NE 155
Introduction to Numerical Simulations in Radiation Transport

Lecture 2: Computing

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Outline

1. History and terminology
2. Basic computer architecture
3. Introduction to Parallelism
4. Current supercomputers

How do we measure utility?[1]

IPS (Instructions Per Second) is a measure of a computer's processor speed. IPS can be useful when comparing performance between processors made from a similar architecture, but are difficult to compare between CPU architectures

Clock rate typically refers to the frequency at which a CPU is running. It is measured in the SI unit Hertz.

FLOPS (FLoating-point Operations Per Second) is a measure of computer performance, useful in fields of scientific calculations that make heavy use of floating-point calculations.

[1] en.wikipedia.org

Computing Machines, Origins

Figure 1 : Roman Abacus,
http://history-computer.com/CalculatingTools/abacus.html

Early Development of Computing

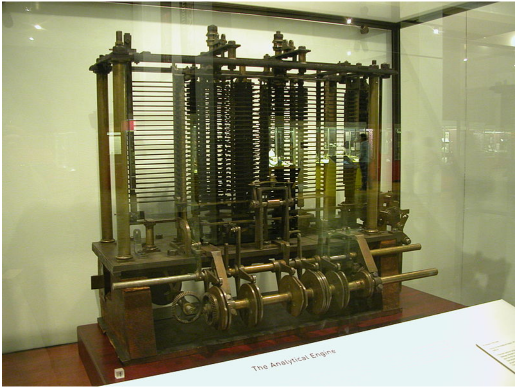


Figure 2 : Reconstruction of Babbage's Analytical Engine, the first general-purpose programmable computer, http://en.wikipedia.org/wiki/History_of_computing_hardware #Punched_card_data_processing

First Electromechanical Computers

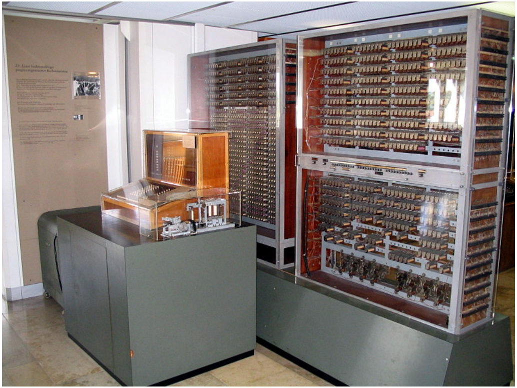


Figure 3 : Zuse Z3 replica on display at Deutsches Museum in Munich, en.wikipedia.org/wiki/Z3_(computer)

Stored Programs

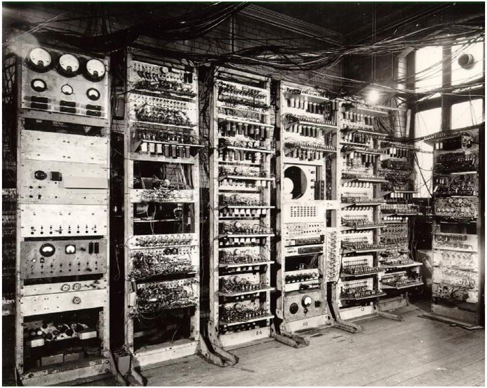


Figure 4 : The Manchester Mark 1 was one of the world's first stored-program computers, http://www.computer50.org/mark1/ip-mm1.mark1.html

Microprogramming, Magnetic Storage, Transistors

- 1951: realization that CPUs can be controlled by a miniature, highly specialized computer program in high-speed ROM
- 1954: magnetic core memory was rapidly displacing most other forms of temporary storage
- 1956: IBM introduced the first disk storage unit: using 50 24-inch metal disks, it stored 5 MB of data for $10,000 per MB ($90,000 in 2014 $s)
- 1947: invention of the bipolar transistor; this replaced vacuum tubes by 1955 → "Second Generation" of computer designs

SUPERCOMPUTERS

Figure 5 : The University of Manchester Atlas 1963, http://en.wikipedia.org/wiki/History_of_computing_hardware #Punched_card_data_processing

Integrated Circuit

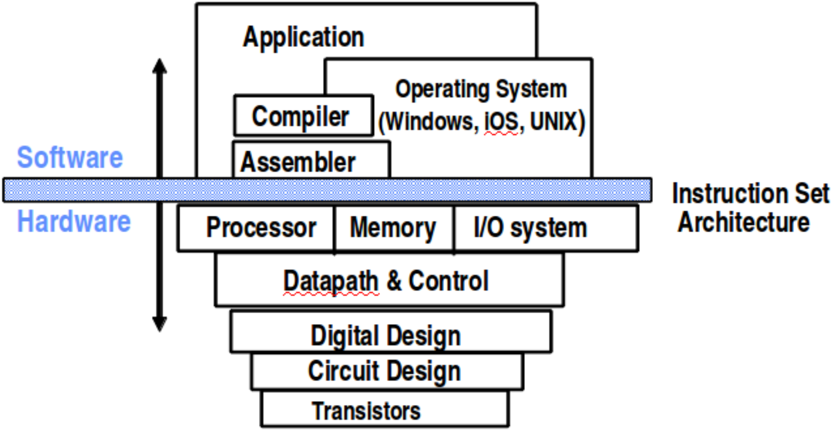
With the advent of the transistor and the work on semi-conductors generally, it now seems possible to envisage electronic equipment in a solid block with no connecting wires. The block may consist of layers of insulating, conducting, rectifying and amplifying materials, the electronic functions being connected directly by cutting out areas of the various layers.

Geoffrey W.A. Dummer, Royal Radar Establishment of the Ministry of Defence, 1952

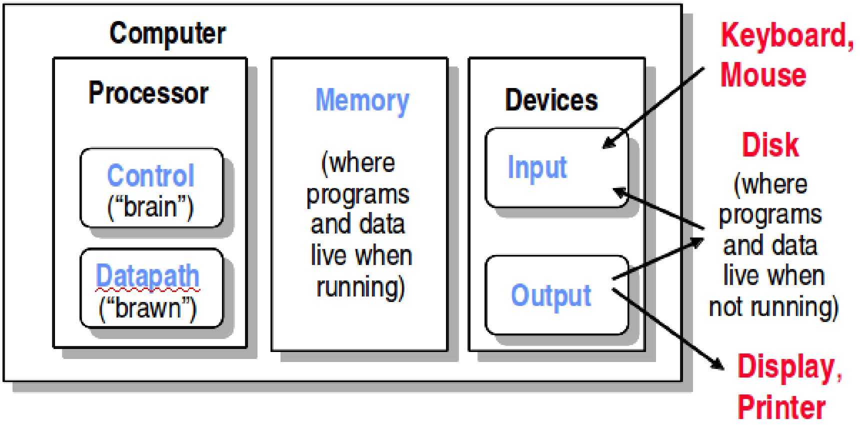
GENERATIONS 4-6

- Very large scale integration of devices on chip
- C and FORTRAN programming languages
- UNIX operating system (Bell labs, Berkeley)
- Large scale parallel processing; supercomputing centers
- Shared and distributed memory
- Parallel/vector shared/distributed memory combinations
- High speed networking

Computer Architecture



COMPONENTS



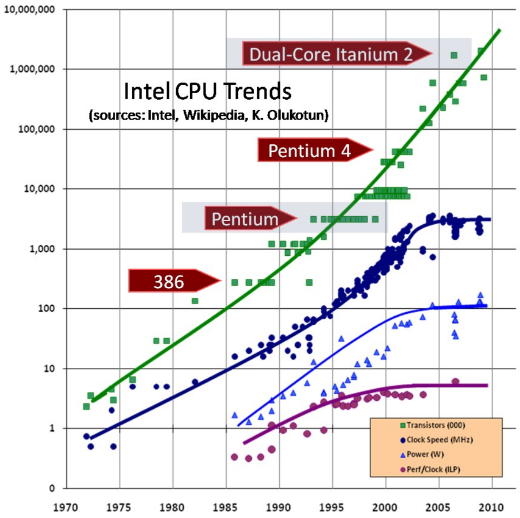
Computer
Processor
Control
("brain")
Datapath
("brawn")
Memory
(where programs and data live when running)
Devices
Input
Output
Keyboard, Mouse
Disk
(where programs and data live when not running)
Display, Printer

MOORE'S "LAW"

The number of transistors on integrated circuits doubles approximately every 18 months.

- In 1965 Gordon E. Moore described this trend and predicted it to hold for at least 10 years
- He worked at Intel
- The trend has held, but is expected to change around now...

MOORE'S "LAW"



Intel CPU Trends
(sources: Intel, Wikipedia, K. Olukotun)
Dual-Core Itanium 2
Pentium 4
Pentium
386
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Transistors (000)
Clock Speed (MHz)
Power (W)
Perf/Clock (ILP)

What is Parallel Architecture?

A parallel computer is a collection of processing elements that cooperate to solve large problems quickly

- Resource allocation
  - How much memory?
  - How many elements?
  - How powerful are the elements?
- Data access, Communication, and Synchronization
  - How do the elements cooperate and communicate?
  - How are data transmitted between processors?
  - What are the abstractions and primitives for cooperation?
- Performance and Scalability
  - How does it all translate into performance?
  - How does it scale?

Forms of Parallelism

- **Bit level**: increases in word size reduced the # of instructions the processor needs
- **Instruction level**: hardware and/or software perform operations simultaneously when possible
- **Memory system**: overlap of memory operations with computation
- **Operating system**: multiple jobs run in parallel on commodity symmetric multiprocessors (SMPs)

There are limitations to all of these

To achieve high performance, the programmer needs to identify, schedule, and coordinate parallel tasks and data

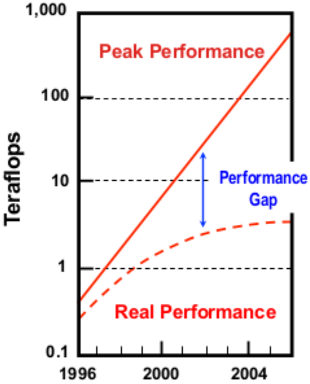
PERFORMANCE

- **Strong Scaling**: increase element count with problem size fixed (solve a problem faster)

  $$Speedup = \frac{\text{Time with P cores}}{\text{Time with 1 core}}$$

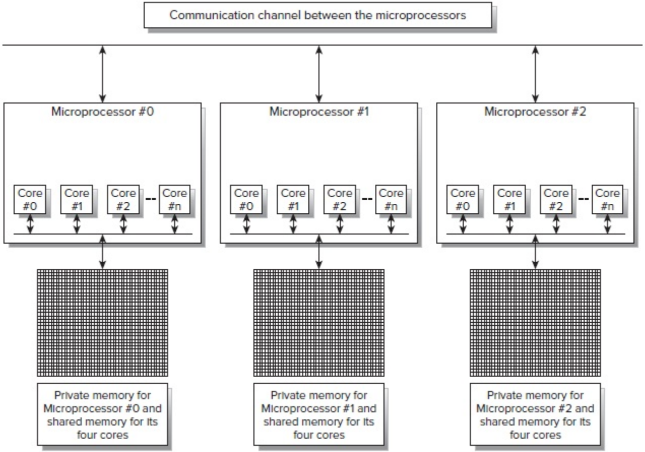
- **Weak Scaling**: increase element count and problem size to keep problem size per element fixed (solve bigger problems)

  $$Speedup = \frac{\text{Time with 1 core}}{\text{Time with P cores}}$$



Types of Memory

Shared Distributed Distributed Shared



GPUs

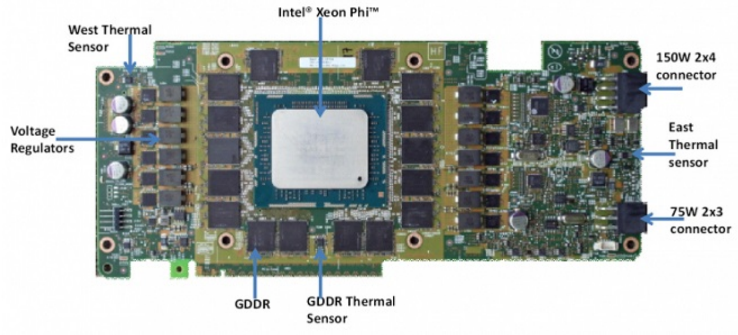
- Graphics Processing Unit (**GPU**): highly parallel, good for processing large blocks of data
- General Purpose GPU (**GPGPU**): Using a GPU to do CPU work - computational science instead of graphics

NVIDIA GPU

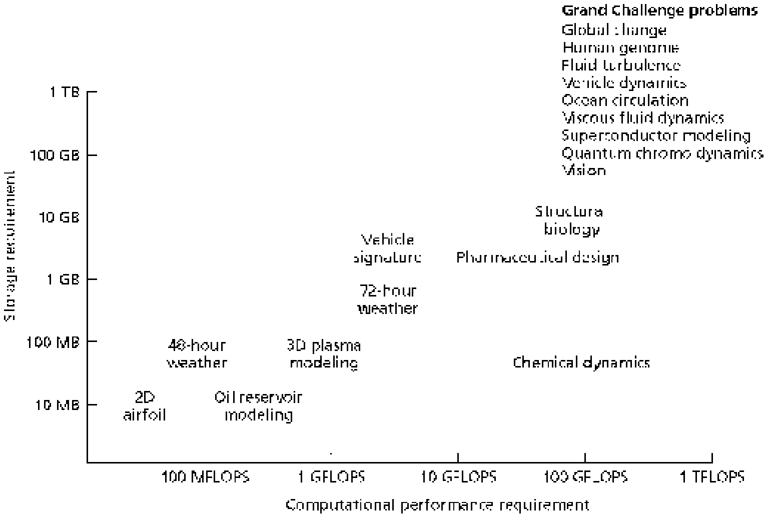
MICs

- Many Integrated Core (**MIC**): combines many CPU cores onto a single chip
- **Heterogeneous** architecture: GPUs + CPUs or MICs + CPUs, etc.

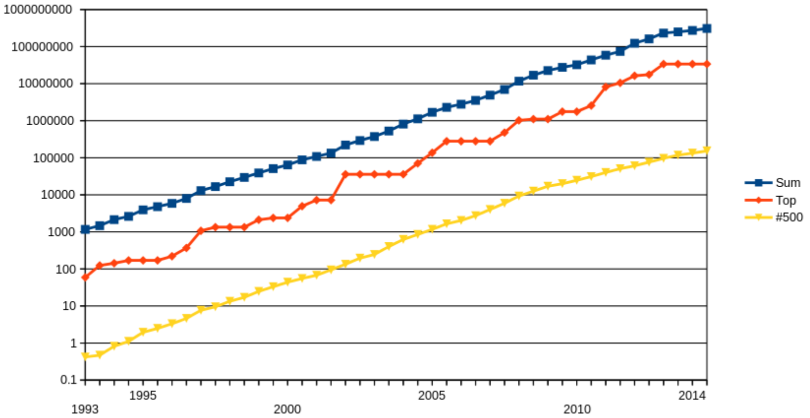
Intel Xeon Phi Board



Scientific Computing Demand



Top 500 Computers, Nov 2014

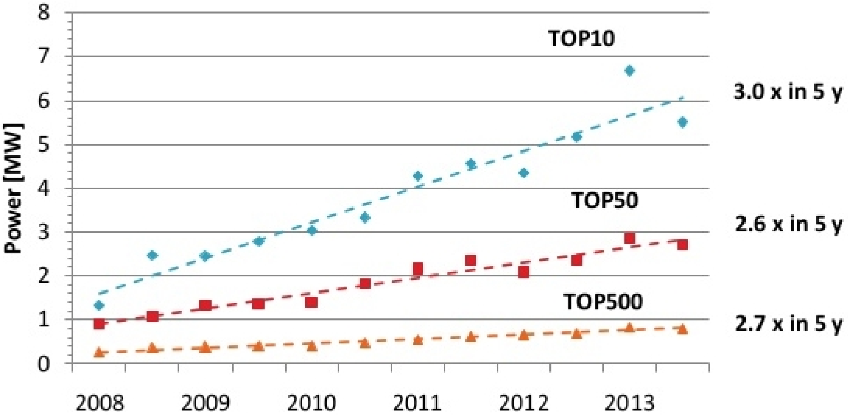


Log y axis in GFLOPS, x axis in years

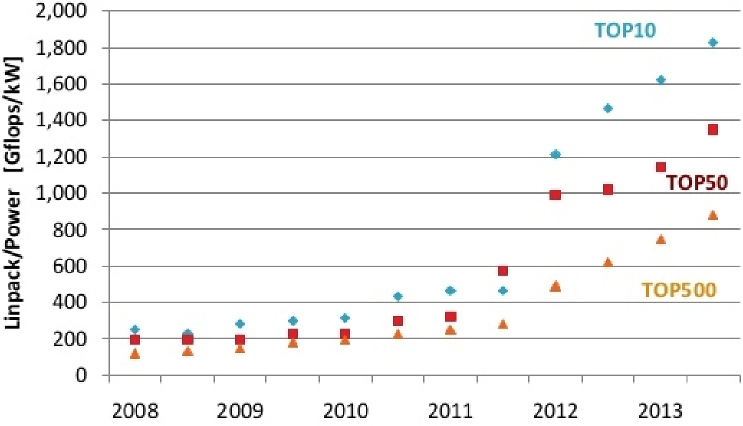
Top 10 Computers, Nov 2014

Rank	Rmax Rpeak (Pflops)	Name	Computer design Processor type, interconnect
1	33.863 54.902	*Tianhe-2*	**NUDT** Xeon E5–2692 + Xeon Phi 31S1P, TH Express-2
2	17.590 27.113	*Titan*	**Cray XK7** Opteron 6274 + Tesla K20X, Cray Gemini Interconnect
3	17.173 20.133	*Sequoia*	**Blue Gene/Q** PowerPC A2, Custom
4	10.510 11.280	*K computer*	**RIKEN** SPARC64 VIIIfx, Tofu
5	8.586 10.066	*Mira*	**Blue Gene/Q** PowerPC A2, Custom
6	6.271 7.779	*Piz Daint*	**Cray XC30** Xeon E5–2670 + Tesla K20X, Aries
7	5.168 8.520	*Stampede*	**PowerEdge C8220** Xeon E5–2680 + Xeon Phi, Infiniband
8	5.008 5.872	*JUQUEEN*	**Blue Gene/Q** PowerPC A2, Custom
9	4.293 5.033	*Vulcan*	**Blue Gene/Q** PowerPC A2, Custom
10	3.577 6.132		**Cray CS** Xeon E5-2660v2 10C and Nvidia K40, Infiniband

Power Consumption, Nov 2013



Power Efficiency, Nov 2013



WHERE ARE WE GOING?

Recap

- Humans have been working to use machines for computation for a very long time
- The 20th century saw the development of the computers we know today $\rightarrow$ development of computational science as a field
- A revolution in supercomputing began at the end of the 20th century $\rightarrow$ computational science is a major contributor to knowledge
- We are reaching the limits of “traditional” architecture growth
- What we can compute and how is tightly tied to computer architecture development