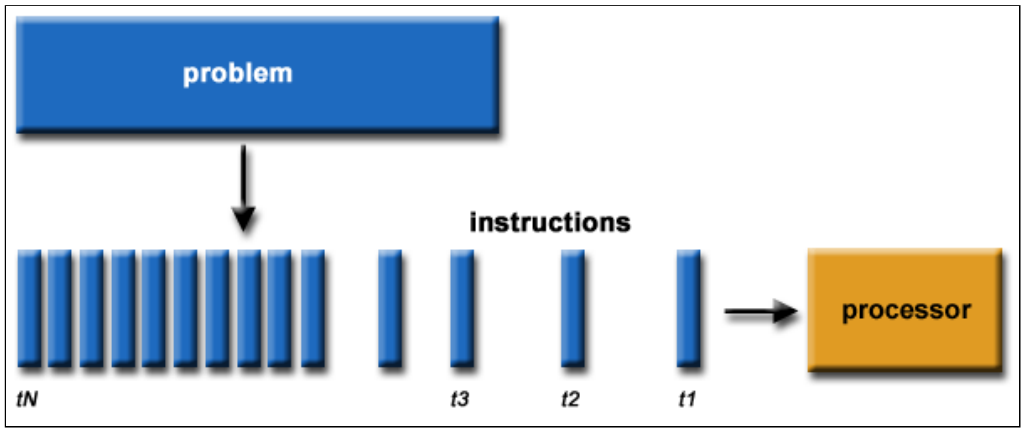
Overview

What is Parallel Computing?

Serial Computing:

- Traditionally, software has been written for ***serial*** computation:
  - A problem is broken into a discrete series of instructions
  - Instructions are executed sequentially one after another
  - Executed on a single processor
  - Only one instruction may execute at any moment in time



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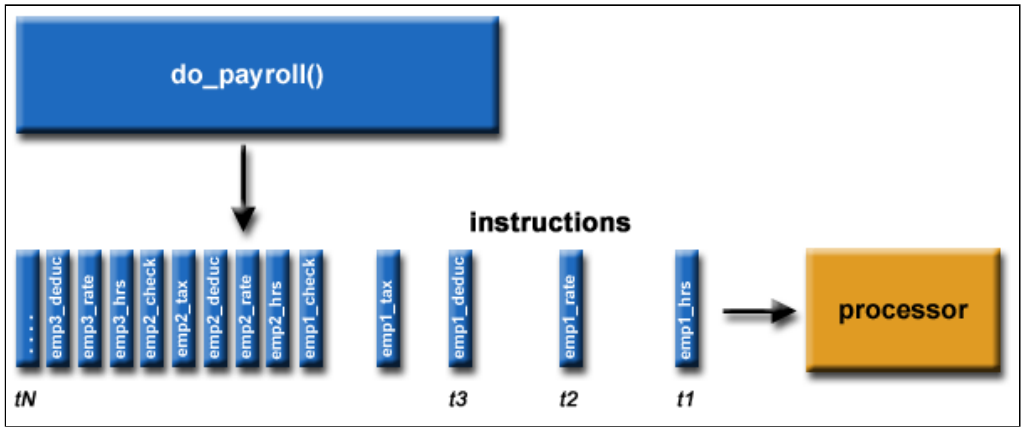
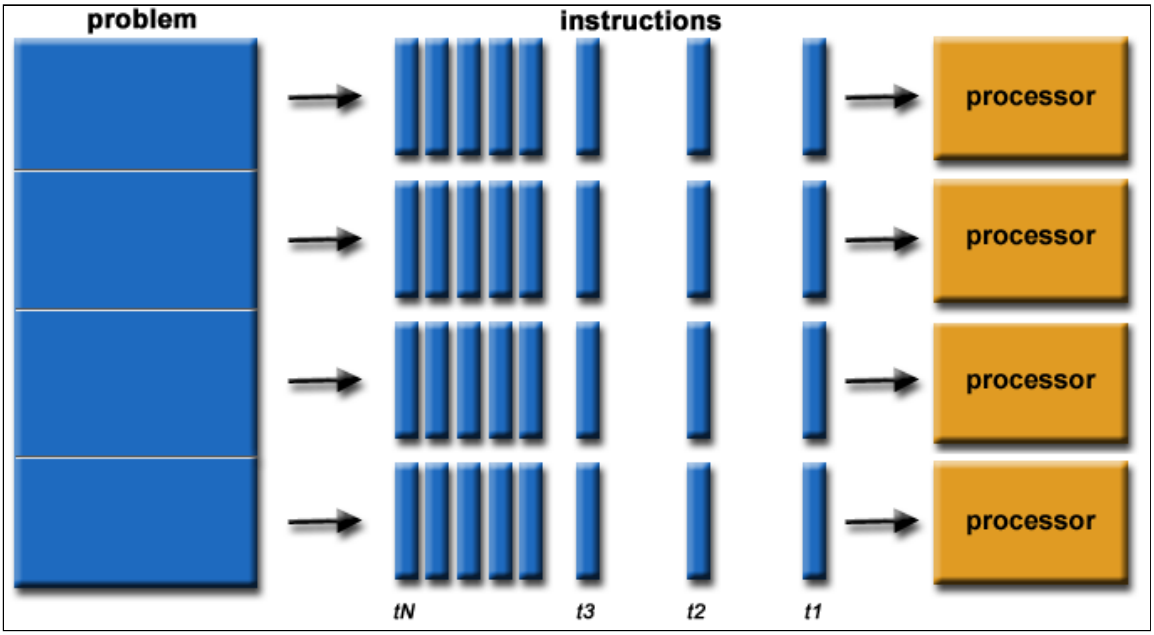


Parallel Computing:

- In the simplest sense, ***parallel computing*** is the simultaneous use of multiple compute resources to solve a computational problem:
  - A problem is broken into discrete parts that can be solved concurrently
  - Each part is further broken down to a series of instructions
  - Instructions from each part execute simultaneously on different processors
  - An overall control/coordination mechanism is employed



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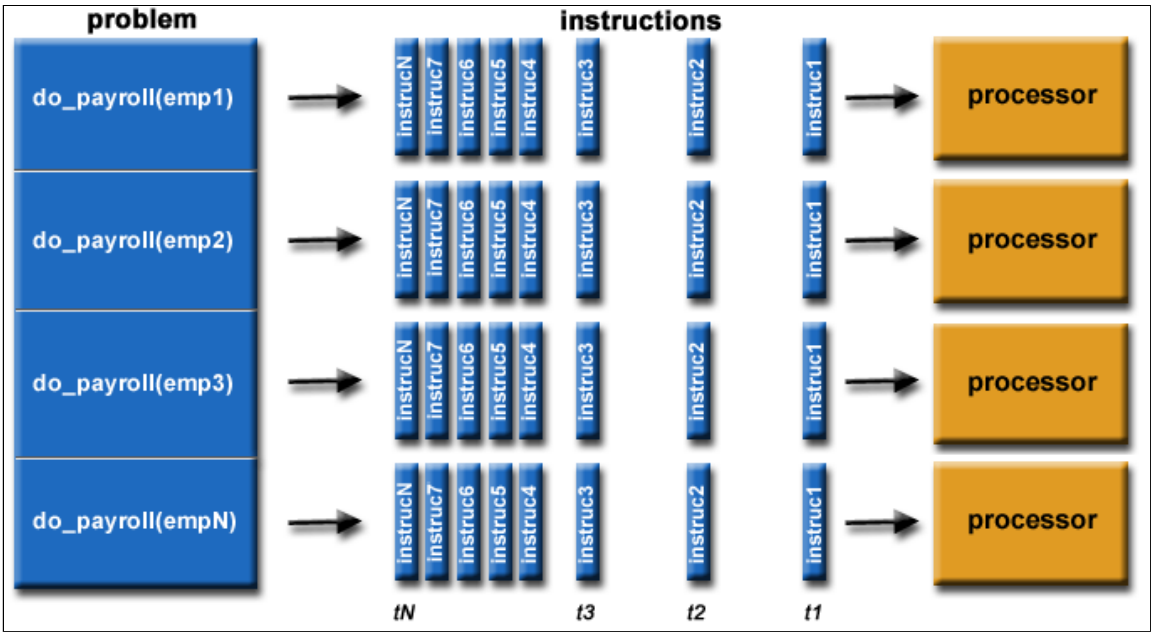
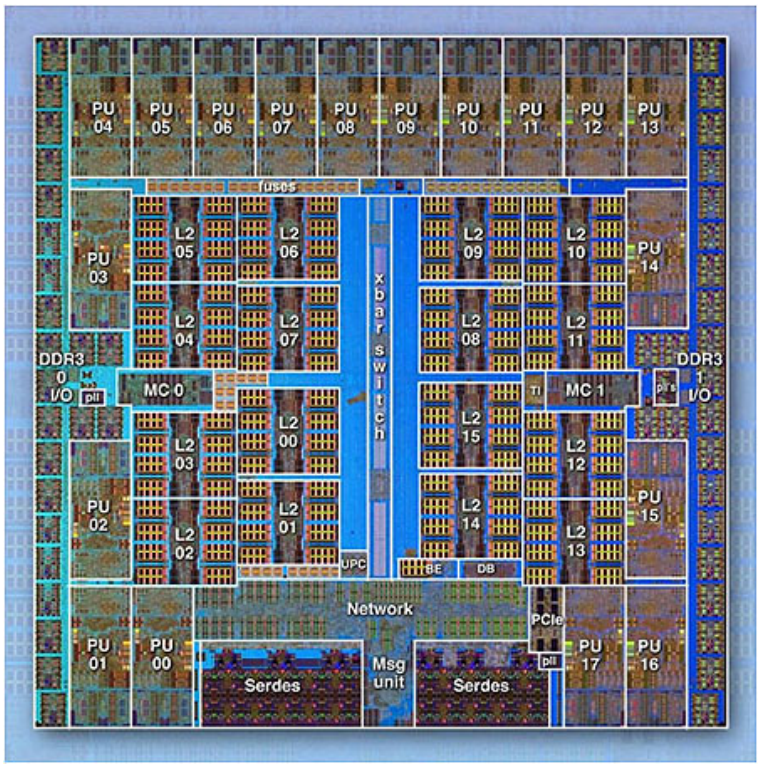


- The computational problem should be able to:
  - Be broken apart into discrete pieces of work that can be solved simultaneously;
  - Execute multiple program instructions at any moment in time;
  - Be solved in less time with multiple compute resources than with a single compute resource.

- The compute resources are typically:
  - A single computer with multiple processors/cores
  - An arbitrary number of such computers connected by a network

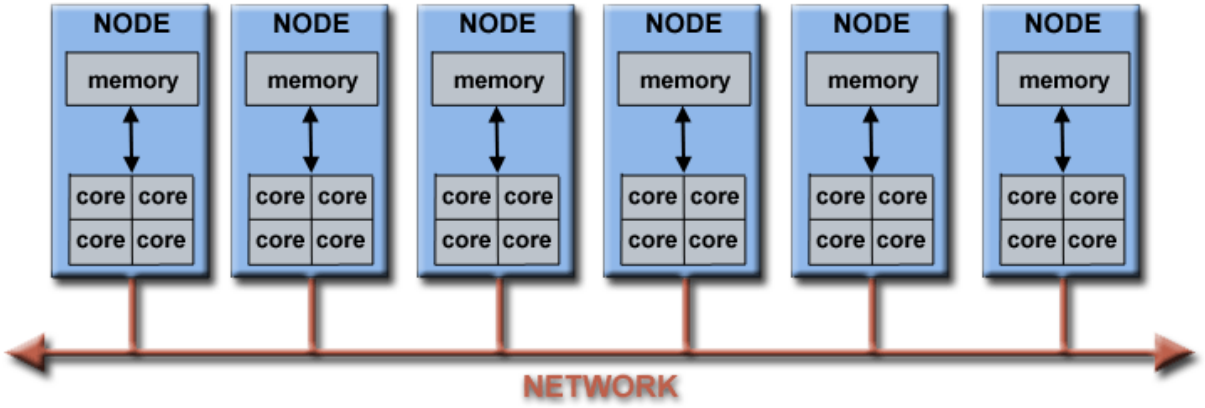
Parallel Computers:

- Virtually all stand-alone computers today are parallel from a hardware perspective:
  - Multiple functional units (L1 cache, L2 cache, branch, prefetch, decode, floating-point, graphics processing (GPU), integer, etc.)
  - Multiple execution units/cores
  - Multiple hardware threads

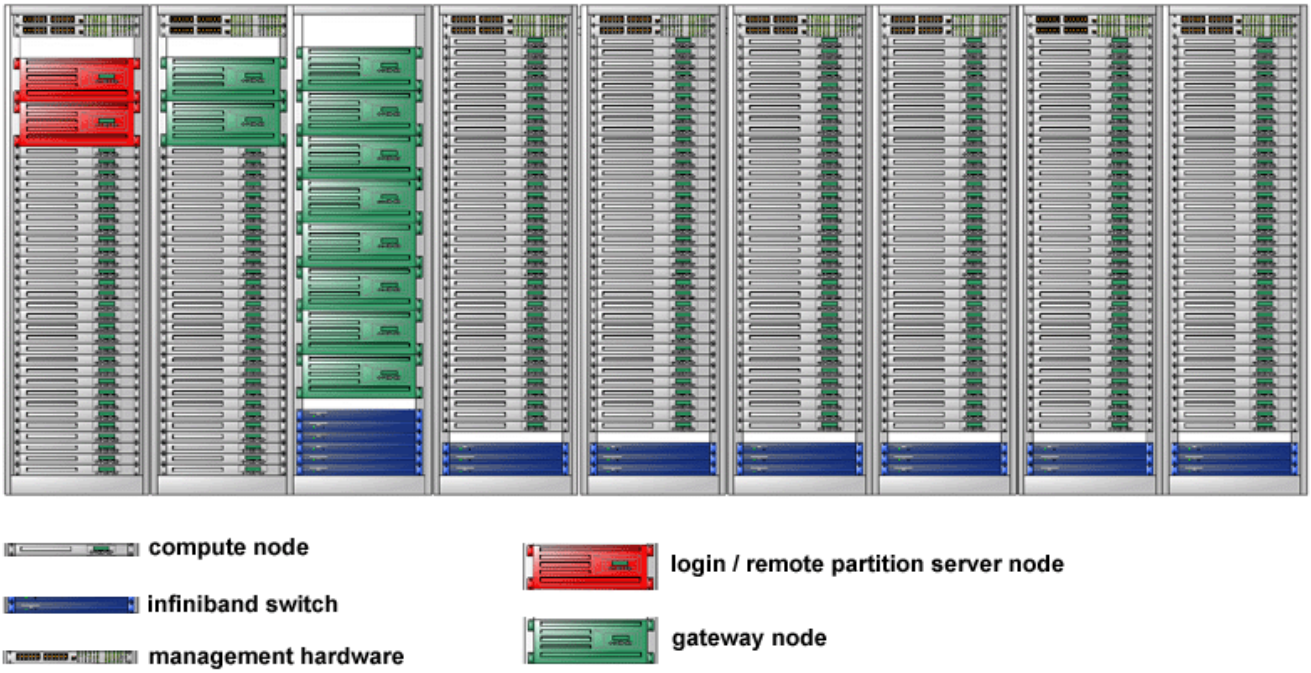


IBM BG/Q Compute Chip with 18 cores (PU) and 16 L2 Cache units (L2)

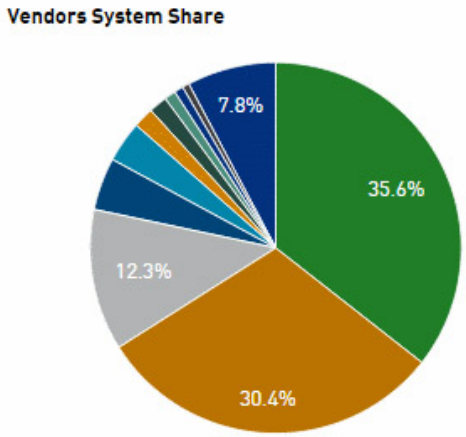
- Networks connect multiple stand-alone computers (nodes) to make larger parallel computer clusters.

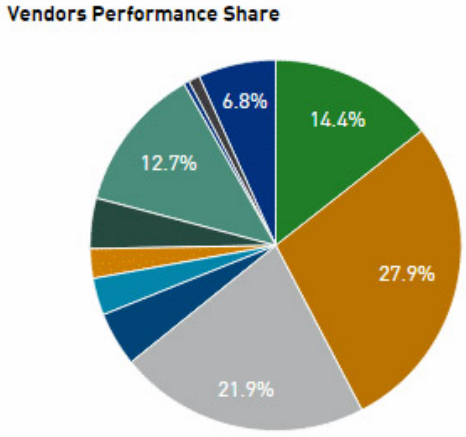


- For example, the schematic below shows a typical LLNL parallel computer cluster:
  - Each compute node is a multi-processor parallel computer in itself
  - Multiple compute nodes are networked together with an Infiniband network
  - Special purpose nodes, also multi-processor, are used for other purposes



- The majority of the world's large parallel computers (supercomputers) are clusters of hardware produced by a handful of (mostly) well known vendors.





VENDORS	COUNT	SYSTEM SHARE (%)
HP	179	35.8
IBM	153	30.6
Cray Inc.	62	12.4
SGI	23	4.6
Bull	18	3.6
Dell	9	1.8
Fujitsu	8	1.6
NUDT	5	1
RSC Group	4	0.8
Atipa	3	0.6
NEC	3	0.6
MEGWARE	3	0.6
T-Platforms	2	0.4
Itautec	2	0.4
Hitachi	2	0.4
Oracle	2	0.4
Self-made	2	0.4
ClusterVision	2	0.4
Dawning	2	0.4
NEC/HP	1	0.2
Acer Group	1	0.2
PEZY Computing / Exascaler Inc.	1	0.2
HP/WIPRO	1	0.2
Inspur	1	0.2
Niagara Computers, Supermicro	1	0.2
Clustervision/Supermicro	1	0.2
AMD, ASUS, FIAS, GSI	1	0.2
Xenon Systems	1	0.2
Netweb Technologies	1	0.2
IPE, Nvidia, Tyan	1	0.2
Adtech	1	0.2
Intel	1	0.2
NRCPCET	1	0.2
Supermicro	1	0.2
Hitachi/Fujitsu	1	0.2

Source: Top500.org

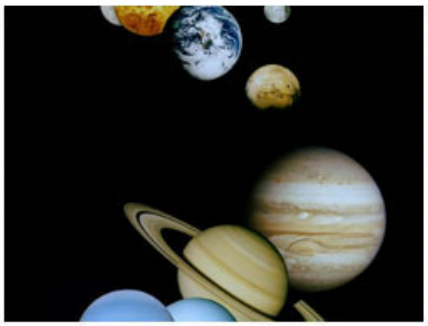
Overview

Why Use Parallel Computing?

The Real World is Massively Parallel:

- In the natural world, many complex, interrelated events are happening at the same time, yet within a temporal sequence.
- Compared to serial computing, parallel computing is much better suited for modeling, simulating and understanding complex, real world phenomena.
- For example, imagine modeling these serially:


Galaxy Formation


Planetary Movments


Climate Change

Rush Hour Traffic


Plate Tectonics


Weather


Auto Assembly

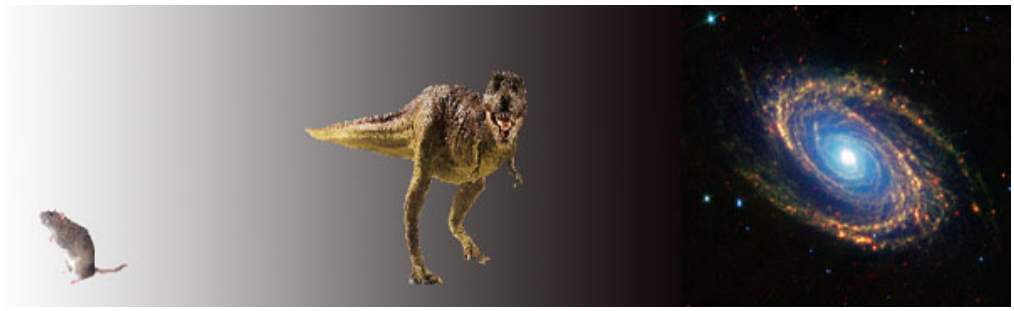

Jet Construction


Drive-thru Lunch

Main Reasons:

- **SAVE TIME AND/OR MONEY:**
  - In theory, throwing more resources at a task will shorten its time to completion, with potential cost savings.
  - Parallel computers can be built from cheap, commodity components.

- **SOLVE LARGER / MORE COMPLEX PROBLEMS:**
  - Many problems are so large and/or complex that it is impractical or impossible to solve them on a single computer, especially given limited computer memory.
  - Example: "Grand Challenge Problems" (en.wikipedia.org/wiki/Grand_Challenge) requiring PetaFLOPS and PetaBytes of computing resources.
  - Example: Web search engines/databases processing millions of transactions every second

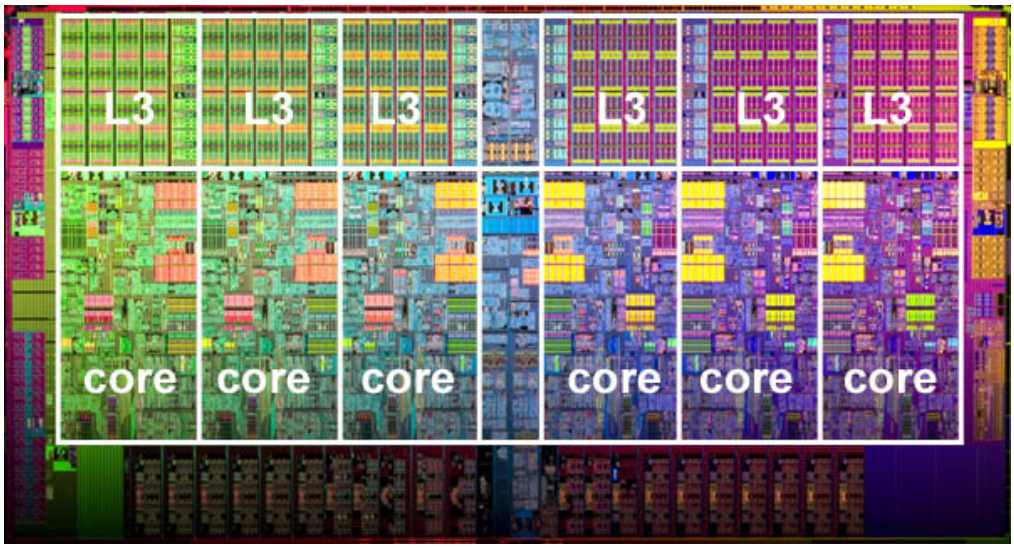


- **PROVIDE CONCURRENCY:**
  - A single compute resource can only do one thing at a time. Multiple compute resources can do many things simultaneously.
  - Example: Collaborative Networks provide a global venue where people from around the world can meet and conduct work "virtually".

- **TAKE ADVANTAGE OF NON-LOCAL RESOURCES:**
  - Using compute resources on a wide area network, or even the Internet when local compute resources are scarce or insufficient.
  - Example: SETI@home (setiathome.berkeley.edu) over 1.5 million users in nearly every country in the world. Source: www.boincsynergy.com/stats/ (June, 2015).
  - Example: Folding@home (folding.stanford.edu) uses over 160,000 computers globally (June, 2015)

- **MAKE BETTER USE OF UNDERLYING PARALLEL HARDWARE:**

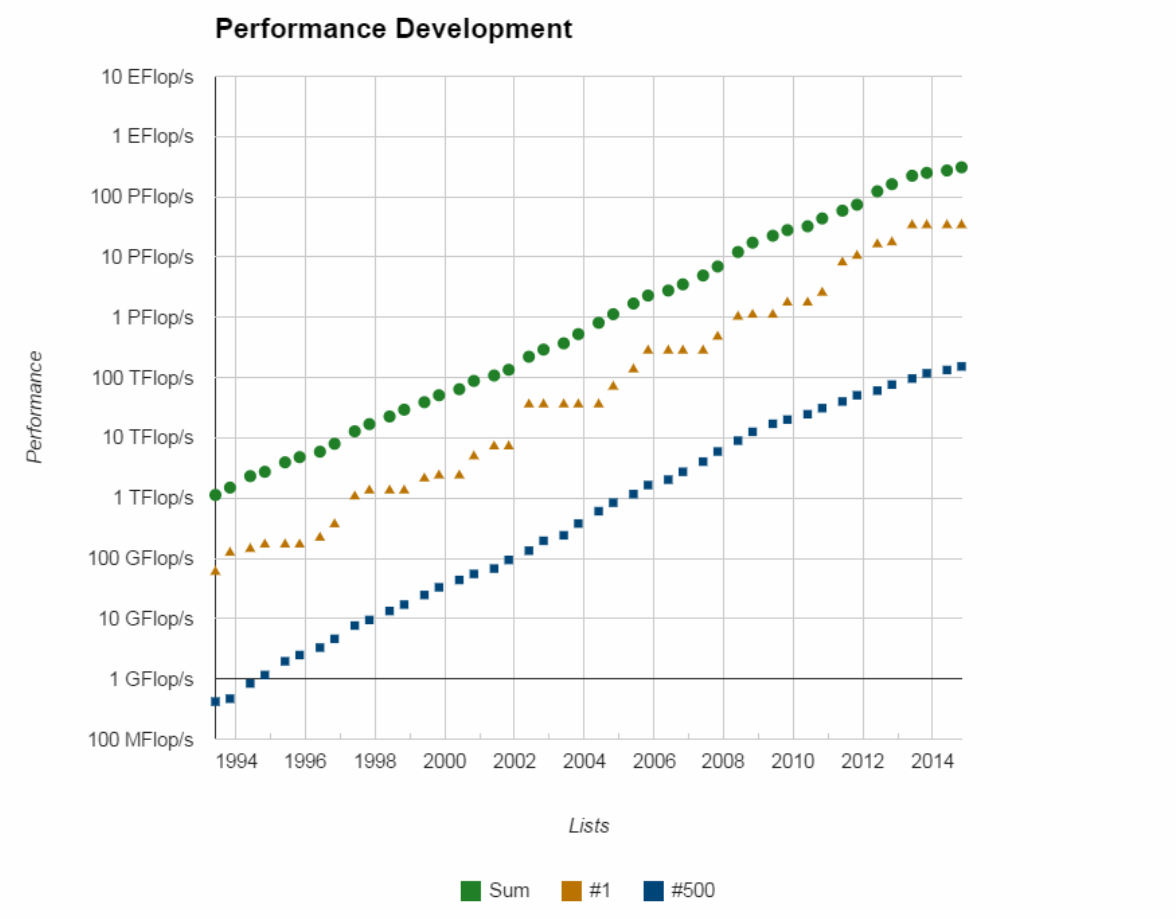
- Modern computers, even laptops, are parallel in architecture with multiple processors/cores.
- Parallel software is specifically intended for parallel hardware with multiple cores, threads, etc.
- In most cases, serial programs run on modern computers "waste" potential computing power.



Intel Xeon processor with 6 cores and 6 L3 cache units

The Future:

- During the past 20+ years, the trends indicated by ever faster networks, distributed systems, and multi-processor computer architectures (even at the desktop level) clearly show that***parallelism is the future of computing***.
- In this same time period, there has been a greater than **500,000x** increase in supercomputer performance, with no end currently in sight.
- ***The race is already on for Exascale Computing!***
  - Exaflop = 10^{18} calculations per second



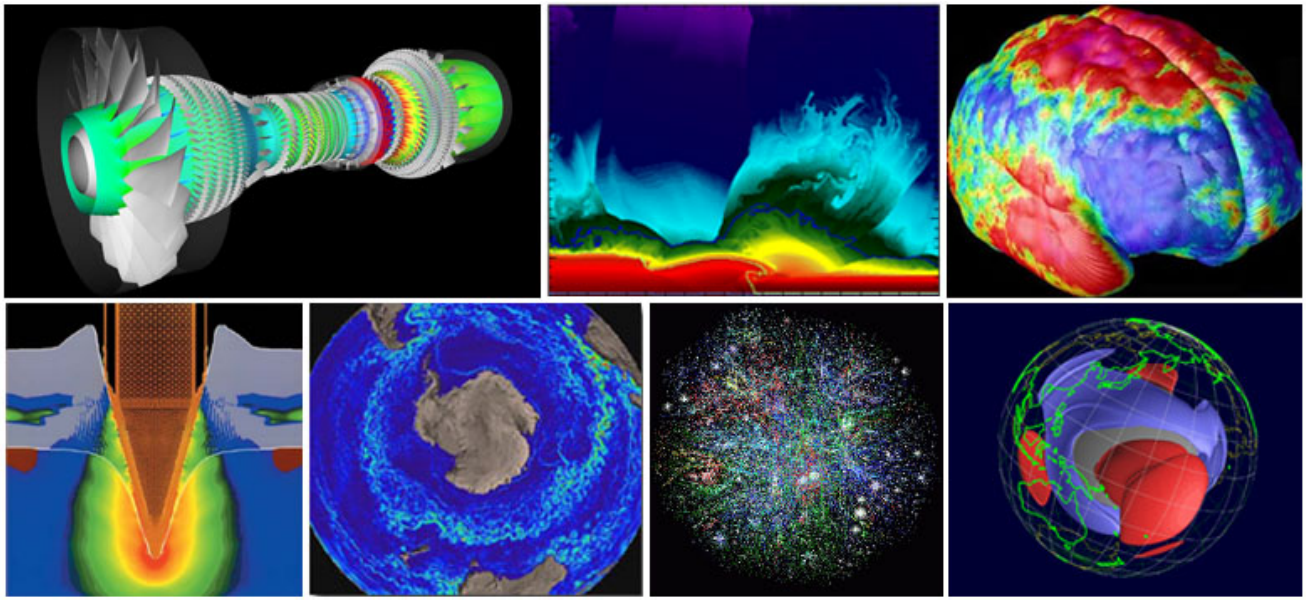
Source: Top500.org

Overview

Who is Using Parallel Computing?

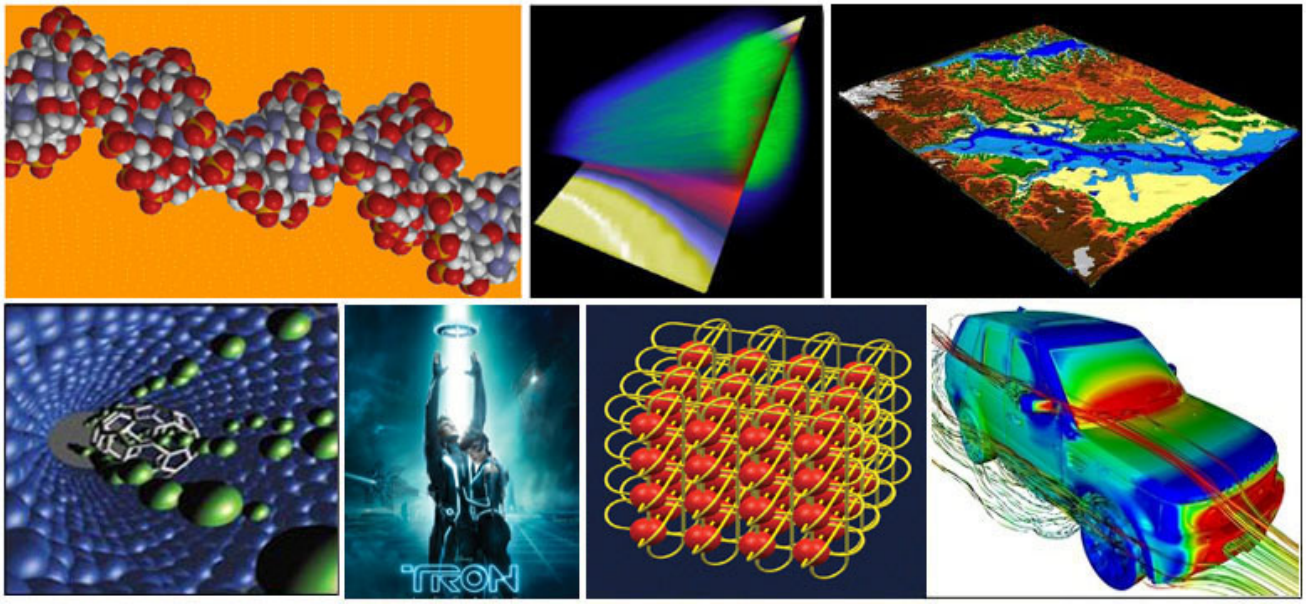
Science and Engineering:

- Historically, parallel computing has been considered to be "the high end of computing", and has been used to model difficult problems in many areas of science and engineering:
  - Atmosphere, Earth, Environment
  - Physics - applied, nuclear, particle, condensed matter, high pressure, fusion, photonics
  - Bioscience, Biotechnology, Genetics
  - Chemistry, Molecular Sciences
  - Geology, Seismology
  - Mechanical Engineering - from prosthetics to spacecraft
  - Electrical Engineering, Circuit Design, Microelectronics
  - Computer Science, Mathematics
  - Defense, Weapons



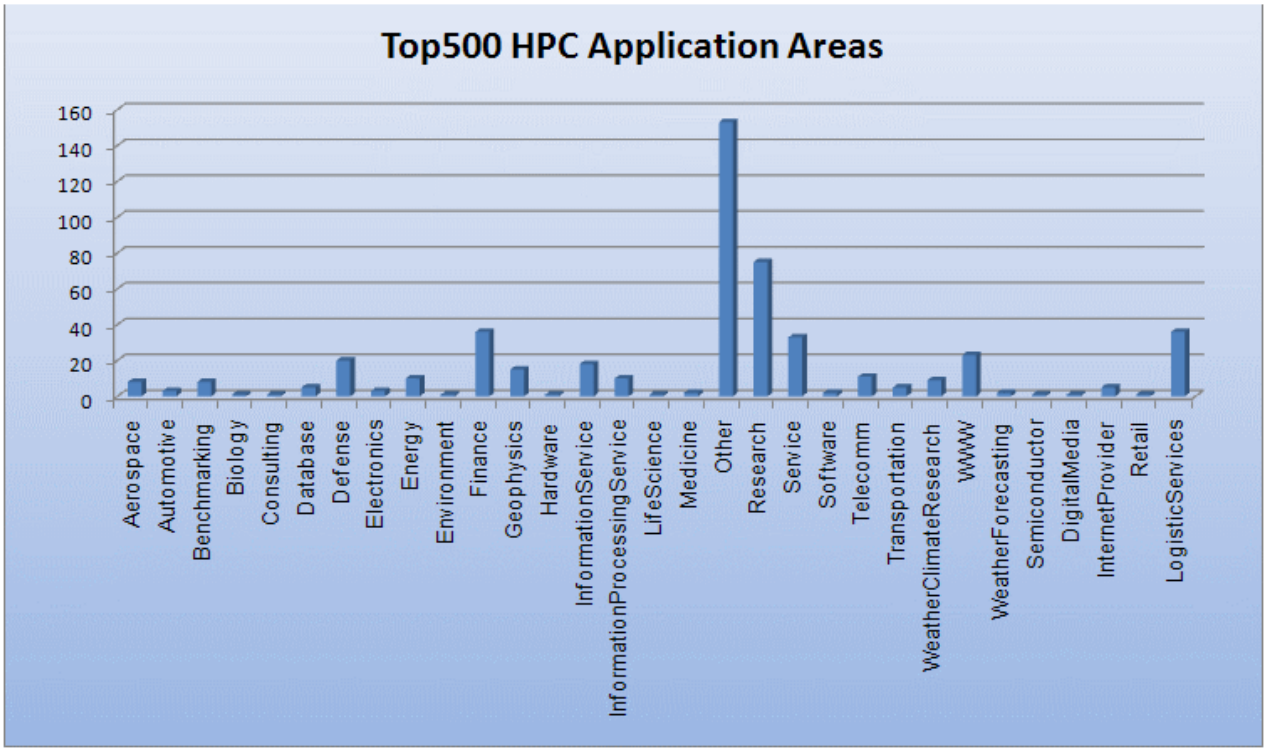
Industrial and Commercial:

- Today, commercial applications provide an equal or greater driving force in the development of faster computers. These applications require the processing of large amounts of data in sophisticated ways. For example:
  - "Big Data", databases, data mining
  - Oil exploration
  - Web search engines, web based business services
  - Medical imaging and diagnosis
  - Pharmaceutical design
  - Financial and economic modeling
  - Management of national and multi-national corporations
  - Advanced graphics and virtual reality, particularly in the entertainment industry
  - Networked video and multi-media technologies
  - Collaborative work environments



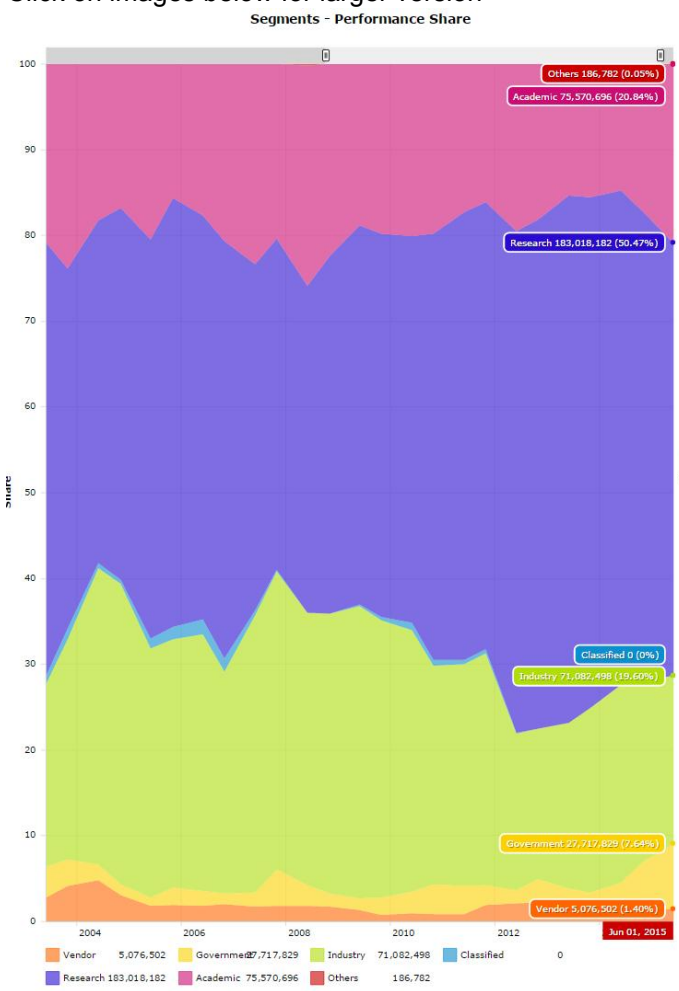
Global Applications:

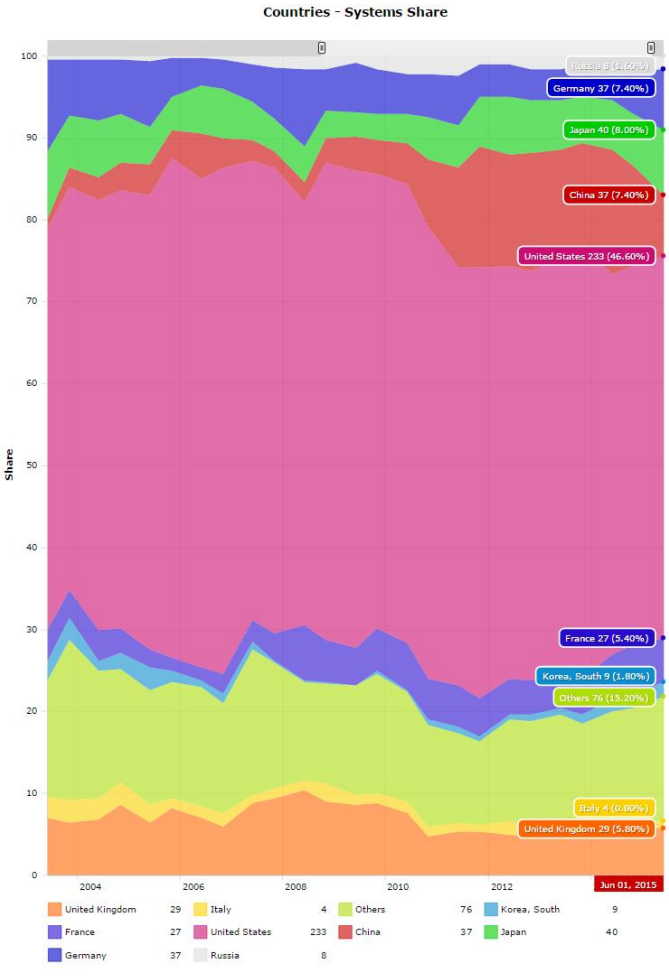
- Parallel computing is now being used extensively around the world, in a wide variety of applications.



Source: Top500.org

Click on images below for larger version





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