Parallelism and Concurrency

COS 326
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Parallelism

- What is it?
- Today's technology trends.
- How can we take advantage of it?
- Why is it so much harder to program?
- Some preliminary linguistic constructs
  - thread creation
  - thread coordination: futures and locks

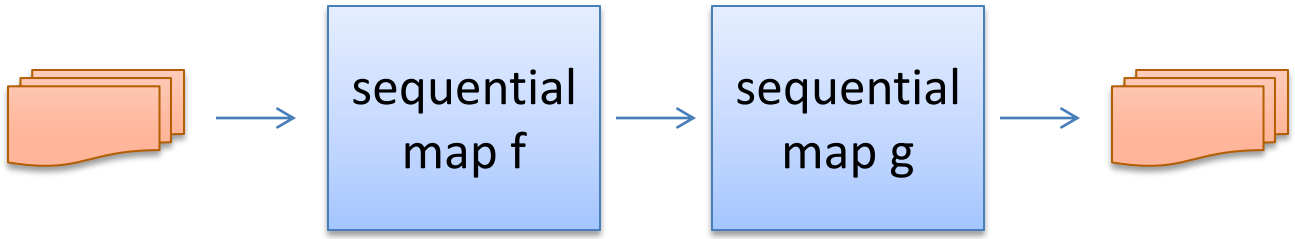
PARALLELISM: WHAT IS IT?

Parallelism

- What is it?
  - doing many things at the same time instead of sequentially (one-after-the-other).

Flavors of Parallelism

- Data Parallelism
  - same computation being performed on a lot of data
  - e.g., adding two vectors of numbers
- Task Parallelism
  - different computations/programs running at the same time
  - e.g., running web server and database
- Pipeline Parallelism
  - assembly line:



Parallelism vs. Concurrency

Parallelism: performs many tasks *simultaneously*

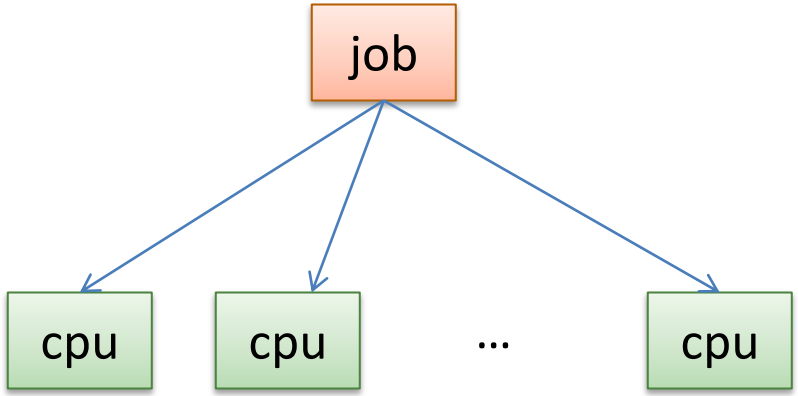
- purpose: improves throughput
- mechanism:
  - many independent computing devices
  - decrease run time of program by utilizing multiple cores or computers
- eg: running your web crawler on a cluster versus one machine.

Concurrency: mediates multi-party access to shared resources

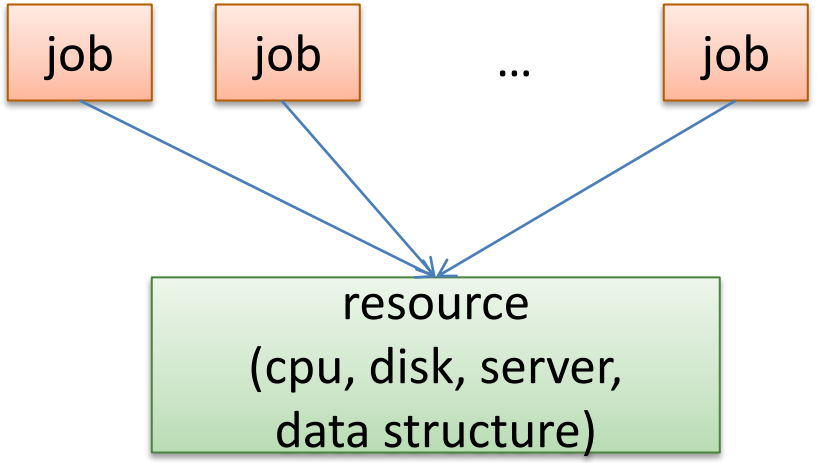
- purpose: decrease response time
- mechanism:
  - switch between different threads of control
  - work on one thread when it can make useful progress; when it can't, suspend it and work on another thread
- eg: running your clock, editor, chat at the same time on a single CPU.
  - OS gives each of these programs a small time-slice (~10msec)
  - often *slows* throughput due to cost of switching contexts
- eg: don't block while waiting for I/O device to respond, but let another thread do useful CPU computation

Parallelism vs. Concurrency

Parallelism:
perform several independent tasks simultaneously



Concurrency:
mediate/multiplex access to shared resource



many efficient programs use some parallelism and some concurrency

UNDERSTANDING TECHNOLOGY TRENDS

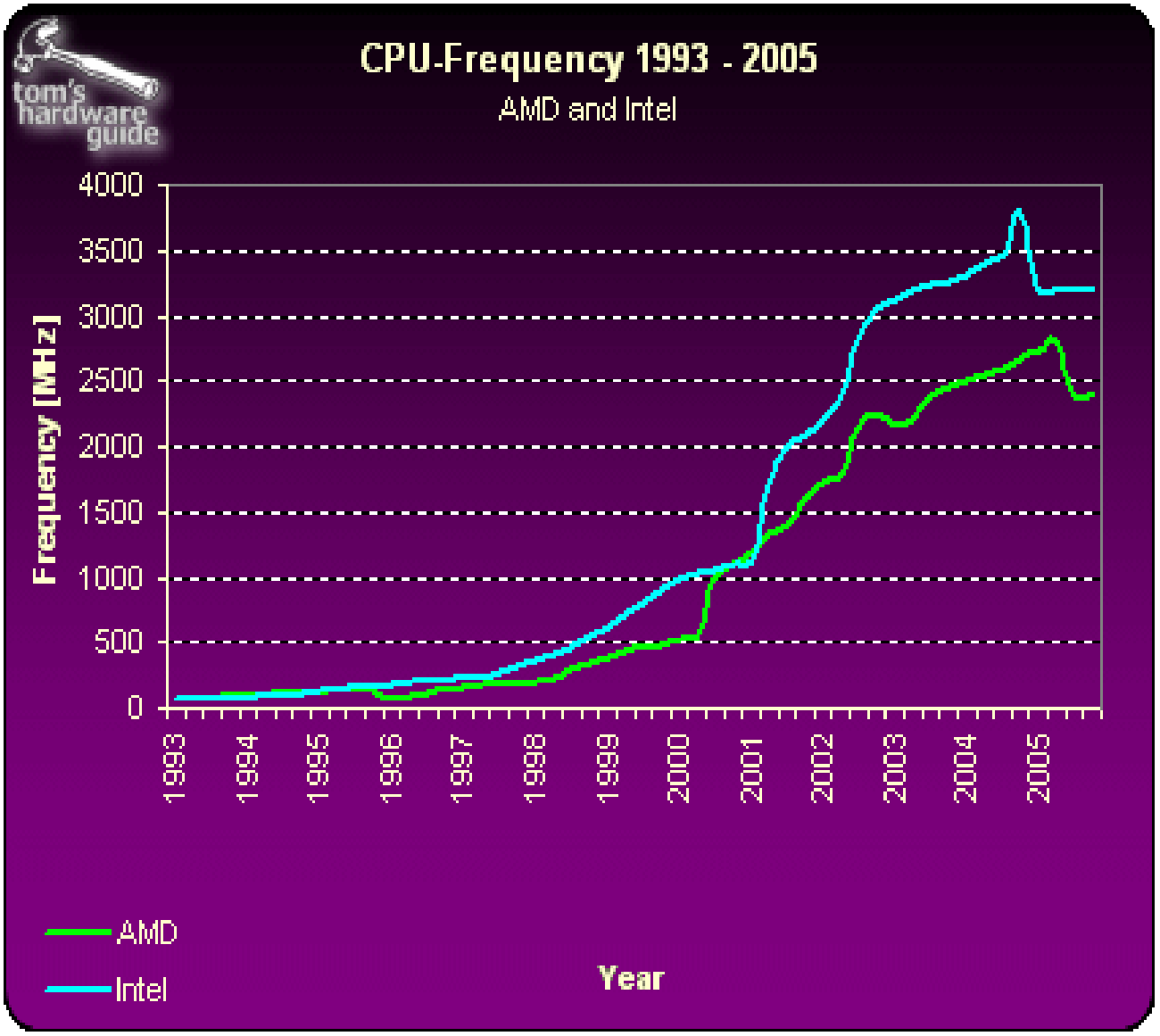
Moore's Law

- Moore's Law: *The number of transistors you can put on a computer chip doubles (approximately) every couple of years.*

- Consequence for most of the history of computing: *All programs double in speed every couple of years.*
  - Why? Hardware designers are wicked smart.
  - They have been able to use those extra transistors to (for example) double the number of instructions executed per time unit, thereby processing speed of programs

- Consequence for application writers:
  - *watch TV for a while and your programs optimize themselves*!
  - perhaps more importantly: new applications thought impossible became possible because of increased computational power

CPU Clock Speeds from 1993-2005



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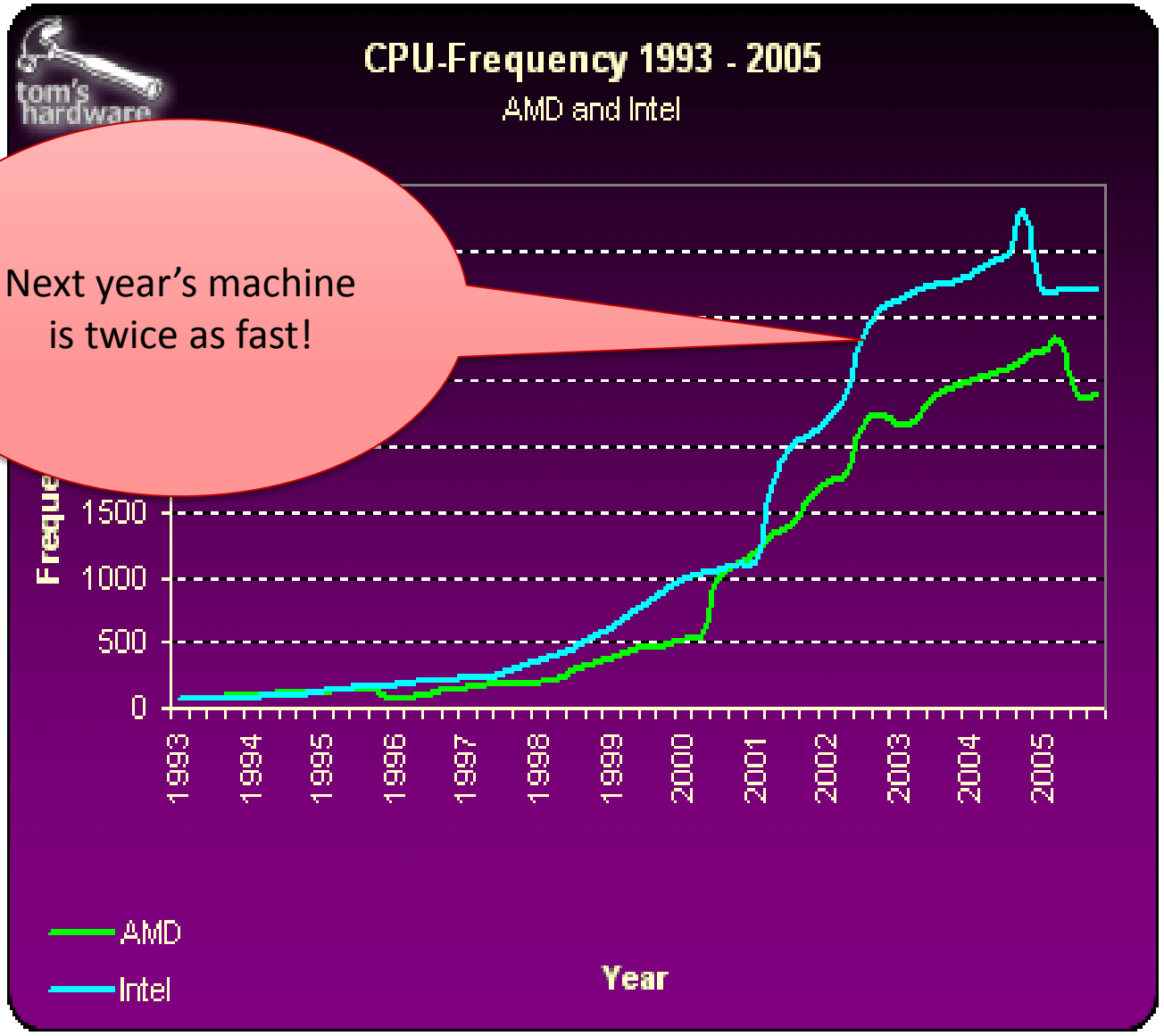

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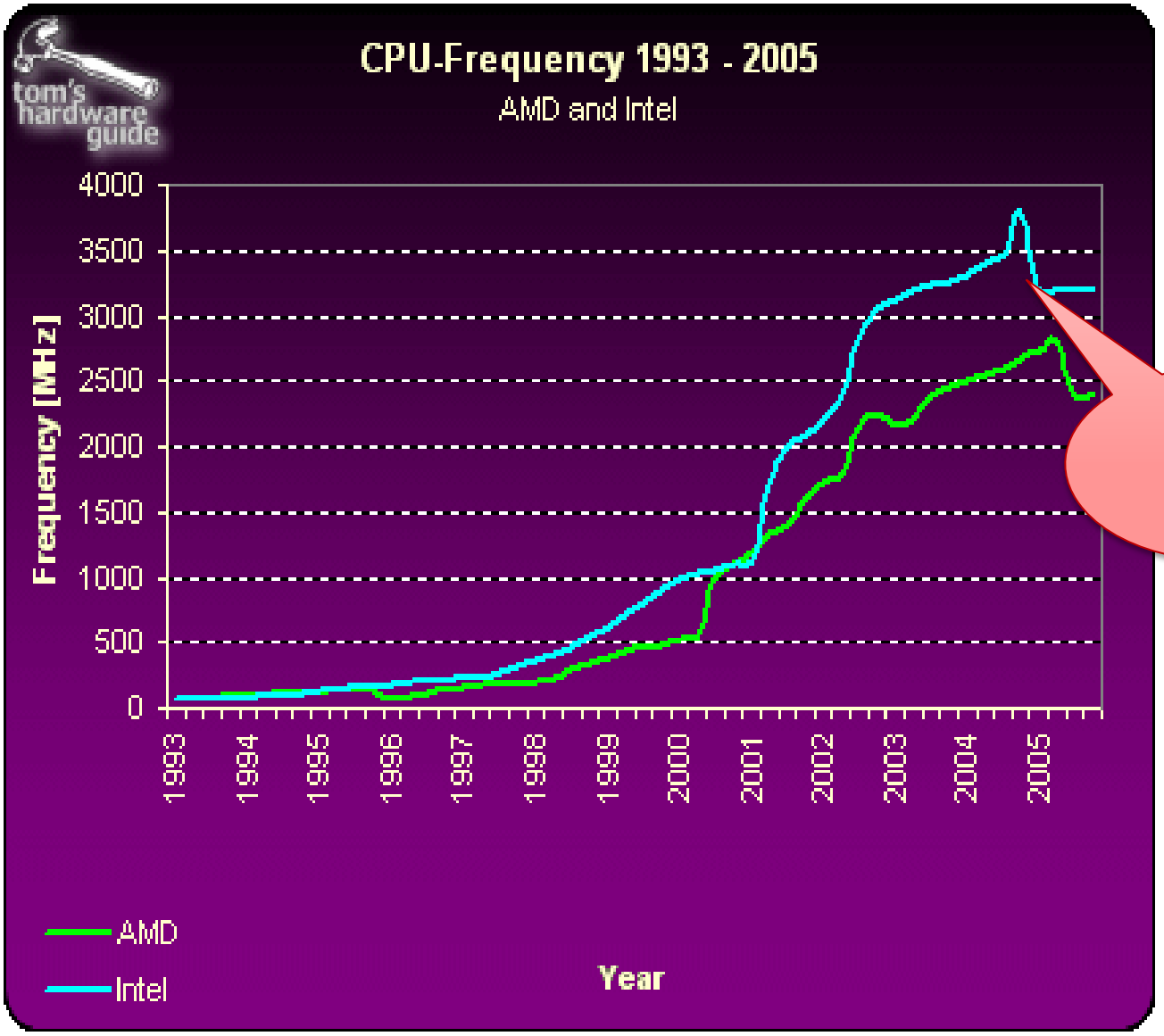
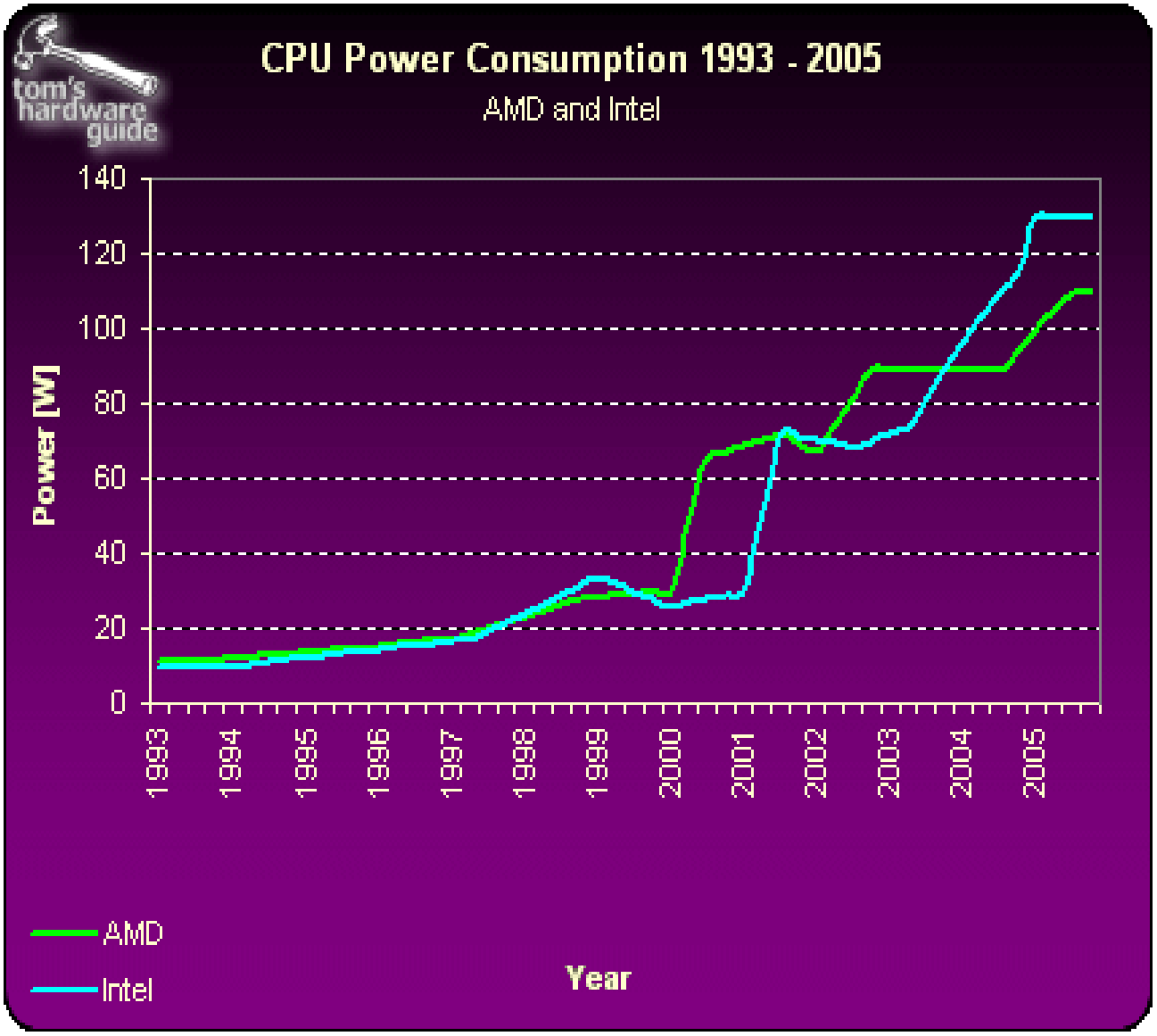


CPU Power 1993-2005



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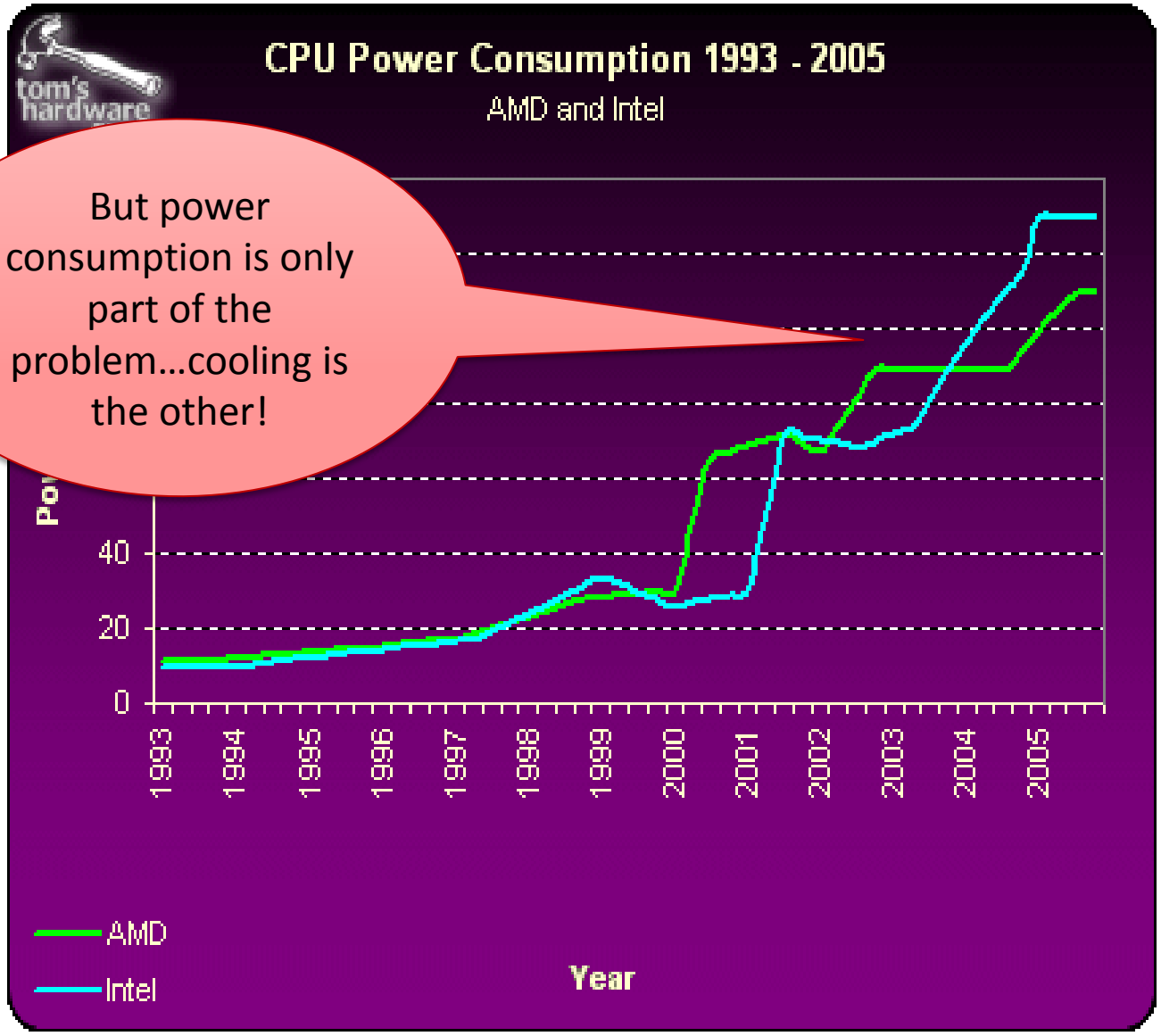
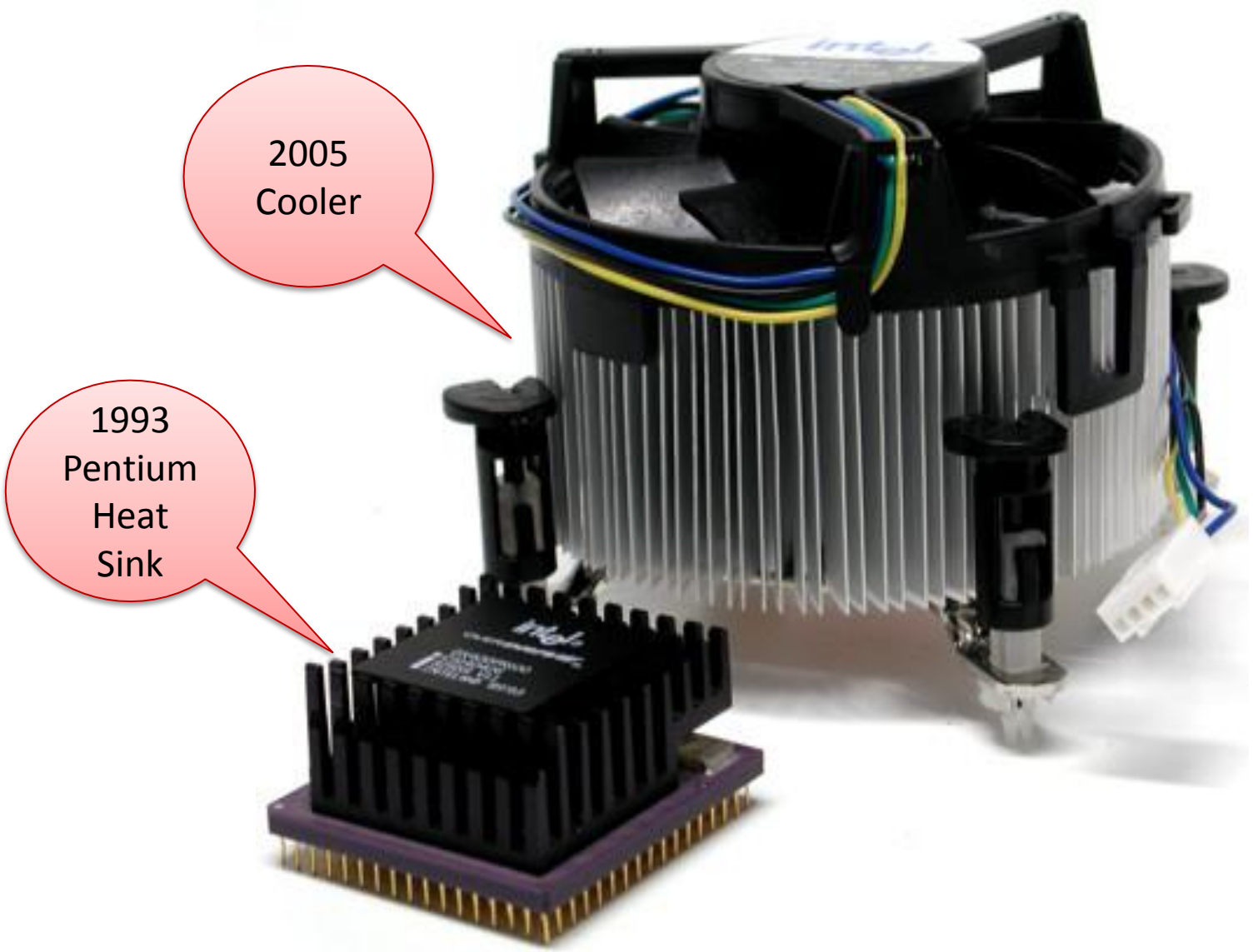
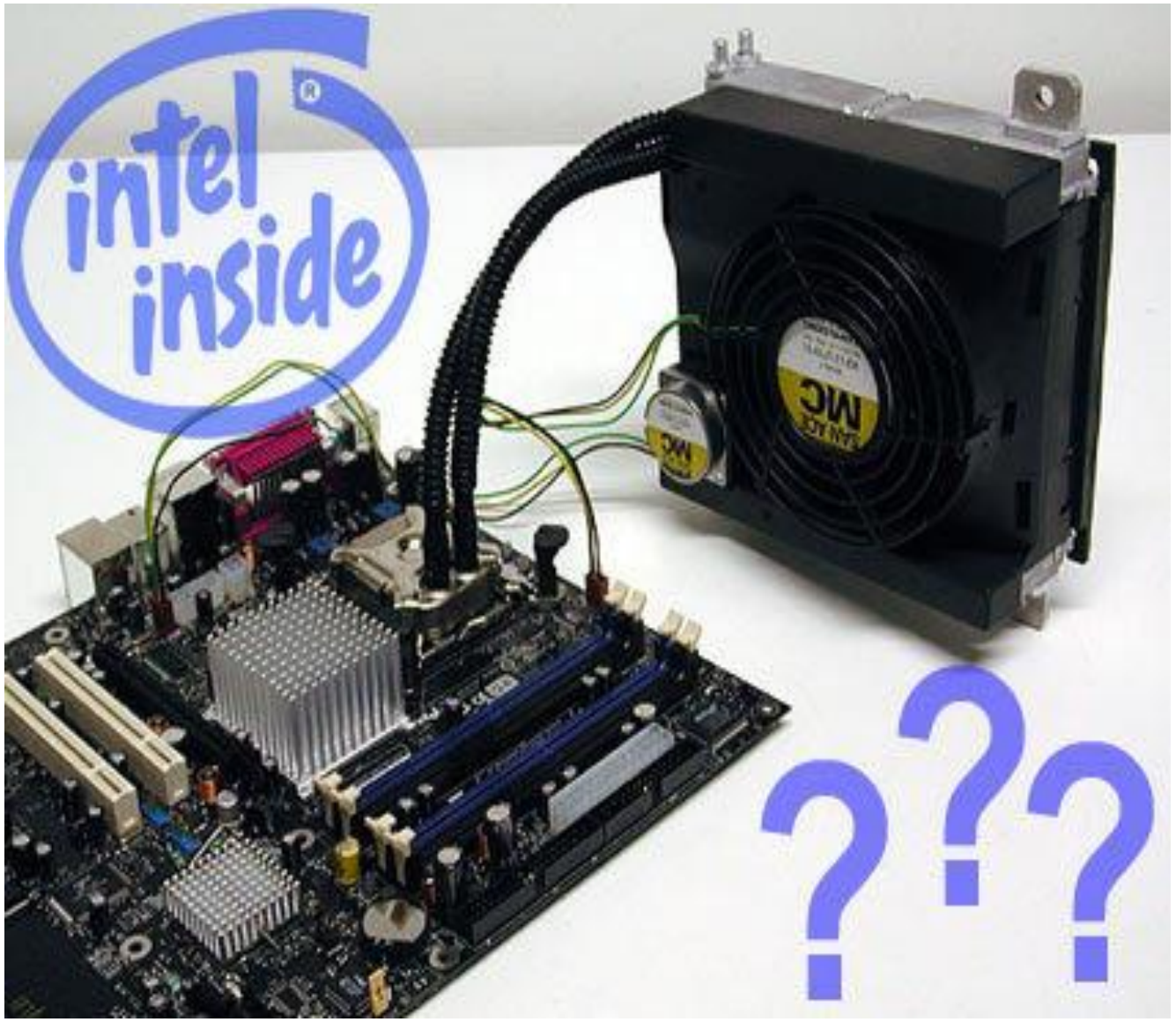


The Heat Problem

The Problem



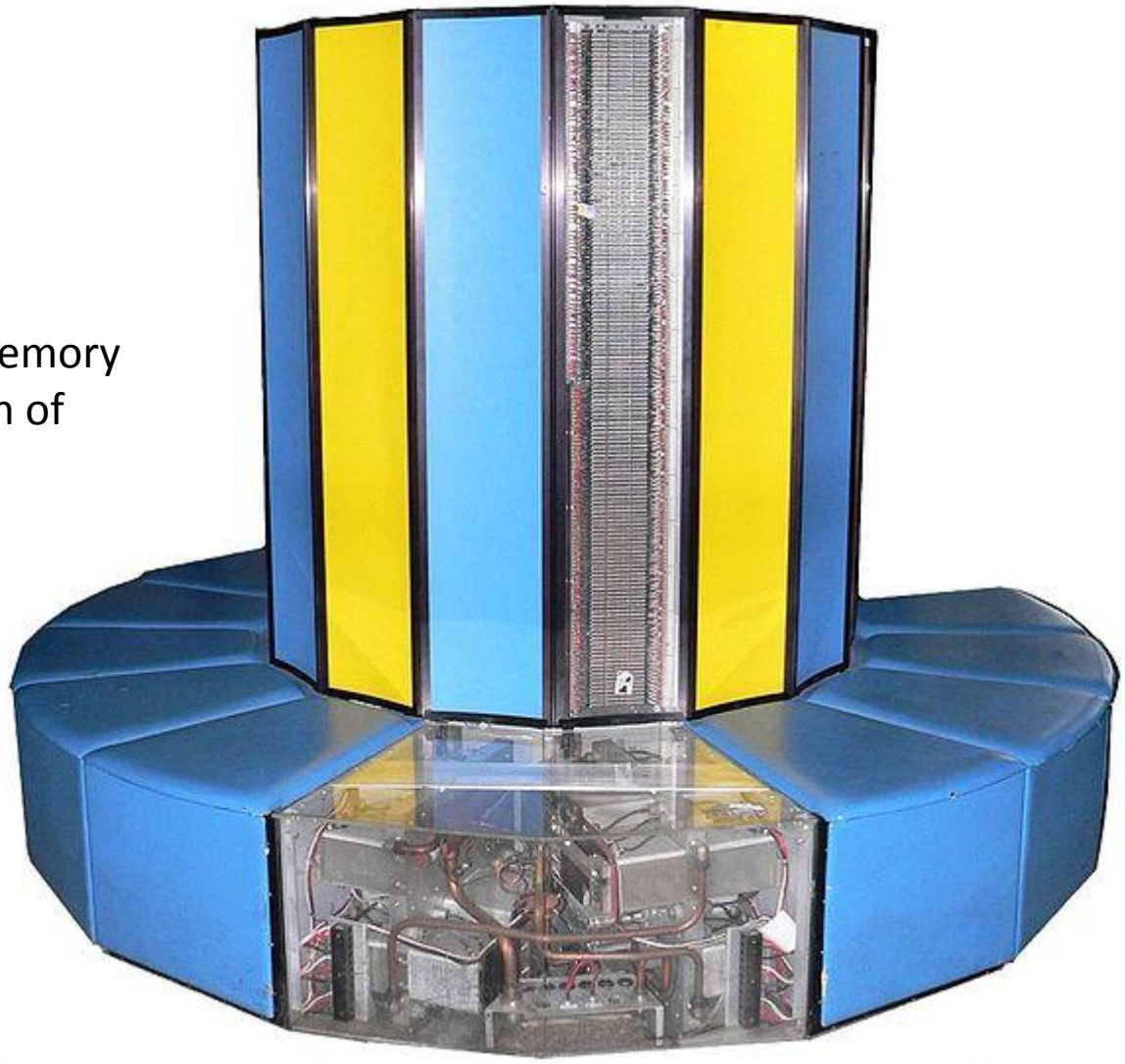
Today: water cooled!



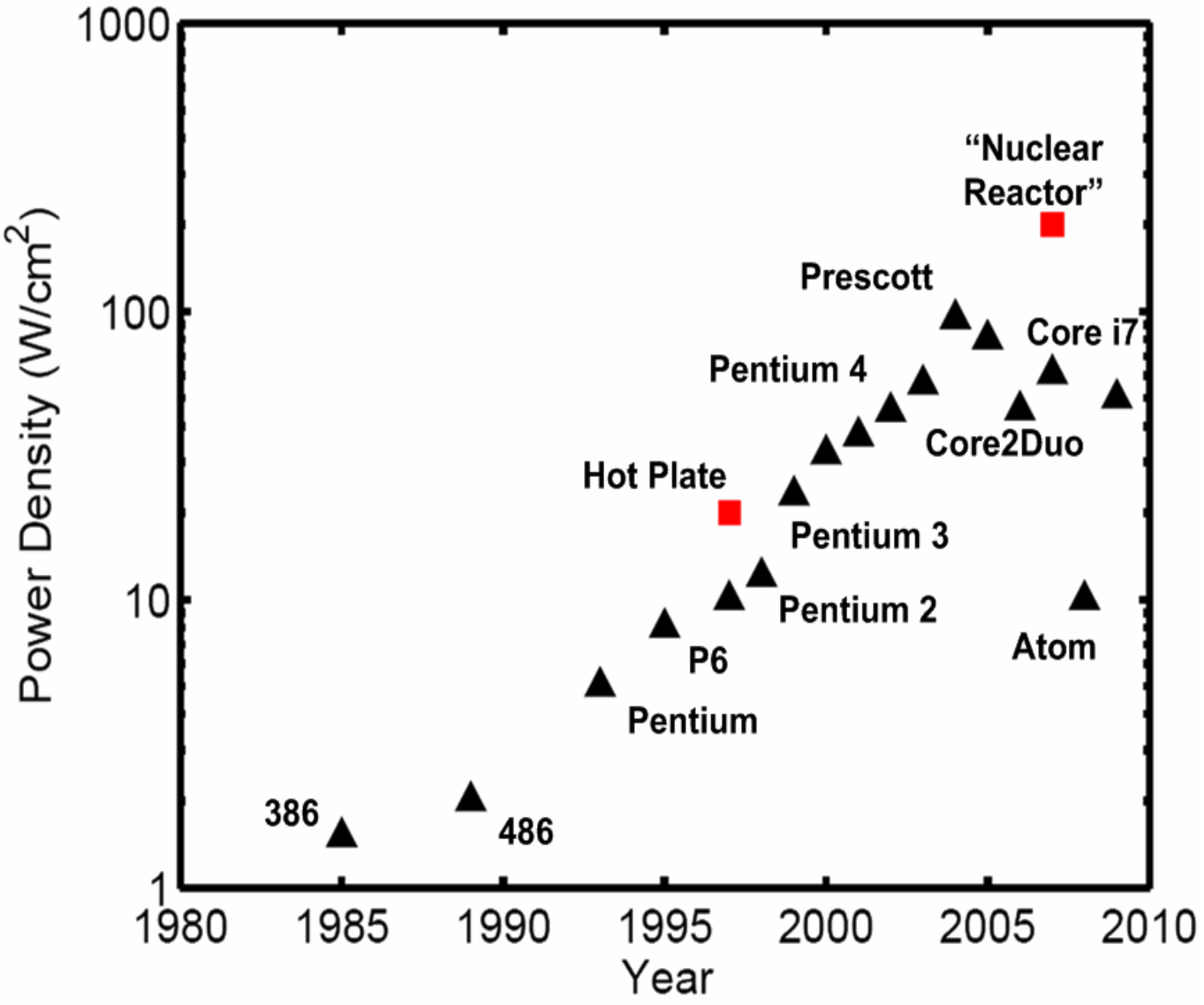
Cray-4: 1994

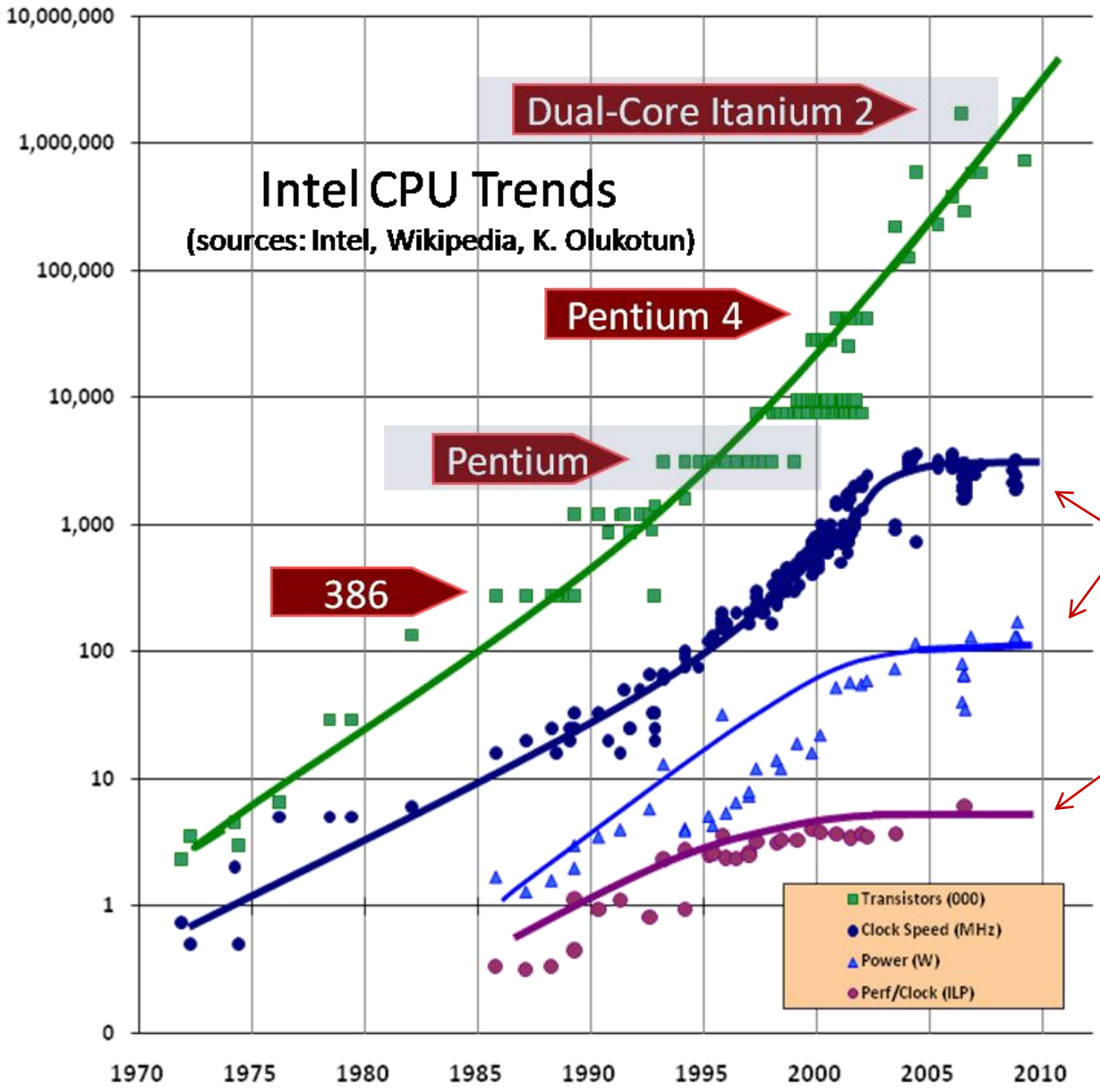
Up to 64 processors
Running at 1 GHz
8 Megabytes of RAM
Cost: roughly $10M

The CRAY 2,3, and 4 CPU and memory boards were immersed in a bath of electrically inert cooling fluid.



Power Dissipation





Power to chip peaking

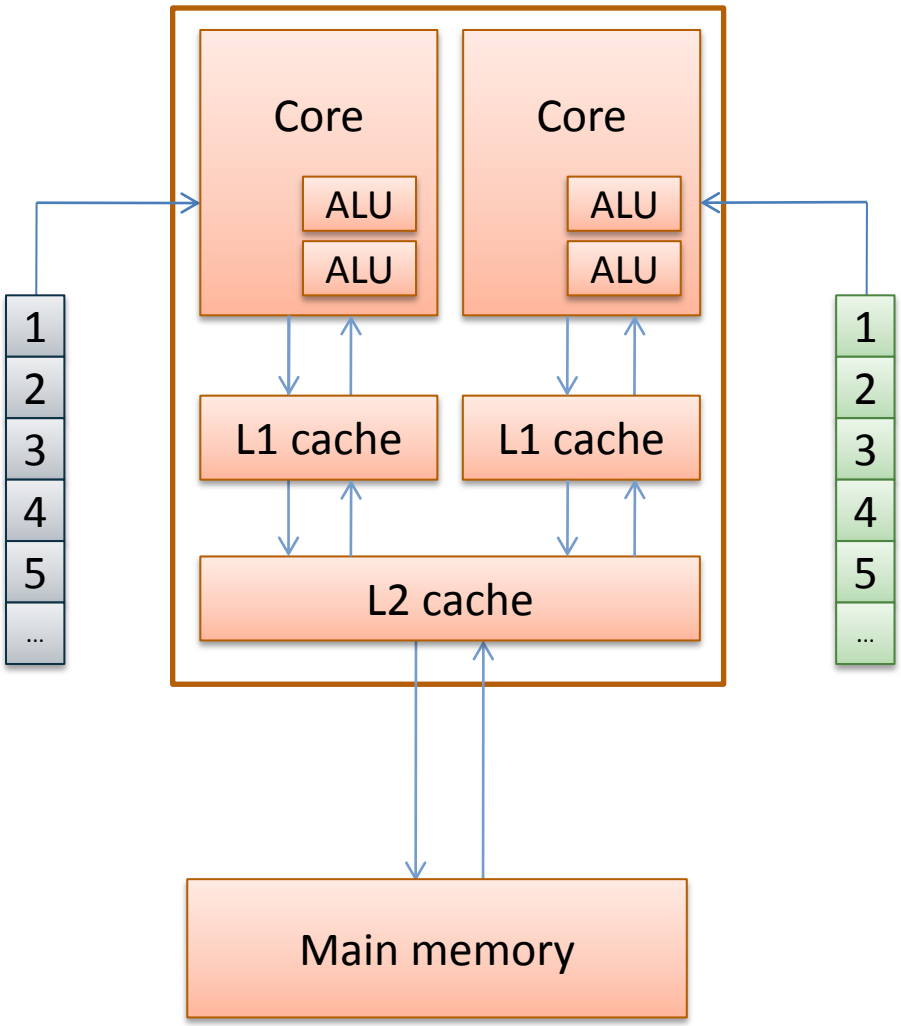
Darn!
Intel engineers no longer optimize my programs while I watch TV!

Parallelism

Why is it particularly important (today)?

- Roughly every other year, a chip from Intel would:
  - halve the feature size (size of transistors, wires, etc.)
  - double the number of transistors
  - double the clock speed
  - this drove the economic engine of the IT industry (and the US!)
- No longer able to double clock or cut voltage: a processor won't get any faster!
  - (so why should you buy a new laptop, desktop, etc.?)
  - power and heat are limitations on the clock
  - errors, variability (noise) are limitations on the voltage
  - but we can still pack a lot of transistors on a chip… (at least for another 10 to 15 years.)

Multi-core h/w – common L2

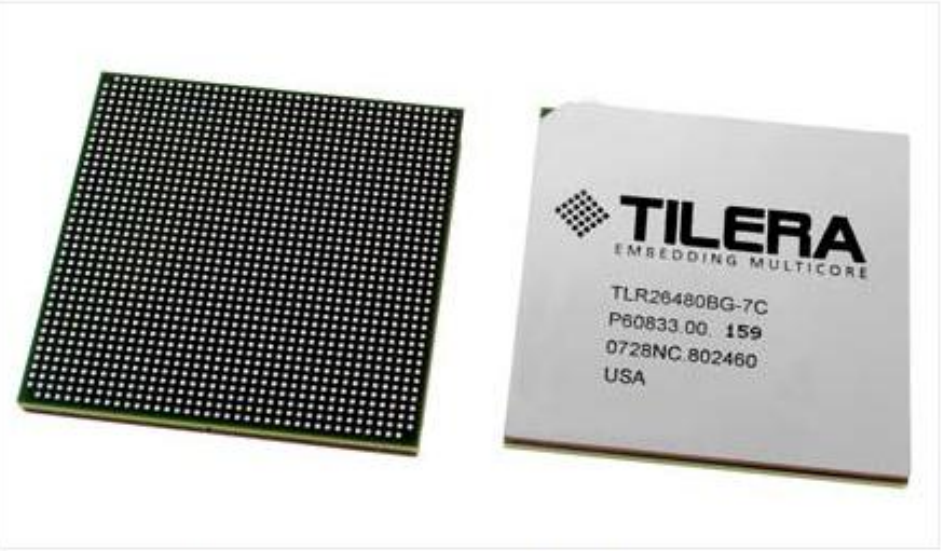


Today… (actually 5 years ago!)

Tilera announces 64-core processor

Posted on August 20, 2007 - 00:00 by **Wolfgang Gruener**

Palo Alto (CA) – Silicon Valley startup Tilera today announced the Tile64, a processor with 64 programmable cores that, according to the company, houses ten times the performance and 30 times the power efficiency of Intel's dual-core Xeon processors.



Intel may be getting tired of hearing about products performing better than its dual-core processors targeting server and embedded, as the company describes dual-core processors, at least when it comes to performance, as last year's product. However, when there's a company claiming that it can beat Intel's last year's product by a factor of 10x and 30x, depending on discipline, it's certainly worth a look.

The Tile64 is a 90 nm RISC-based processor clocked between 600 MHz and 1 GHz aiming for integration in embedded applications such as routers, switches, appliances, video conferencing systems and set-top boxes. Its manufacturer claims that the CPU solves a critical problem in multi-core scaling and opens the door to hundreds or even thousands of cores using this new architecture.

GPUs

- There's nothing like video gaming to drive progress in computation!
- GPUs can have hundreds or even thousands of cores
- Three of the 5 most powerful supercomputers in the world take advantage of GPU acceleration.
- Scientists use GPUs for simulation and modelling
  - eg: protein folding and fluid dynamics

So…

Instead of trying to make your CPU go faster, Intel's just going to pack more CPUs onto a chip.

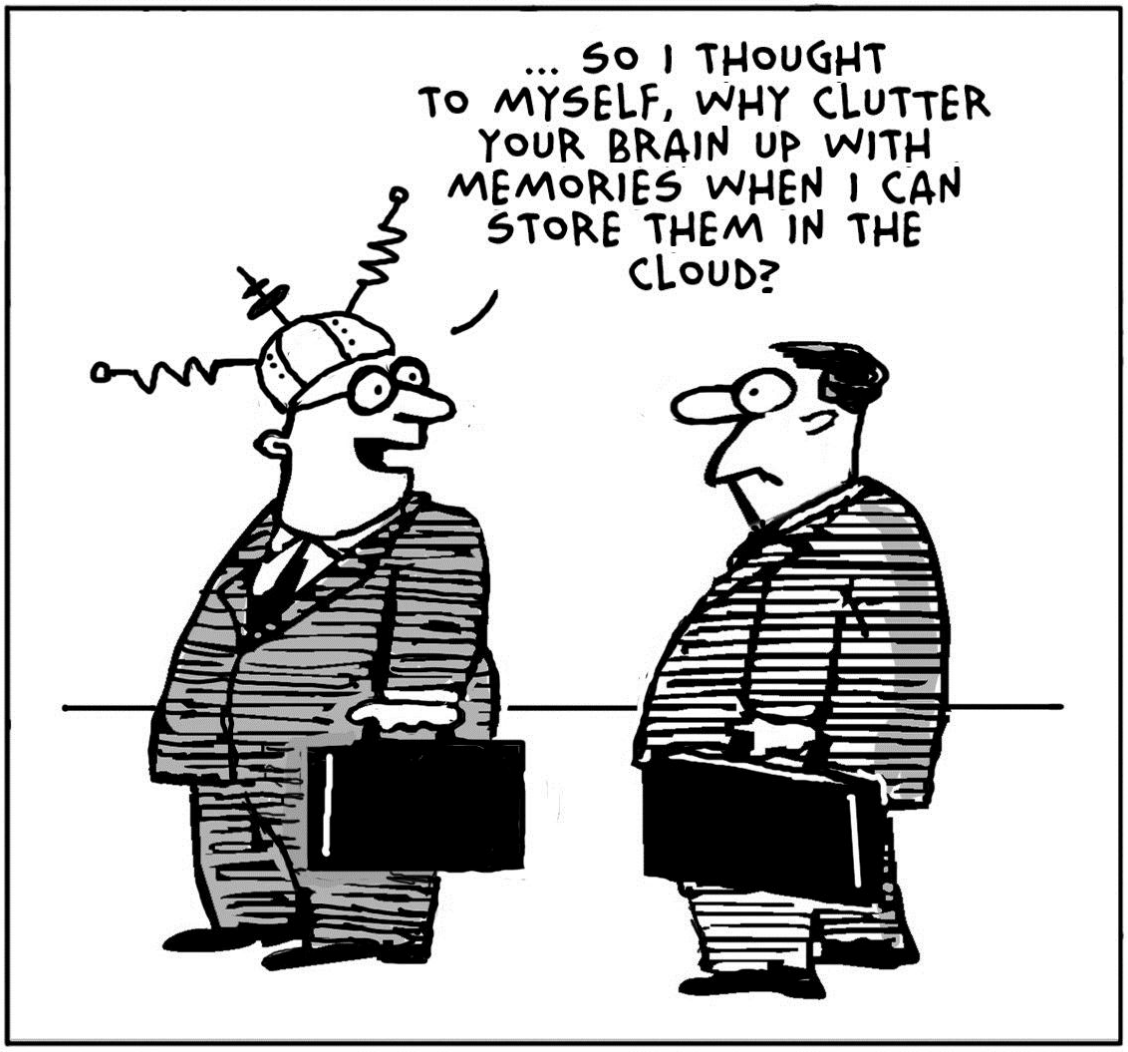
- last year: dual core (2 CPUs).
- this year: quad core (4 CPUs).
- Intel is testing 48-core chips with researchers now.
- Within 10 years, you'll have ~1024 Intel CPUs on a chip.

In fact, that's already happening with graphics chips (eg, Nvidia).

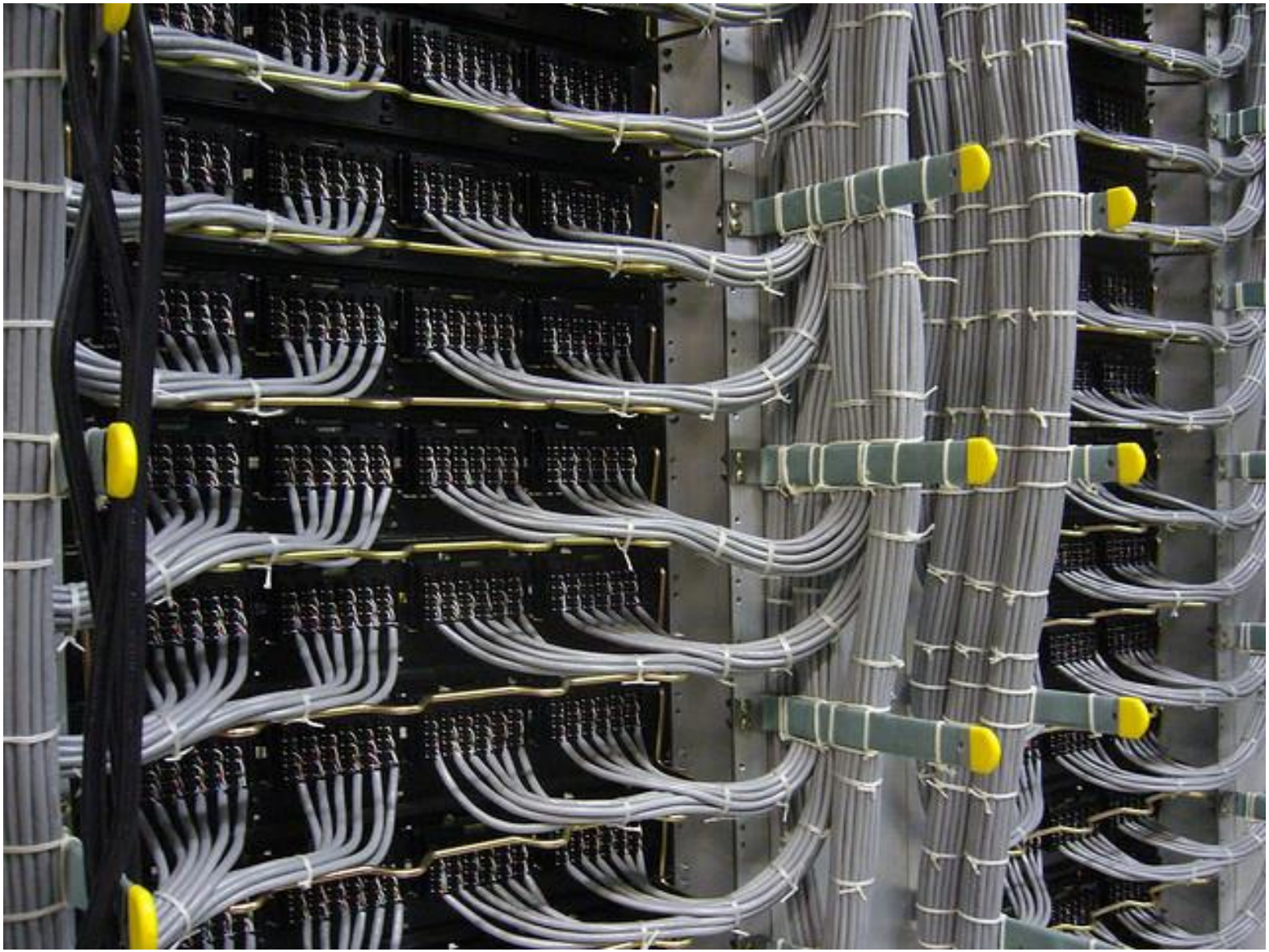
- really good at simple data parallelism (many deep pipes)
- but they are *much* dumber than an Intel core.
- and right now, chew up a *lot* of power.
- watch for GPUs to get "smarter" and more power efficient, while CPUs become more like GPUs.

STILL MORE PROCESSORS: THE DATA CENTER

Data Centers: Generation Z Super Computers



Data Centers: *Lots* of Connected Computers!



Data Centers

- *10s or 100s of thousands* of computers
- All connected together
- Motivated by new applications and scalable web services:
  - let's catalogue all N billion webpages in the world
  - let's all allow any one in the world to search for the page he or she needs
  - let's process that search in less than a second
- It's Amazing!
- It's Magic!

Data Centers: Lots of Connected Computers

Computer containers for plug-and-play parallelism:

Sounds Great!

- So my old programs will run 2x, 4x, 48x, 256x, 1024x faster?

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  - no way!

Sounds Great!

- So my old programs will run 2x, 4x, 48x, 256x, 1024x faster?
  - no way!
  - to upgrade from Intel 386 to 486, the app writer and compiler writer did not have to do anything (much)
    - IA 486 interpreted the same sequential stream of instructions; it just did it faster
    - this is why we could watch TV while Intel engineers optimized our programs for us
  - to upgrade from Intel 486 to dual core, we need to figure out how to split a single stream of instructions in to two streams of instructions that collaborate to complete the same task.
    - *without work & thought, our programs don't get any faster at all*
    - *it takes ingenuity to generate efficient parallel algorithms from sequential ones*

END