为什么要并行计算?

任课教师：黄聃（Huang,Dan)

Roadmap

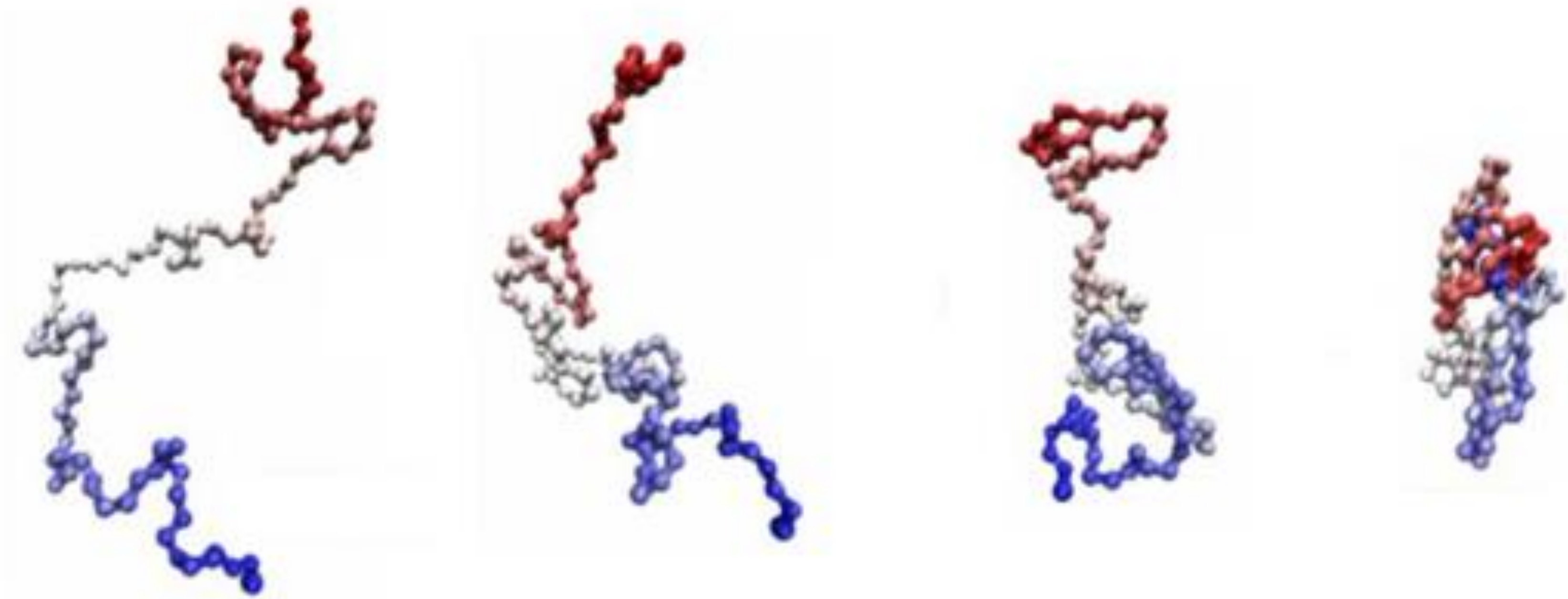
- Why we need ever-increasing performance.
- Why we're building parallel systems.
- Why we need to write parallel programs.
- How do we write parallel programs?
- What we'll be doing.
- **Concurrent, parallel, distributed**!

Why we need ever-increasing performance

- Computational power is increasing, but so are our computation problems and needs.
- Problems we never dreamed of have been solved because of past increases, such as decoding the human genome.
- More complex problems are still waiting to be solved.

Climate modeling

Protein folding



Drug discovery

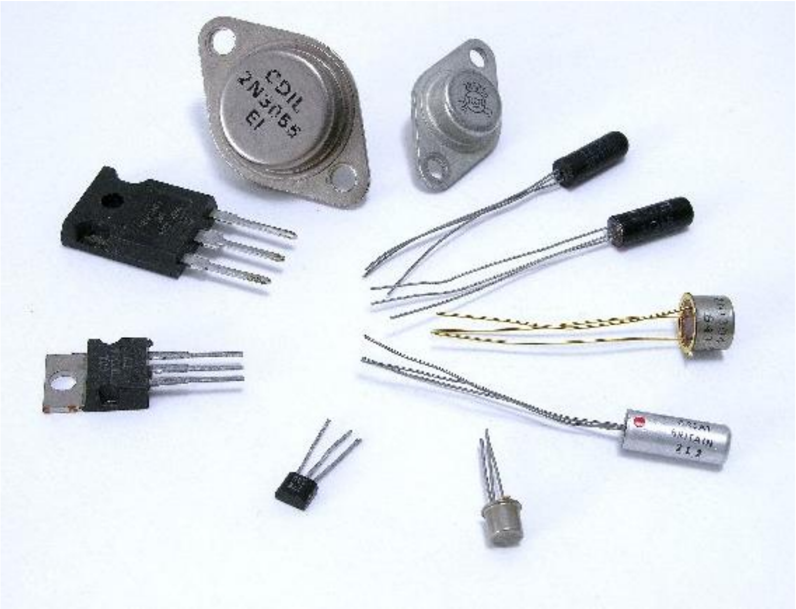
Energy research

Data analysis

Why we’re building parallel systems

- Up to now, performance increases have been attributable to increasing density of transistors.

- But there are inherent problems.



A Brief History of Processor Performance

A Brief History of Processor Performance

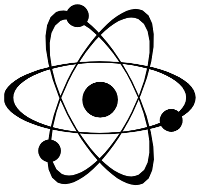
- **Wider data paths**
  - 4 bit → 8 bit → 16 bit → 32 bit → 64 bit
- **More efficient pipelining**
  - e.g., 3.5 Cycles Per Instruction (CPI) → 1.1 CPI
- **Exploiting instruction-level parallelism (ILP)**
  - "Superscalar" processing: e.g., issue up to 4 instructions/cycle
  - "Out-of-order" processing: extract parallelism from instruction stream
- **Faster clock rates**
  - e.g., 10 MHz → 200 MHz → 3 GHz

A Brief History of Processor Performance

- From 1986 – 2002, microprocessors were speeding like a rocket, increasing in performance an average of 50% per year.

- Since then, it's dropped to about **20%** increase per year.

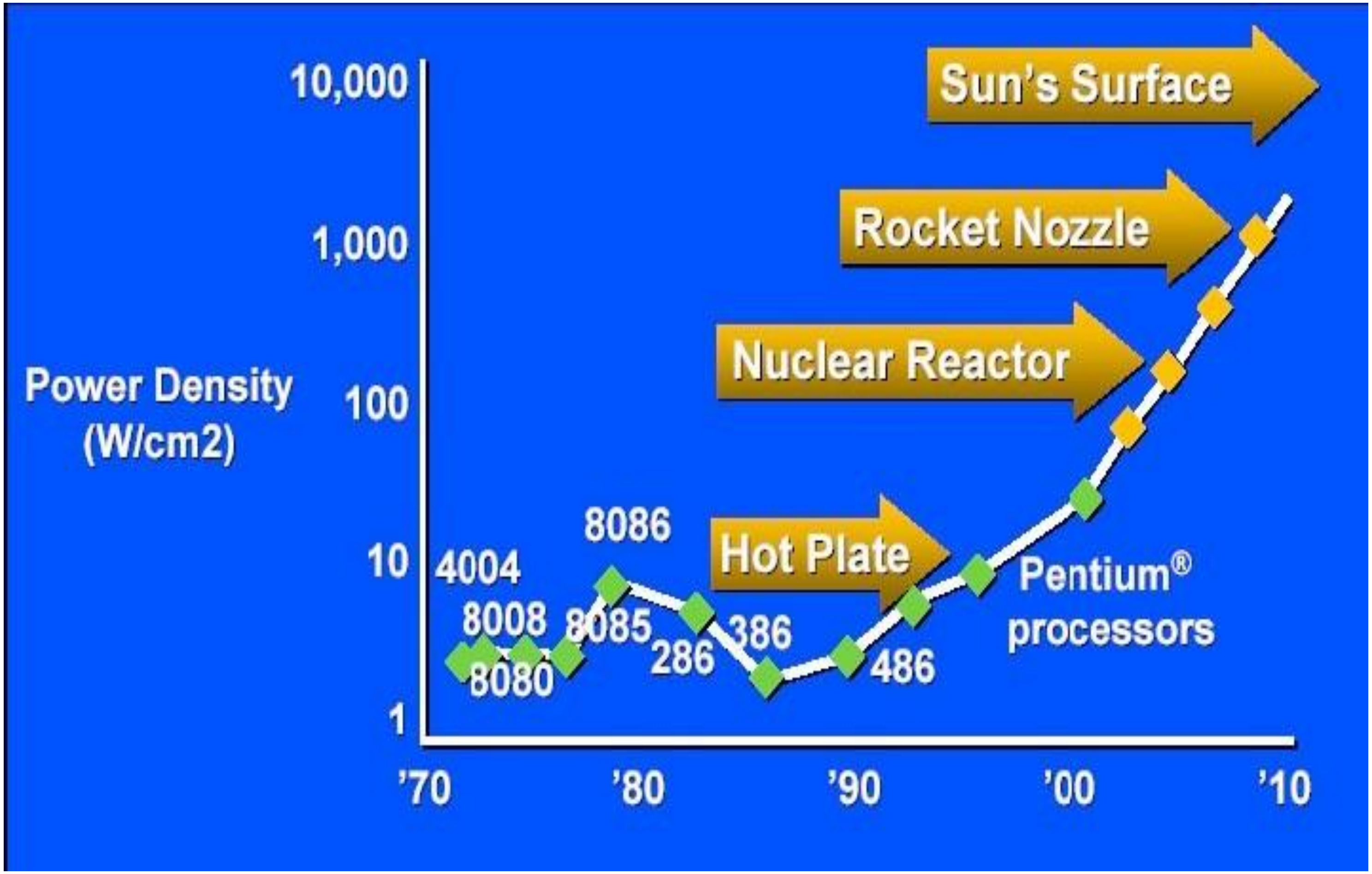
A little physics lesson



- Smaller transistors = faster processors.
- Faster processors = increased power consumption.
- Increased power consumption = increased heat.
- Increased heat = unreliable processors.

Intel hits the Power Density Wall

- Inflection point in 2004

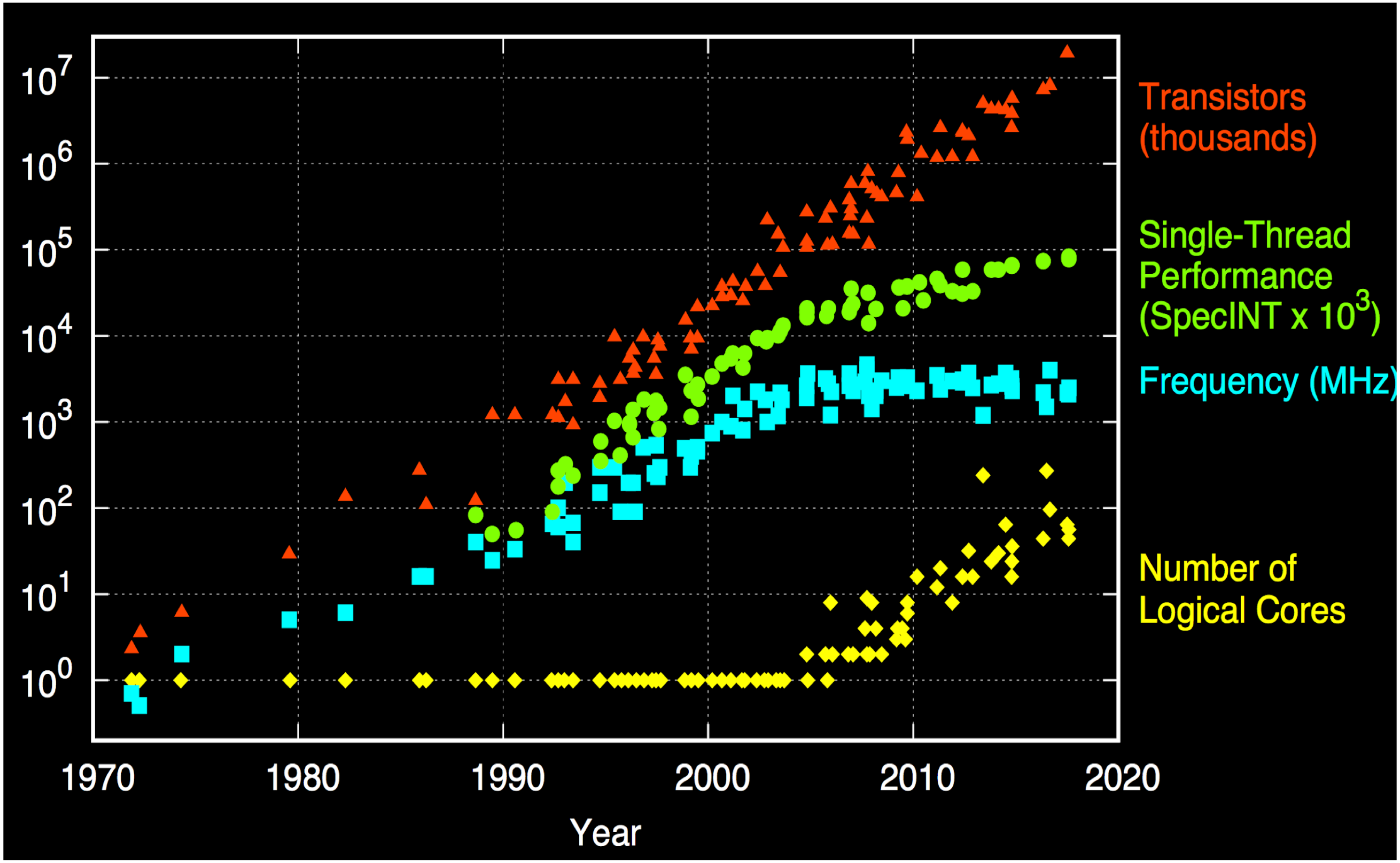


Pat Gelsinger, ISSCC 2001

Intel's Big Shift After Hitting Technical Wall

- Intel 's newest microprocessor was running slower and hotter than its predecessor.
- Intel publicly acknowledged that it had hit a "thermal wall" on its microprocessor line.

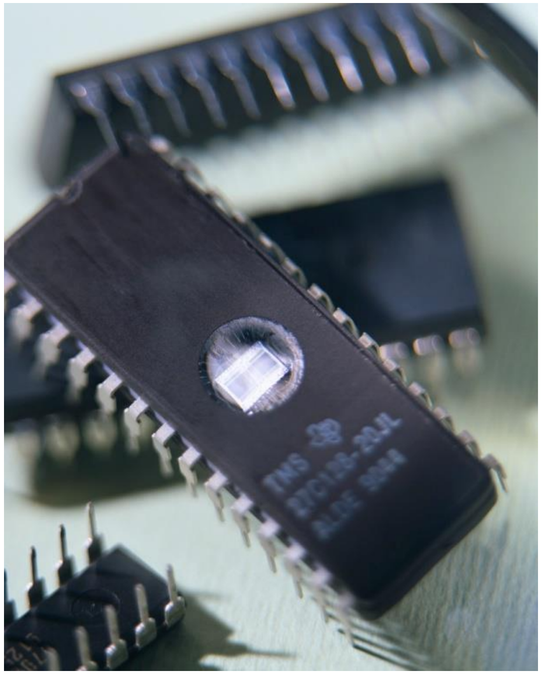
End of frequency scaling



Cores rather than clock frequency is doubling

Solution

- Move away from single-core systems to **multicore processors.**
- “core” = central processing unit (CPU)



- Introducing parallelism!!!

Parallel Machines Today

Examples from Apple's product line:

Mac Pro
8 Intel Xeon E5 cores

MacBook Pro Retina 15"
6 Intel Core i9 cores

iPhone XR

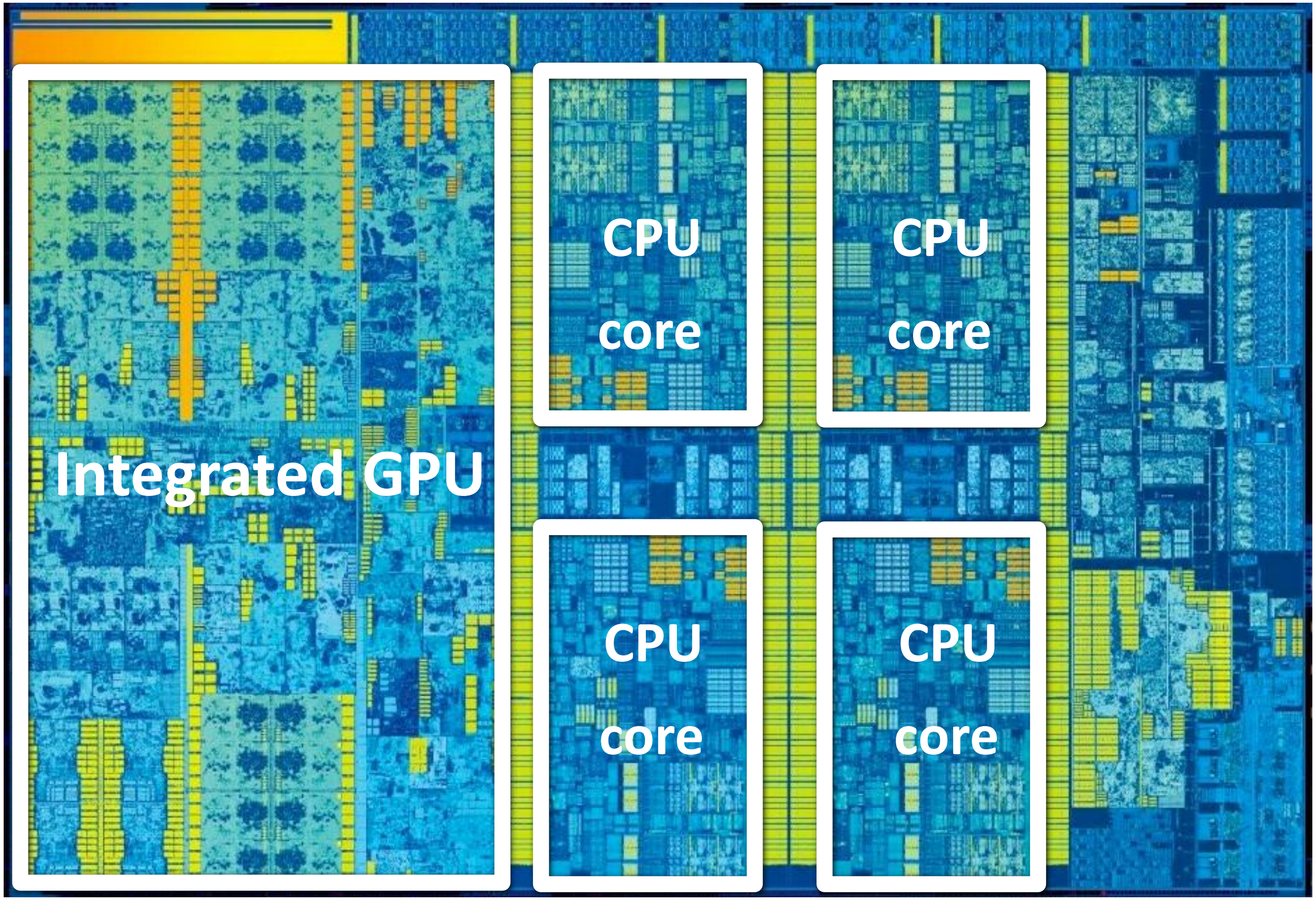
4 CPU cores
6 GPU cores

iMac Pro
18 Intel Xeon W cores

(images from apple.com)

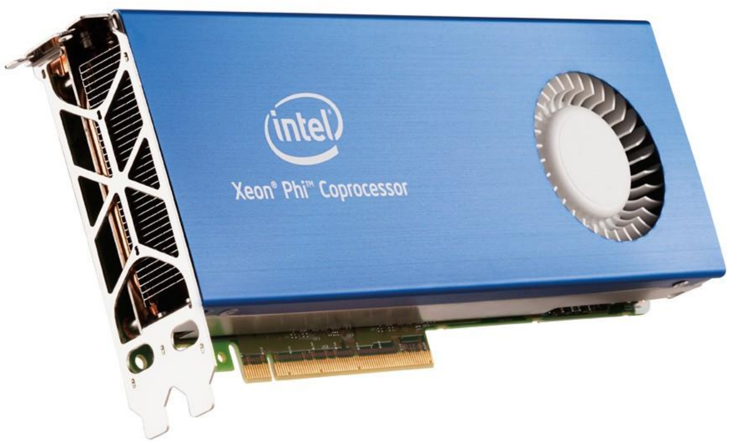
Intel Skylake (2015) (aka “6th generation Core i7”)

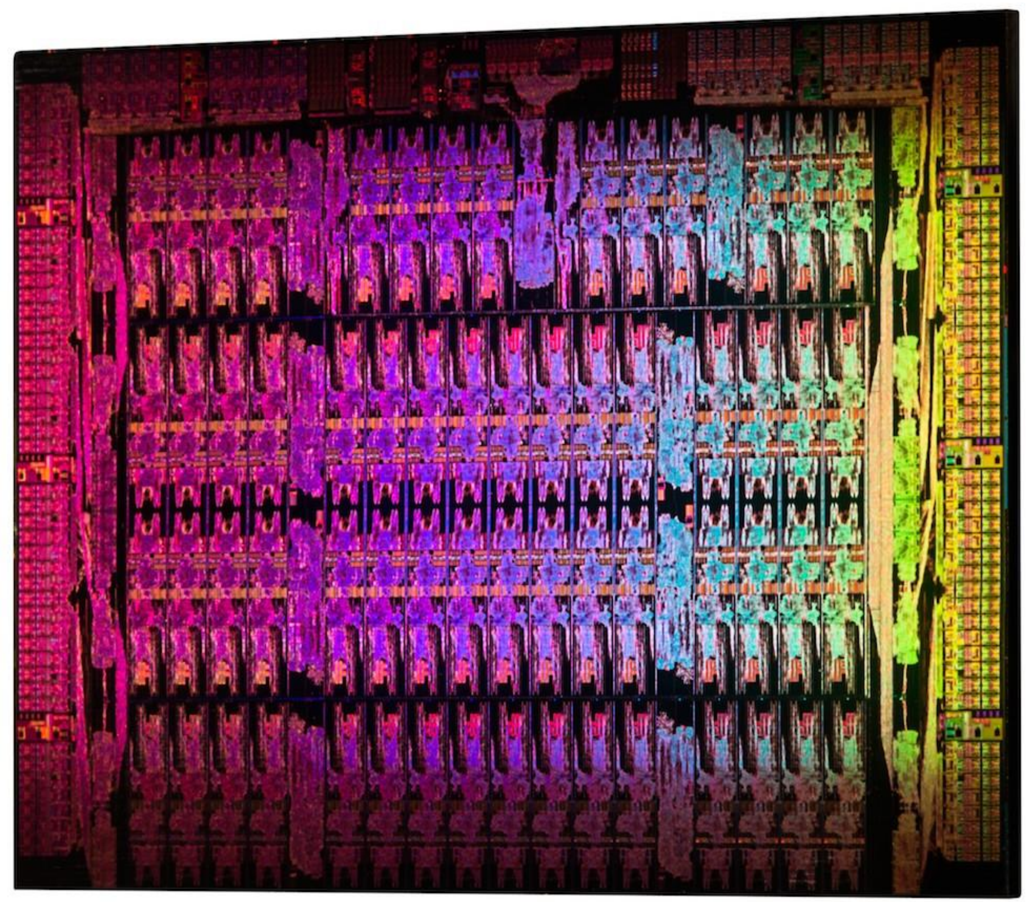
Quad-core CPU + multi-core GPU integrated on one chip



Intel Xeon Phi 7120A “coprocessor”

- 61 “simple” x86 cores (1.3 Ghz, derived from Pentium)
- Targeted as an accelerator for supercomputing applications

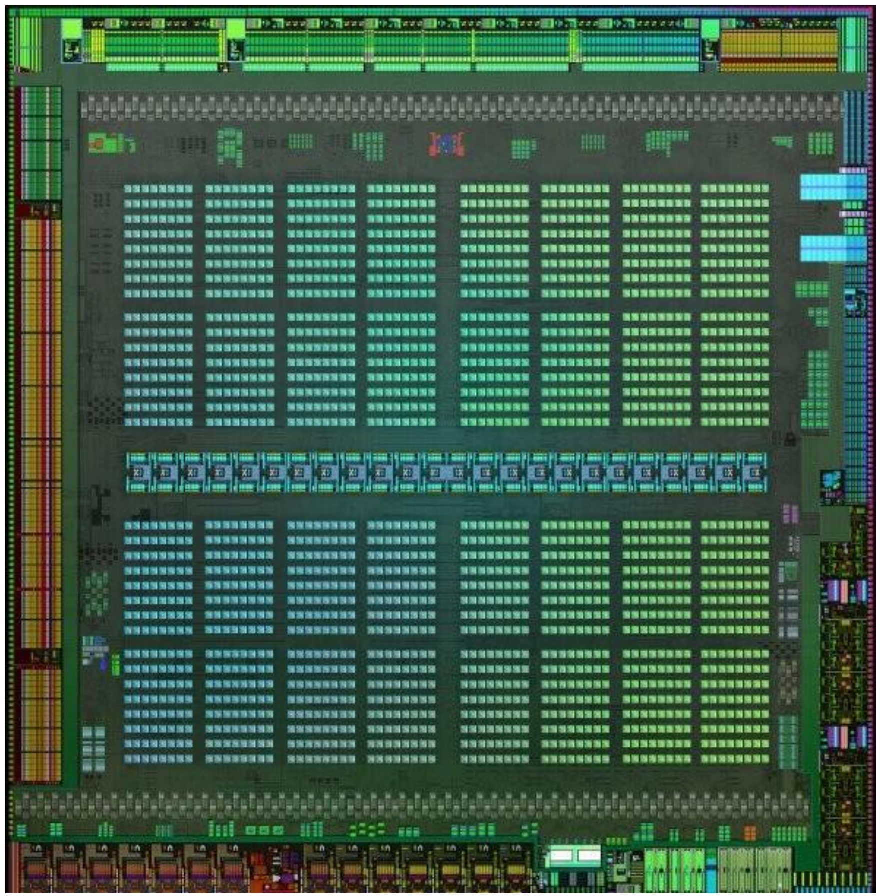




NVIDIA GV100 Volta GPU (2017)

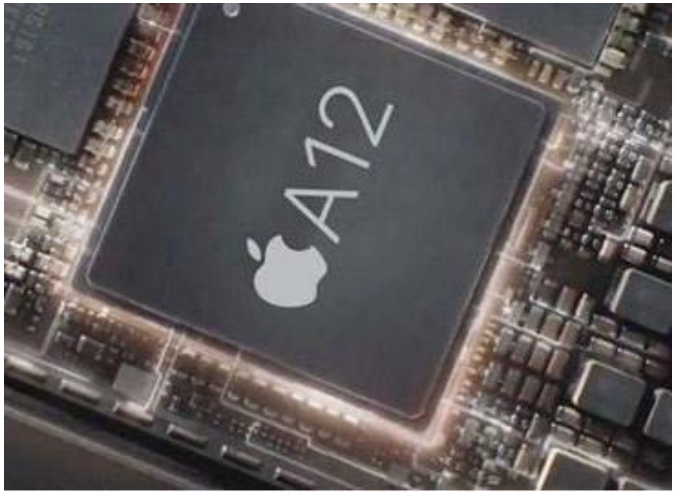
80 major processing blocks

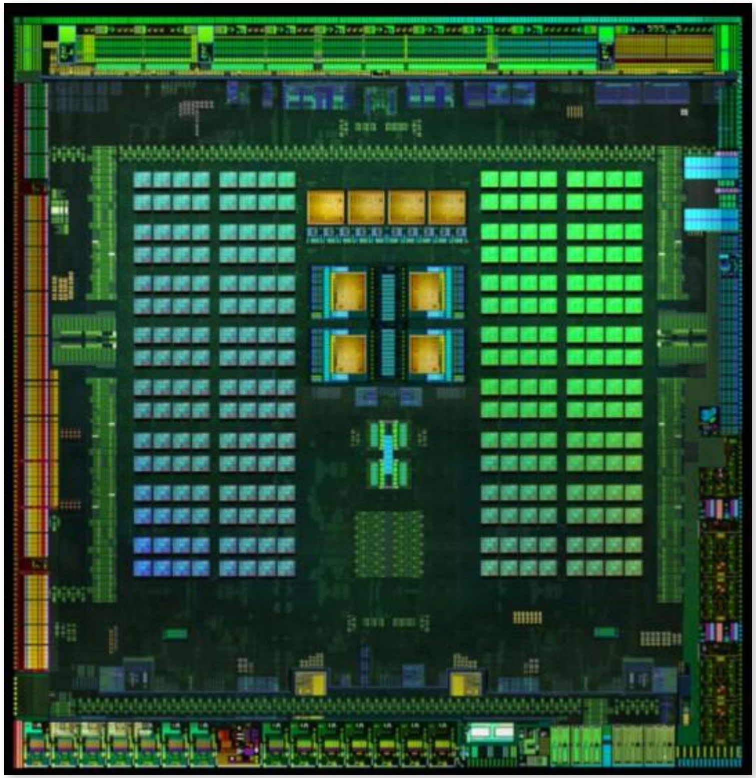
(but much, much more parallelism available... details coming soon)



Mobile parallel processing

Power constraints heavily influence design of mobile systems





Apple A12: (in iPhone XR)
4 CPU cores
4 GPU cores
Neural net engine
+ much more

NVIDIA Tegra K1:
Quad-core ARM A57 CPU + 4 ARM A53 CPUs +
NVIDIA GPU + image processor...

Supercomputing

- Today: clusters of multi-core CPUs + GPUs
- Oak Ridge National Lab: Summit (Top #1 in world)
  - 4,608 nodes
  - Each with two 22-core CPUs + 6 GPUs

Programmer’s Perspective on Performance

Question: **How do you make your program run faster?**

Answer before 2004:

- **Just wait 6 months, and buy a new machine!**

Answer after 2004:

- **You need to write parallel software.**

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).

Why we need to write parallel programs

- Running multiple instances of a serial program often isn’t very useful.

- Think of running multiple instances of your favorite game.

- What you really want is for it to run **faster**.

Approaches to the serial problem

- Rewrite serial programs so that they're parallel.

- Write translation programs that automatically convert serial programs into parallel programs.
    - This is **very difficult** to do.
    - Success has been limited.

More problems

- Some coding constructs can be recognized by an automatic program generator, and converted to a parallel construct.
- However, it's likely that the result will be a very inefficient program.
- Sometimes the best parallel solution is to step back and devise an entirely new algorithm.

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.)

- After each core completes execution of the code, a private variable my_sum contains the sum of the values computed by its calls to Compute_next_value.

- Ex., 8 cores, n = 24, then the calls to Compute_next_value return:

1,4,3, 9,2,8, 5,1,1, 5,2,7, 2,5,0, 4,1,8, 6,5,1, 2,3,9

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;
}
```

Example (cont.)

Core	0	1	2	3	4	5	6	7
my_sum	8	19	7	15	7	13	12	14

Global sum

8 + 19 + 7 + 15 + 7 + 13 + 12 + 14 = 95

Core	0	1	2	3	4	5	6	7
my_sum	95	19	7	15	7	13	12	14

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.

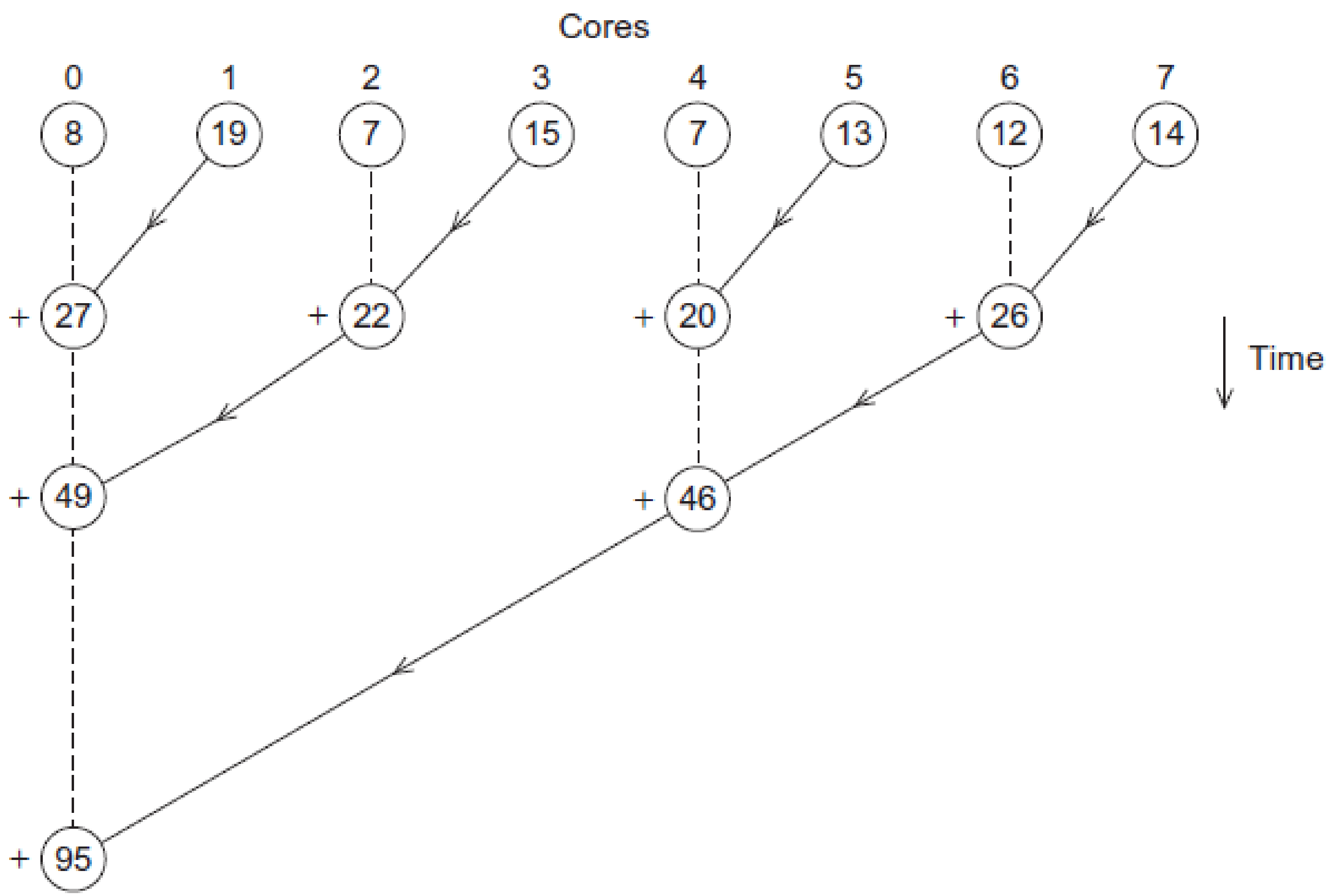
- Pair the cores so that core 0 adds its result with core 1's result.
- Core 2 adds its result with core 3's result, etc.
- Work with odd and even numbered pairs of cores.

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 example, the master core performs 7 receives and 7 additions.

- In the second example, 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!

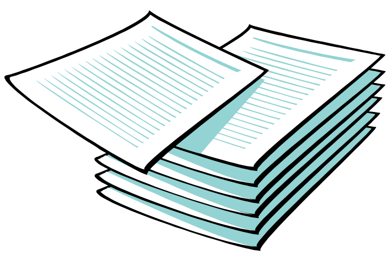
How do we write parallel programs?

- **Task parallelism**
  - Partition various tasks carried out solving the problem among the cores.
- **Data parallelism**
  - Partition the data used in solving the problem among the cores.
  - Each core carries out similar operations on it’s part of the data.

Professor P

15 questions

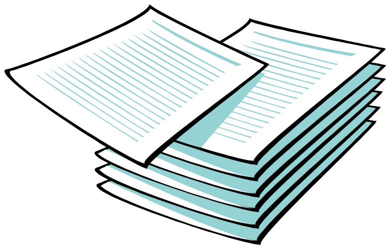
300 exams



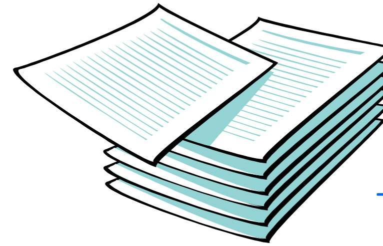
Professor P’s grading assistants

Division of work – data parallelism

TA#1

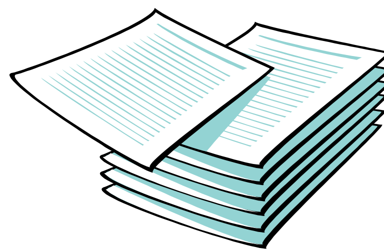


100 exams



TA#3

100 exams



TA#2

100 exams

Division of work – task parallelism

TA#1

Questions 11 - 15

TA#3

Questions 1 - 5

TA#2

Questions 6 - 10

Division of work – data parallelism

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

Division of work – task parallelism

```
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;
}
```

<u>Tasks</u>

1) Receiving
2) Addition

Coordination

- Cores usually need to **coordinate** their work.

- Communication – one or more cores send their current partial sums to another core.
- Load balancing – share the work evenly among the cores so that one is not heavily loaded.
- Synchronization – because each core works at its own pace, make sure cores do not get too far ahead of the rest.

What we'll be doing

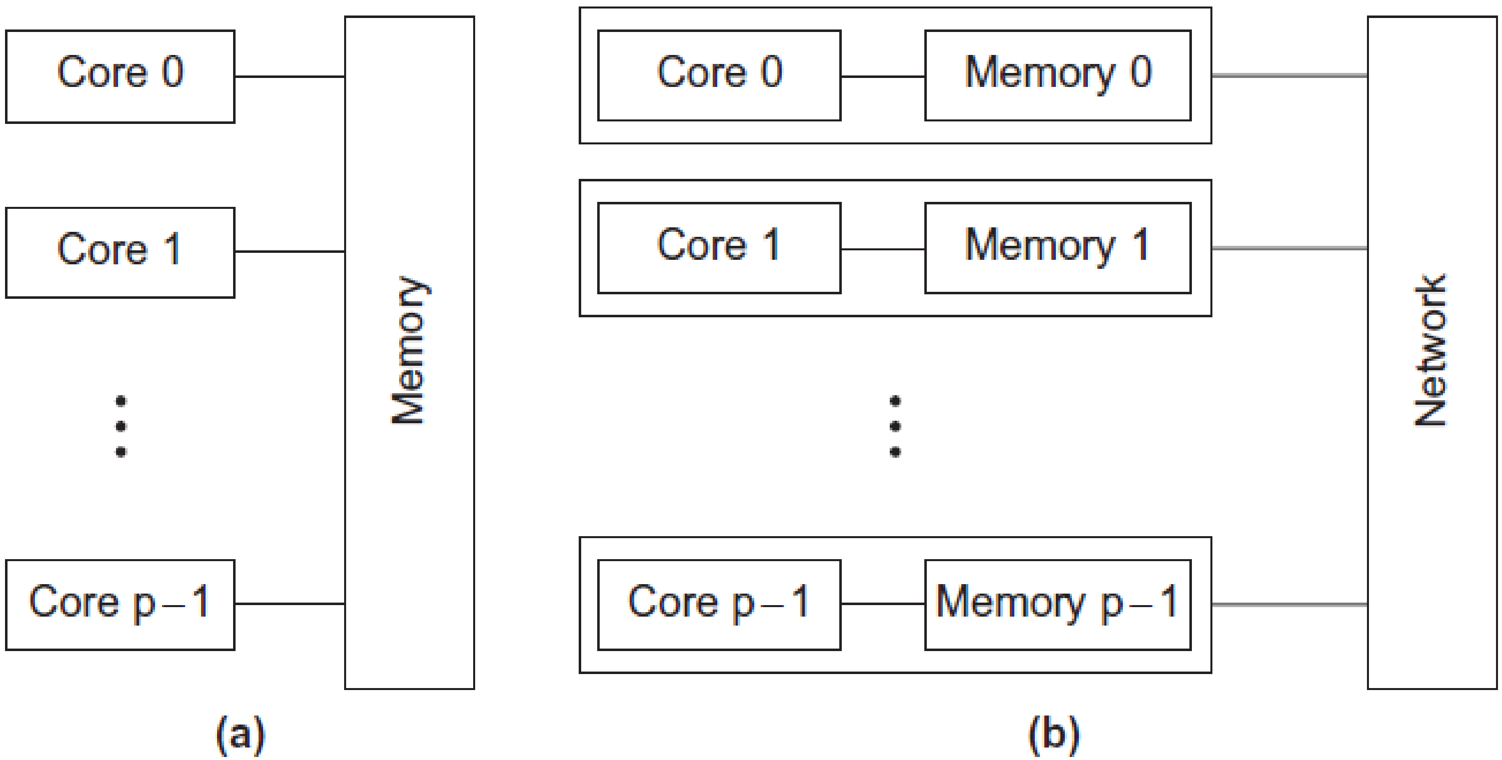
- Learning to write programs that are explicitly parallel.
- Using the C language.
- Using three different extensions to C.
  - Message-Passing Interface (MPI)
  - Posix Threads (Pthreads)
  - OpenMP

Type of parallel systems

- **Shared-memory**
  - The cores can share access to the computer's memory.
  - Coordinate the cores by having them examine and update shared memory locations.

- **Distributed-memory**
  - Each core has its own, private memory.
  - The cores must communicate explicitly by sending messages across a network.

Type of parallel systems



Shared-memory

Distributed-memory

Terminology

- Concurrent computing – a program is one in which multiple tasks can be in progress at any instant.
- Parallel computing – a program is one in which multiple tasks cooperate closely to solve a problem
- Distributed computing – a program may need to cooperate with other programs to solve a problem.

Concluding Remarks (1)

- The laws of physics have brought us to the doorstep of multicore technology.

- Serial programs typically don't benefit from multiple cores.

- Automatic parallel program generation from serial program code isn't the most efficient approach to get high performance from multicore computers.

Concluding Remarks (2)

- Learning to write parallel programs involves learning how to coordinate the cores.

- Parallel programs are usually very complex and therefore, require sound program techniques and development.