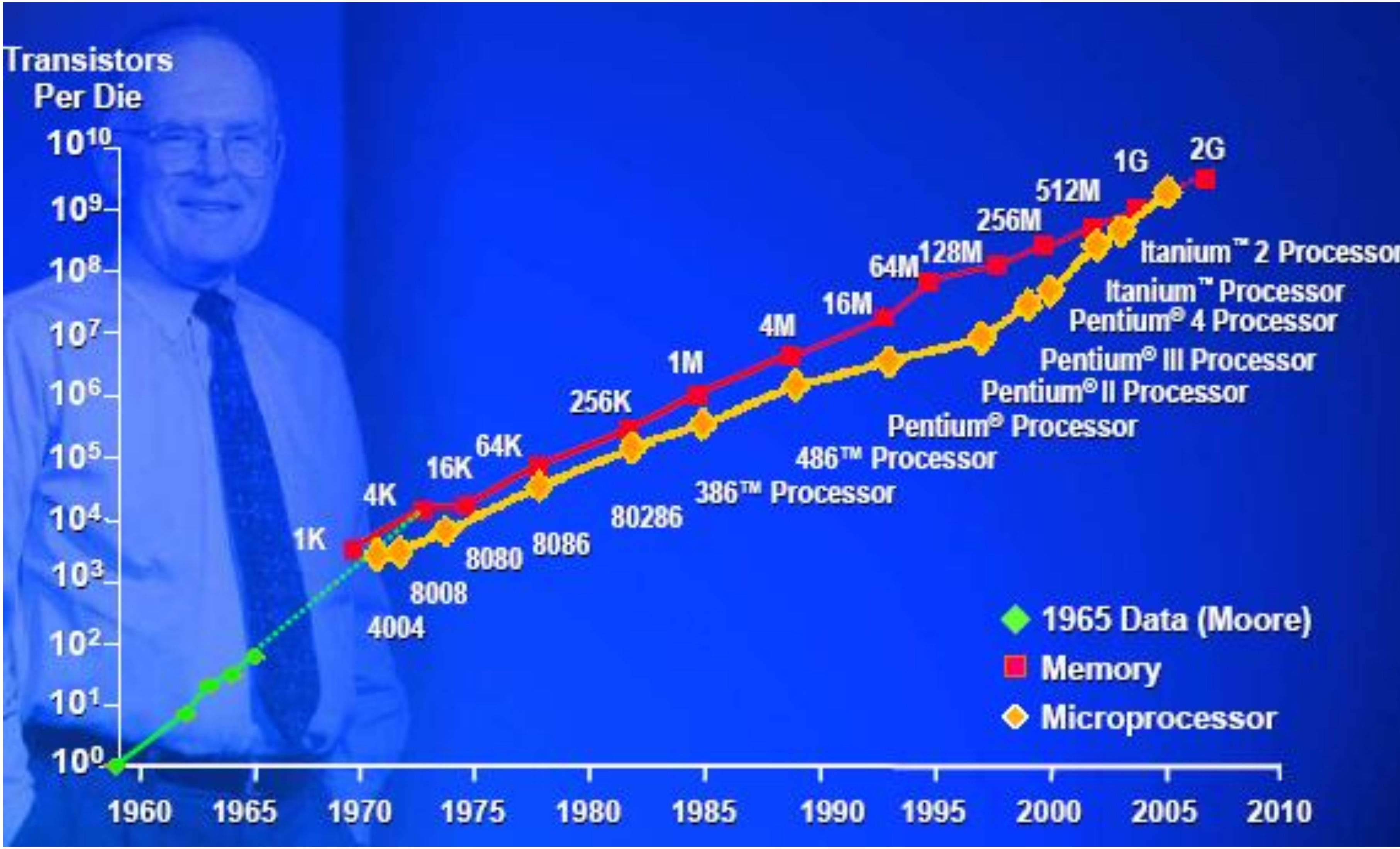
- Lectures
  - Higher level concepts
- Homework assignments (20%)
  - The theoretical part
  - Usually due one week later
- Programming labs (20%)
  - 1-2 weeks each
  - Provide in-depth understanding of some aspect of systems
- One midterm exam (20%)
- One final exam (40%)

Policies: Assignments

- You must work **alone** on all assignments
  - Post all questions on NYU classes forums,
  - You are encouraged to answer others' questions, but refrain from explicitly giving away solutions.
- Hand-ins
  - Labs due at 11:59pm on the due date
  - Homework assignments due at the end of the lecture of the due date
  - (-1) for each day of late submission **up to 3 days then zero** for the corresponding assignment/lab

Now, what is this story of parallel computing, multicore, multiprocessing, multi-this and multi-that?

The Famous Moore's Law



It was implicitly assumed that more transistors per chip = more performance. BUT …

Effect of Moore's law

- ~1986 - 2002 → 50% performance increase
- Since 2002 → ~20% performance increase

Hmmm …

- Why do we care? 20%/year is still nice.
- What happened at around 2002?
- Can't we have auto-parallelizing programs?

Why do we care?

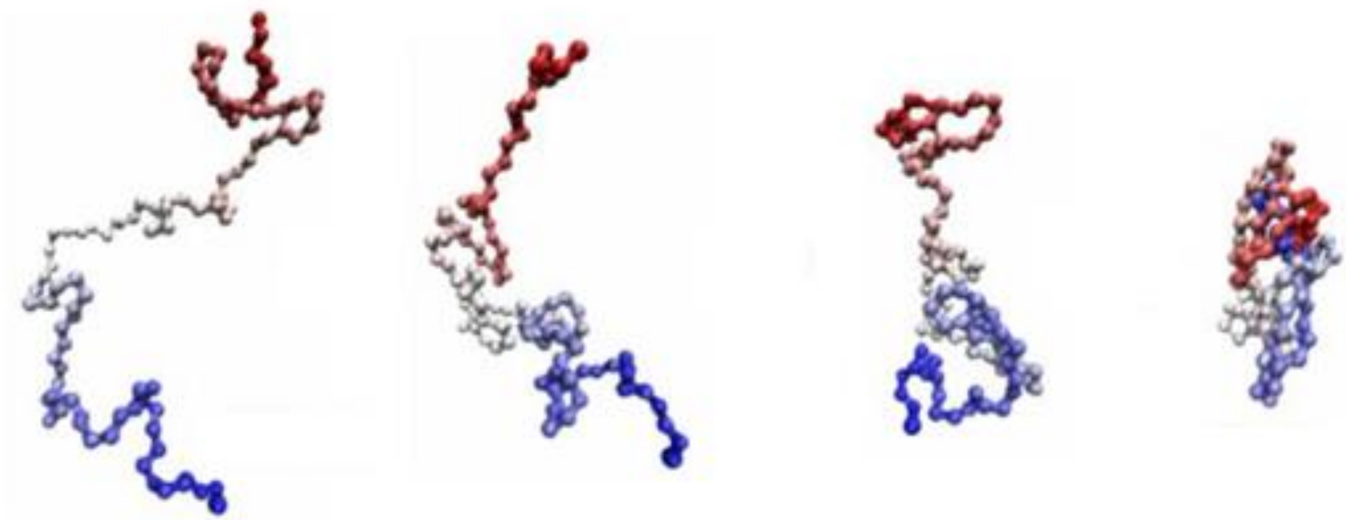
- More realistic games
- Decoding the human genome
- More accurate medical applications

The list goes on and on ....

As our computational power increases → the number of problems we can seriously consider also increases.

Climate modeling

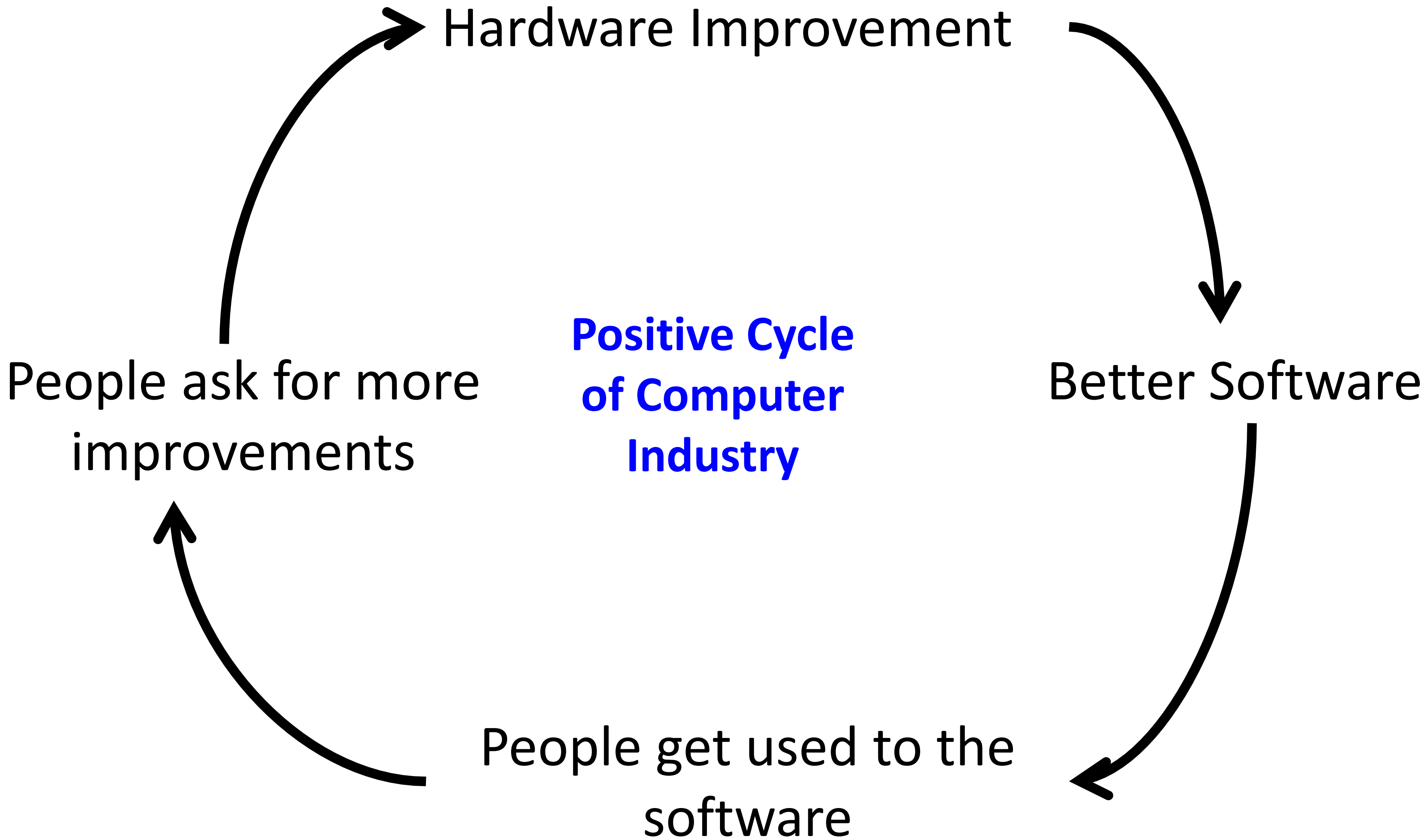
Protein folding



Drug discovery

Energy research

Data analysis

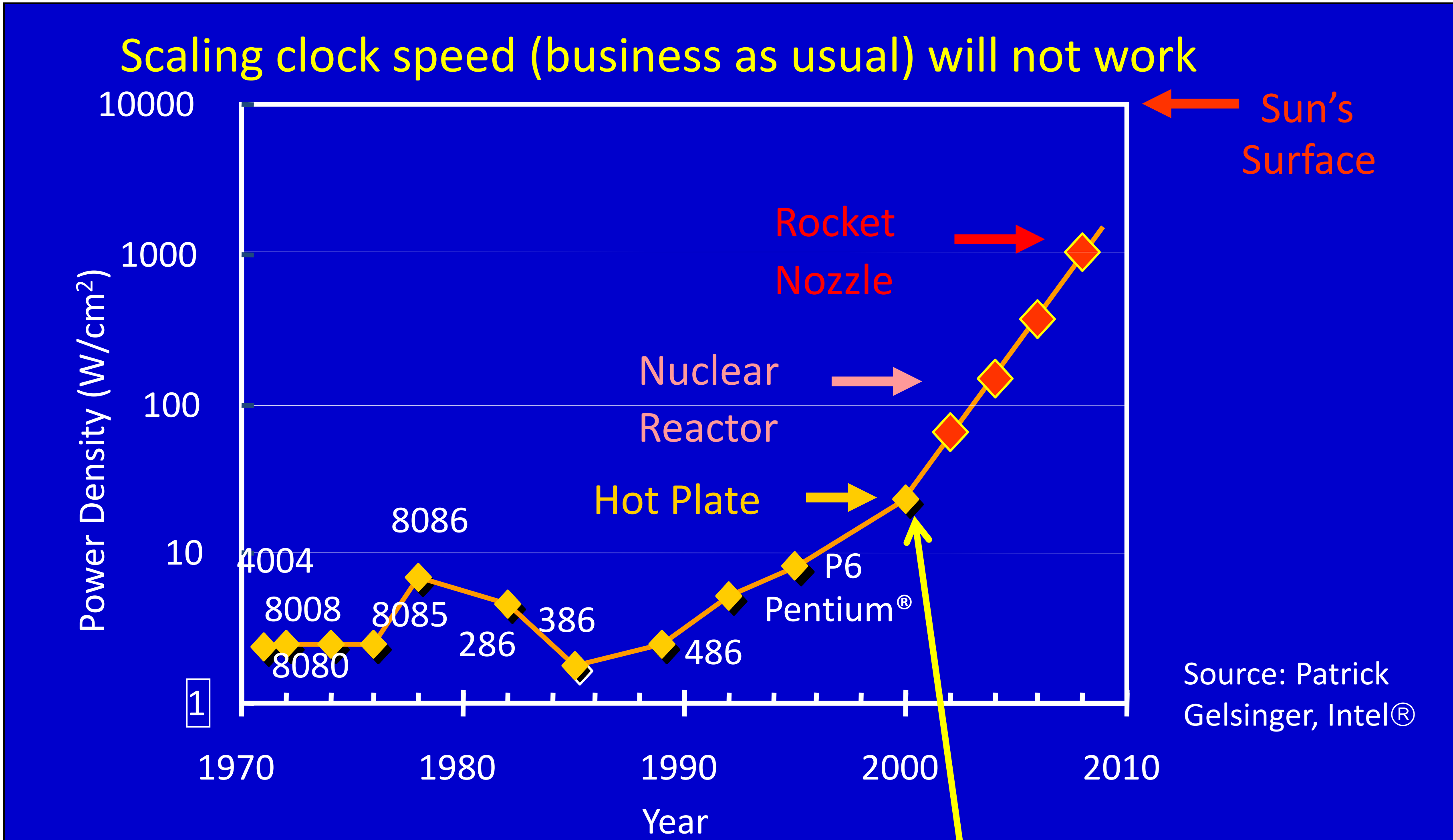

Hardware Improvement
Better Software
People get used to the software
People ask for more improvements
Positive Cycle of Computer Industry

Why did we build parallel machines (and continue to do so)?

(multicore, multiprocessors, multi-anything!)

Power Density

Moore's law is giving us more transistors than we can afford!



This is what happened at around 2002!

Multicore Processors Save Power

Power = $C * V^2 * F$

Performance = Cores * F

Let's have two cores

Power = $2*C * V^2 * F$

Performance = 2*Cores * F

But decrease frequency by 50%

Power = $2*C * V^2/4 * F/2$

Performance = 2*Cores * F/2

Power = $C * V^2/4 * F$

Performance = Cores * F

A Case for Multiple Processors

- Can exploit different types of parallelism
- Reduces power
- An effective way to hide memory latency
- Simpler cores

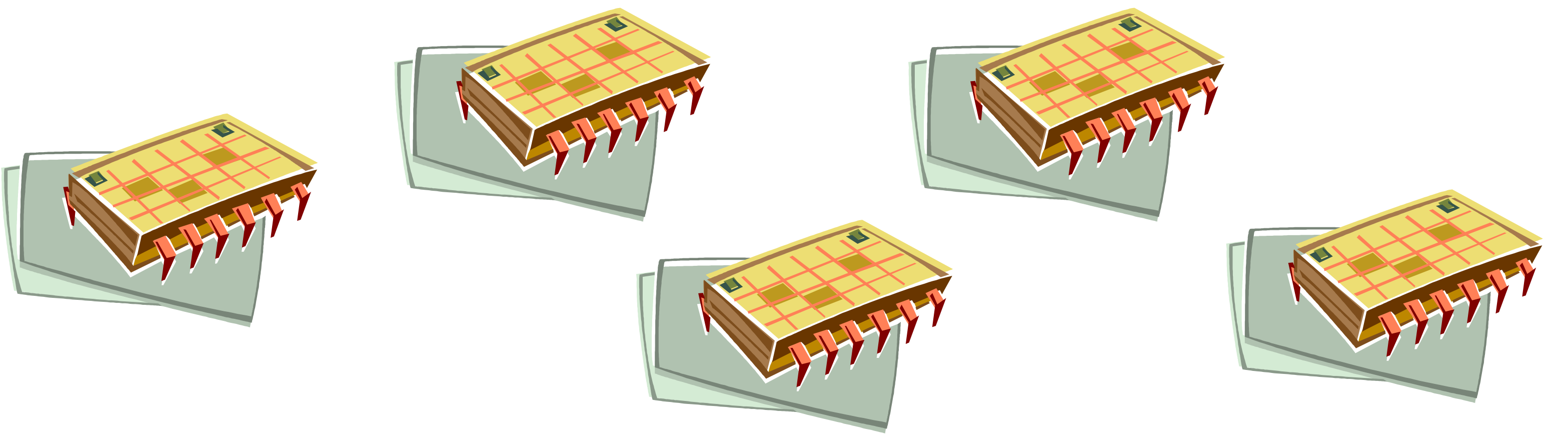
  = easier to design and test

  = higher yield

  = lower cost

An intelligent solution

- Instead of designing and building faster microprocessors, put <u>multiple</u> processors on a single integrated circuit.



Now it's up to the programmers

- Adding more processors doesn't help much if programmers aren't aware of them…
- … or don't know how to use them.

- Serial programs don't benefit from this approach (in most cases).

The Need for Parallel Programming

Parallel computing: using multiple processors in parallel to solve problems more quickly than with a single processor

Examples of parallel machines:

A cluster computer that contains multiple PCs combined together with a high speed network

A shared memory multiprocessor (SMP) by connecting multiple processors to a single memory system

A Chip Multi-Processor (i.e. multicore) (CMP) contains multiple processors (called cores) on a single chip

Attempts to Make Multicore Programming Easy

- 1st idea: The right computer language would make parallel programming straightforward
  - **Result so far**: Some languages made parallel programming easier, but none has made it as fast, efficient, and flexible as traditional sequential programming.

Attempts to Make Multicore Programming Easy

- 2nd idea: If you just design the hardware properly, parallel programming would become easy.
  - **Result so far**: no one has yet succeeded!

Attempts to Make Multicore Programming Easy

- 3rd idea: Write software that will automatically parallelize existing sequential programs.
  - **Result so far**: Success here is inversely proportional to the number of cores!

Parallelizing a sequential program is not very easy!

- It is not about parallelizing every step of the sequential program.
- Maybe we need a totally new algorithm.
- Our parallelization strategy also depends on the software!

Example

- Compute n values and add them together.
- Serial solution:

```
sum = 0;
for (i = 0; i < n; i++) {
    x = Compute_next_value(. . .);
    sum += x;
}
```

Example (cont.)

- We have p cores, p much smaller than n.
- Each core performs a partial sum of approximately n/p values.

```
my_sum = 0;
my_first_i = . . . ;
my_last_i = . . . ;
for (my_i = my_first_i; my_i < my_last_i; my_i++) {
   my_x = Compute_next_value( . . .);
   my_sum += my_x;
}
```

Each core uses it's own private variables and executes this block of code independently of the other cores.

Example (cont.)

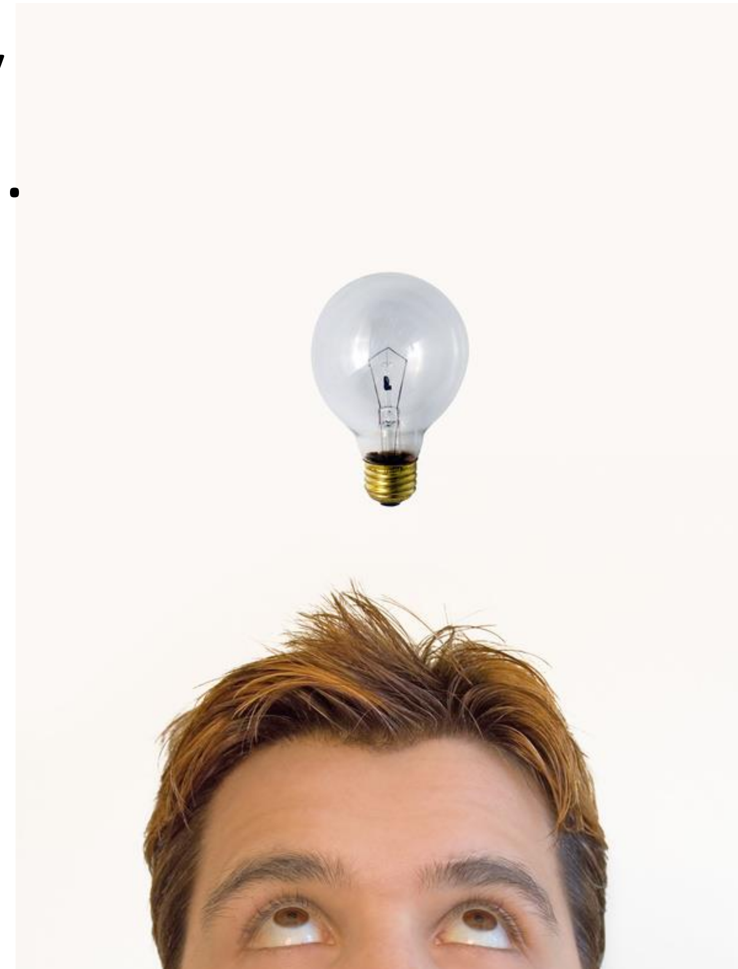
- Once all the cores are done computing their private my_sum, they form a global sum by sending results to a designated "master" core which adds the final result.

Example (cont.)

```
if (I'm the master core) {
    sum = my_x;
    for each core other than myself {
        receive value from core;
        sum += value;
    }
} else {
    send my_x to the master;
}
```

But wait!

There's a much better way to compute the global sum.



Better parallel algorithm

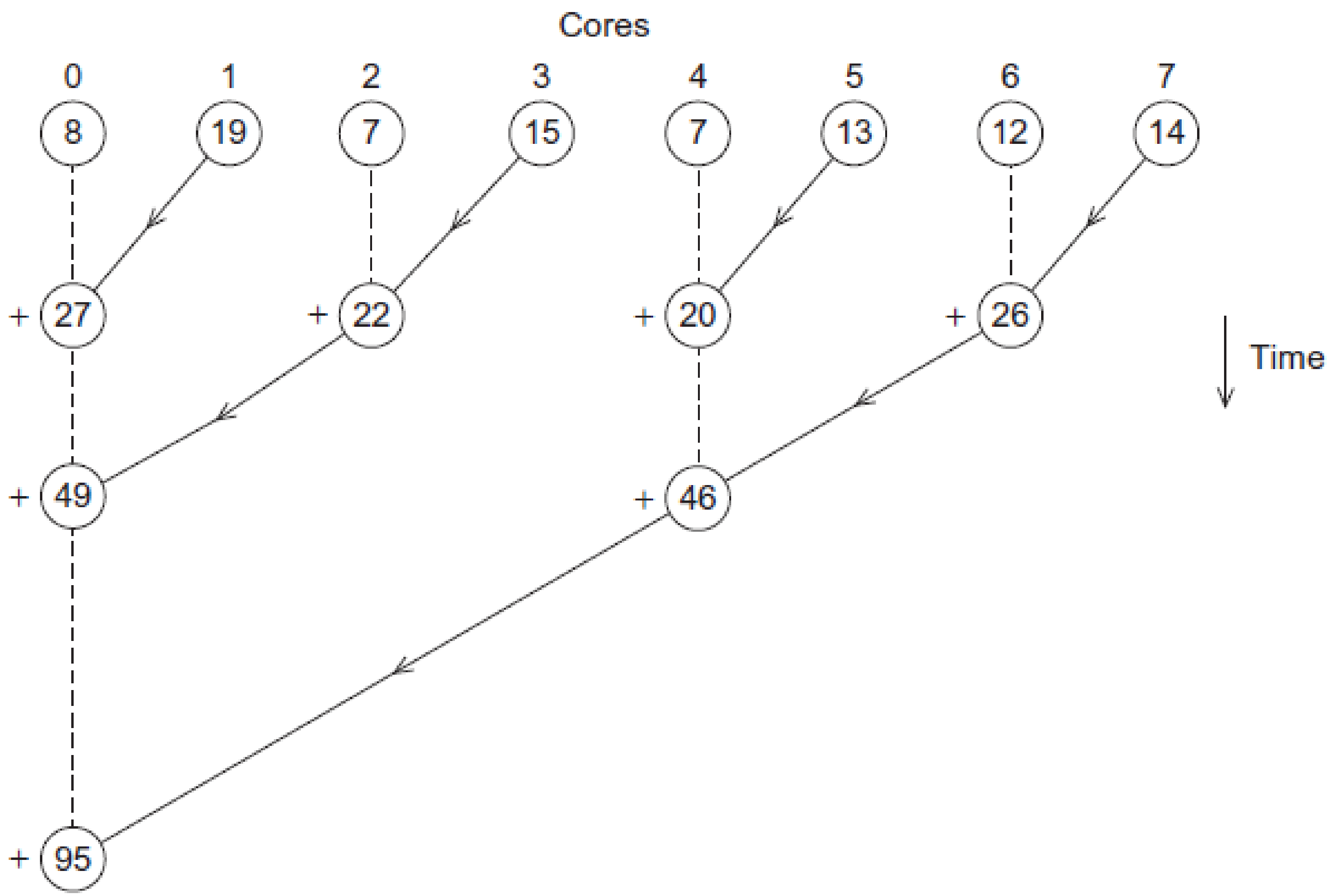
- Don't make the master core do all the work.
- Share it among the other cores.
- Pair the cores so that core 0 adds its result with core 1's result.
- Core 2 adds its result with core 3's result, etc.
- Work with odd and even numbered pairs of cores.

Better parallel algorithm (cont.)

- Repeat the process now with only the evenly ranked cores.
- Core 0 adds result from core 2.
- Core 4 adds the result from core 6, etc.

- Now cores divisible by 4 repeat the process, and so forth, until core 0 has the final result.

Multiple cores forming a global sum



Analysis

- In the first version, the master core performs 7 receives and 7 additions.
- In the second version, the master core performs 3 receives and 3 additions.
- The improvement is more than a factor of 2.

Analysis (cont.)

- The difference is more dramatic with a larger number of cores.
- If we have 1000 cores:
  - The first example would require the master to perform 999 receives and 999 additions.
  - The second example would only require 10 receives and 10 additions.

- That's an improvement of almost a factor of 100!!

Two Ways Of Thinking …
And one Strategy!

- Strategy: Partitioning!
- Two ways of thinking:
  - Task-parallelism
  - Data-parallelism
- Some constraints:
  - communication
  - load balancing
  - synchronization

Conclusions

- Due to technology constraints, we moved to multicore processors.
- Parallel programming is now a must → The free lunch is over!
- There are different flavors of parallel hardware that we will discuss and also many flavors of parallel programming languages that we will deal with.