Introduction to Parallel Computing

Outline

1) **Sequential** computing → **Parallel** computing
2) **Single** core computers → **Multicore** computers
3) Why parallel?
4) High Performance Computing (**HPC**)
    - Supercomputers
    - Parallel programming
5) The **top 500** supercomputers in the world

Sequential Computing

For decades, programmers could only write programs that ran one instruction at a time (**sequential computing**)

The only way to run multiple things at the same time was merely an illusion by the operating system (e.g. **multitasking**, where programs are moved on and off the CPU extremely quickly to give the appearance of multiple programs running simultaneously)

Overtime, advancements in hardware (driven by problems becoming more and more complex) changed all of this

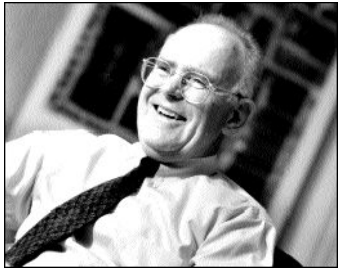
The Transition to Parallel Computing

Between the late 1980's and the early 2000's, computers were increasing in speed by roughly 50% every year

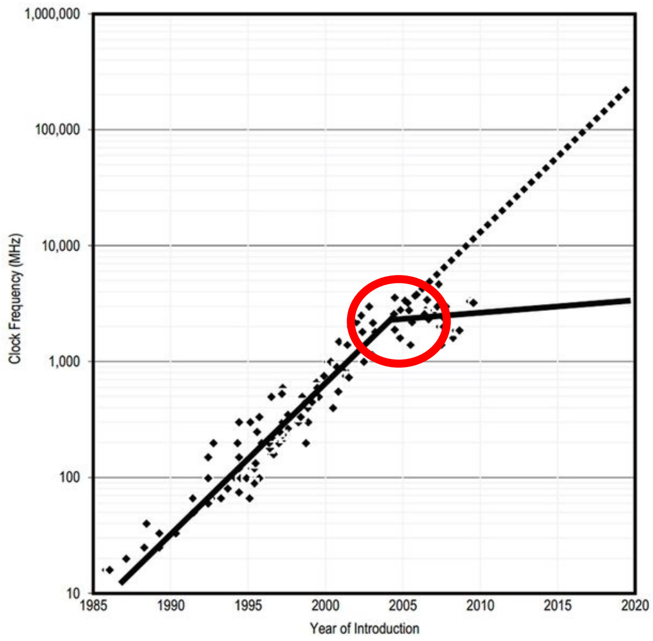
Due to overheating and other physical limitations, it has since dropped to increasing about 20% a year

The solution around this has been to increase the number of CPUs on a single chip

The other problem? The hardware won't help if programmers continue to write programs as they always have (sequentially)



Gordon Moore (Intel Co-Founder)



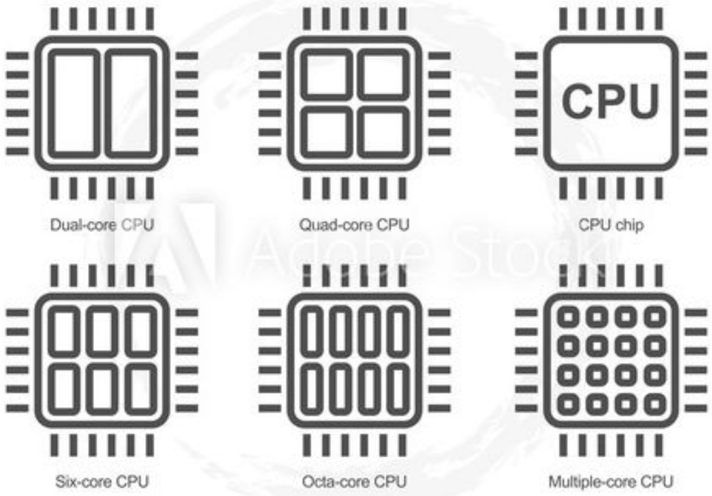
Chip Frequency graphed against year of introduction. Source: The Future of Computing Performance (2011)

From Single Core to Multicore Computers

Computers eventually transitioned to having more than one CPU (two completely separate processors in one machine, each one able to run one instruction at a time)

Overtime, advances in hardware lead to the ability to have more than one processing core on the same processor (**multicore processors**)

Today, most computers have at least 2 processing cores (with some having 4, 8, 16, or even *even more* cores on one chip!)



Why Parallel?

The computational problems we are trying to solve today continue to become *larger* and *more complex* (there is **<u>a lot</u>** of data!)

Why does parallelizing something typically make solving it faster?

Imagine putting together a 2000 piece **jigsaw puzzle**:

- By yourself, this could take awhile
- With another person, you each could work on a different part of the puzzle, combining your bigger pieces together later
- Imagine adding yet another person or two

High Performance Computing (HPC)

This continuous need for solving problems faster and handling more data has lead to the field of **High Performance Computing (HPC)**

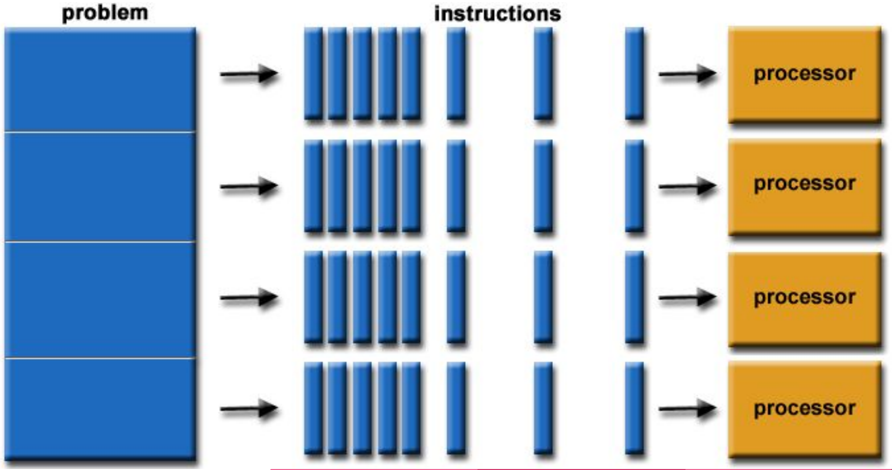
Before doing anything else, we need to carefully distinguish between several definitions that are sometimes thrown around interchangeably

What is High Performance Computing (HPC)?

The field of **High Performance Computing** (or **Supercomputing**) can be defined as *the use of supercomputers and parallel programming toward the goal of solving complex computational problems.*

Thus, it can be broken down into two parts:

- **Supercomputers** (the hardware)
- **Parallel Programming** (the software)



What are Supercomputers?

A **supercomputer** can be defined as *a computer with a high level of performance as compared to a general-purpose computer (PC) at the current point in time.* This means that the idea of a supercomputer *continuously* changes over time...

- Our phones today could have been considered supercomputers decades ago!

A supercomputer is *useful* for:

- <u>Large problems</u> (take too much memory to solve on a general-purpose machine)
- <u>Slow problems</u> (take too long to run on a general-purpose machine)

NASA engineers operating IBM System/360 Model 75 mainframe. Today, even a simple USB stick or WiFi router is more powerful than these mainframes, let alone an iPhone. Put simply, the iPhone 6's clock is 32,600 times faster than the best Apollo era computers and could perform instructions 120,000,000 times faster. You wouldn't be wrong in saying an iPhone could be used to guide 120,000,000 Apollo era spacecraft to the moon, all at the same time.

Spatial & Temporal Problem Scales

Length (m)	Phenomena
10^{-18}-10^{-15}	quarks, strings
10^{-15}-10^{-12}	proton, neutron
10^{-12}-10^{-9}	gamma rays, X rays, hydrogen atom
10^{-9}-10^{-6}	DNA, virus, optical light
10^{-6}-10^{-3}	bacteria, fog, human hair
10^{-3}-10^{0}	mosquito, golf ball, football
10^{0}-10^{3}	people, football field, Eiffel tower
10^{3}-10^{6}	Mt. Everest, Panama Canal, asteroid
10^{6}-10^{9}	Moon, Earth, light-second
10^{9}-10^{12}	Sun, light-minute, Earth's orbit
10^{12}-10^{15}	Solar System
10^{15}-10^{18}	light-year, nearest star
10^{18}-10^{21}	galactic arm
10^{21}-10^{24}	Milky Way, distance to Andromeda galaxy
10^{24}-10^{26}	visible universe

Time Scale (s)	Phenomena
10^{-44}	Planck time
10^{-24}	light crosses nucleus
10^{-15}	atomic vibration, visible light
10^{-12}	IBM SiGe transistor
10^{-9}	1 Gz CPU
10^{-6}	protein folding, lightning bolt
10^{-3}	hard disk seek time, blink of an eye
10^{0}	earthquakes
10^{2}	tornadoes
10^{5}	hurricanes
10^{7}	year
10^{9}	human life span
10^{10}	deep ocean mixing time
10^{12}	first homo sapiens
10^{15}	Milky Way rotation period
10^{17}	age of universe

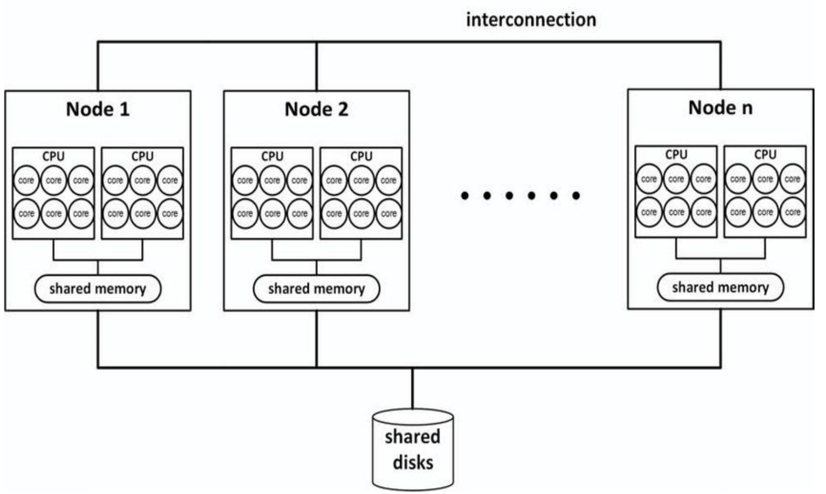
Direct Human Experience

What is Parallel Computing?

Parallel computing (or **parallel programming**) is *the simultaneous use of more than one compute resource to solve a computational problem*.

These compute resources could be multiple cores on a single CPU, multiple CPUs in a single computer, or multiple computers connected together via a high-speed network.

Many times, large problems can be divided into smaller ones, which can then be solved at the same time.



What Problems Are Being Solved with HPC?

Modeling and simulating real-world phenomena:

- Examples include ***weather forecasting***, ***galaxy formation***, and ***spread of disease***

Mining for patterns through large datasets:

- Examples include ***gene sequencing***, ***signal processing***, and ***detecting credit card fraud***

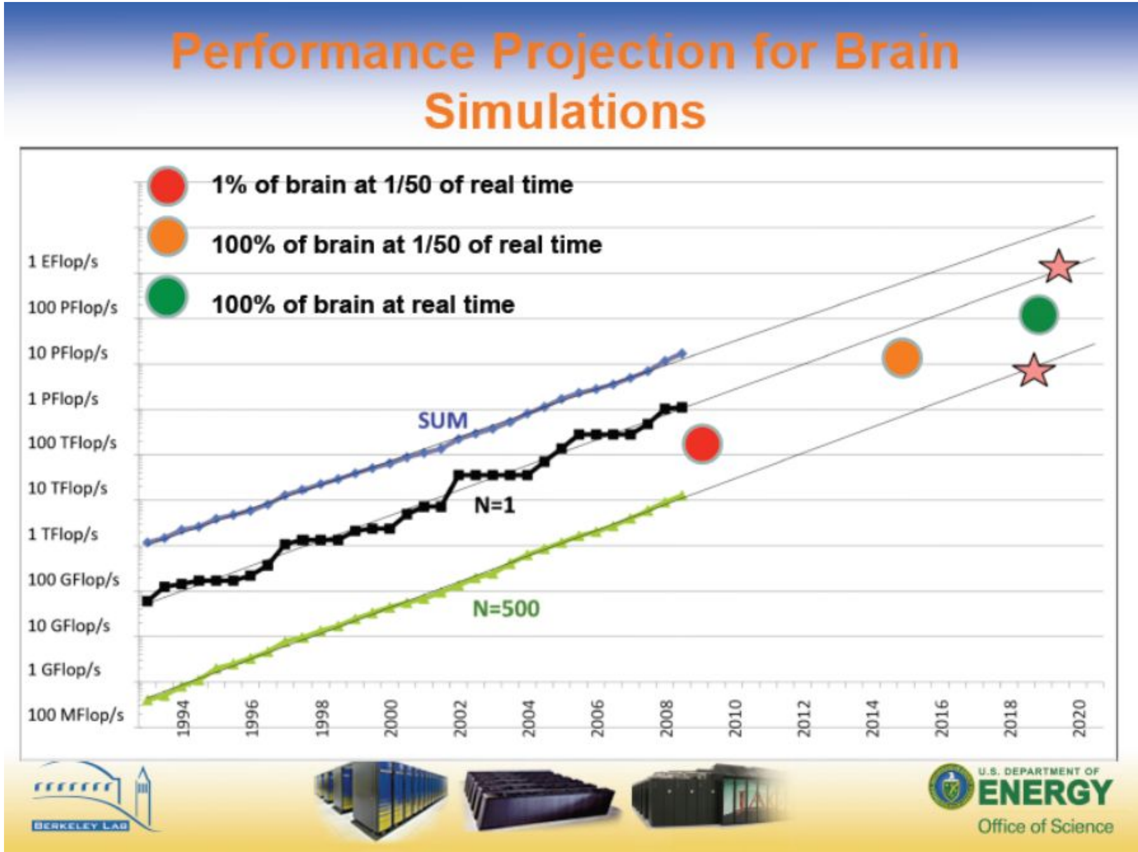
Visualizing complex data

"Pringles potato chips are designed using [supercomputing] capabilities -- to assess their aerodynamic features so that on the manufacturing line they don't go flying off the line," said Dave Turek, vice president of deep computing at IBM. -CNN

← **IBM's Watson on Jeopardy! 2011**

Top 500

Check out https://www.top500.org for a list of the current top 500 fastest supercomputers in the world (updated twice a year)



Top 500 (Green Version)

Supercomputers, as you can imagine, often use a <u>tremendous</u> amount of power to operate.

While the previous Top 500 list is in terms of pure performance, a different version of the list addresses the question of which supercomputers are the *greenest*.

Check out https://www.top500.org/green500