Parallel & Distributed Computing: Lecture 2

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Overview

What is Parallel Computing? 1/4

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

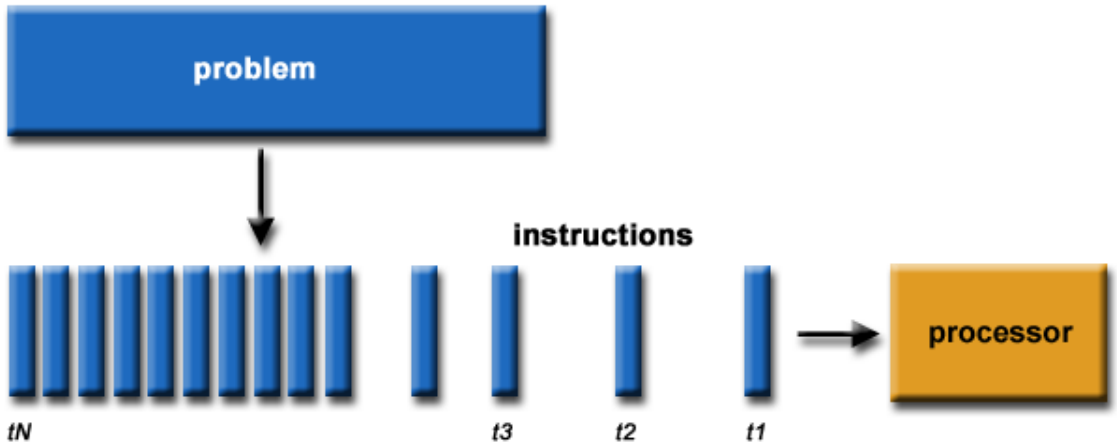


Figure 1: Serial computing

What is Parallel Computing? 2/4

For example:

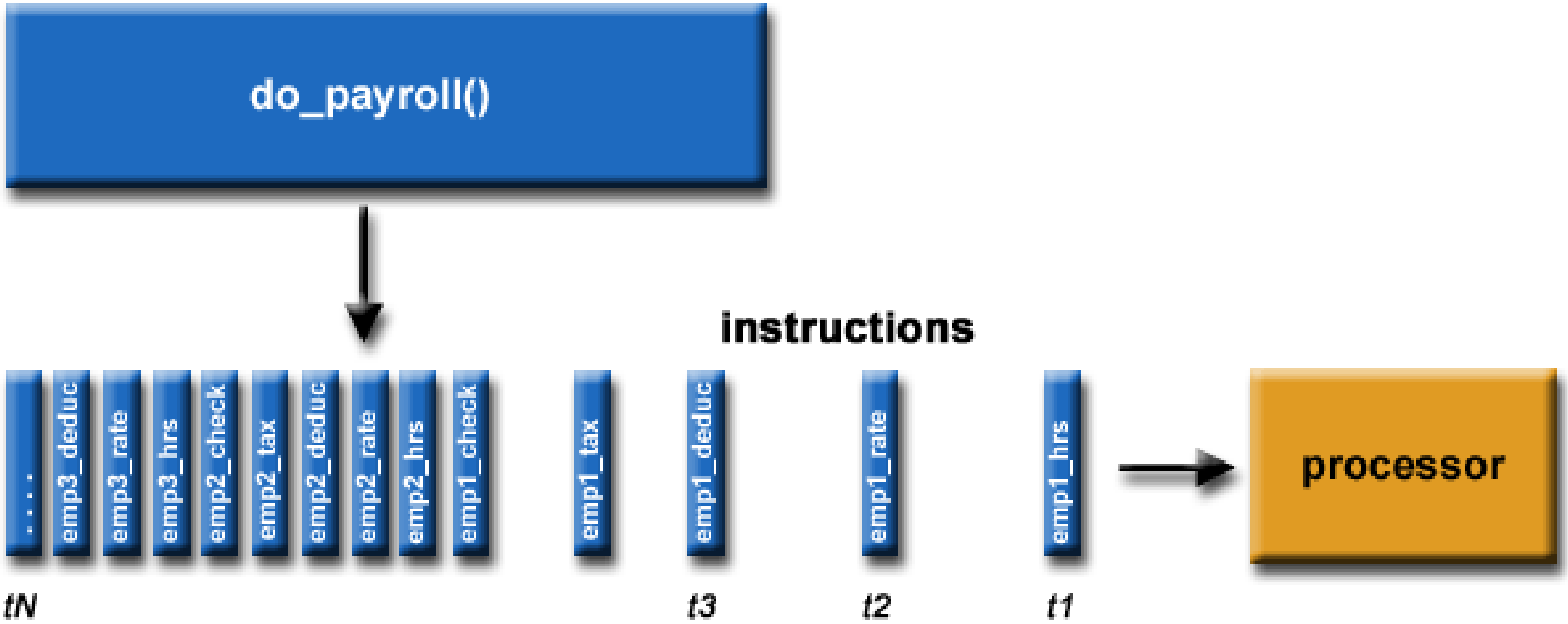


Figure 2: Serial computing

What is Parallel Computing? 3/4

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

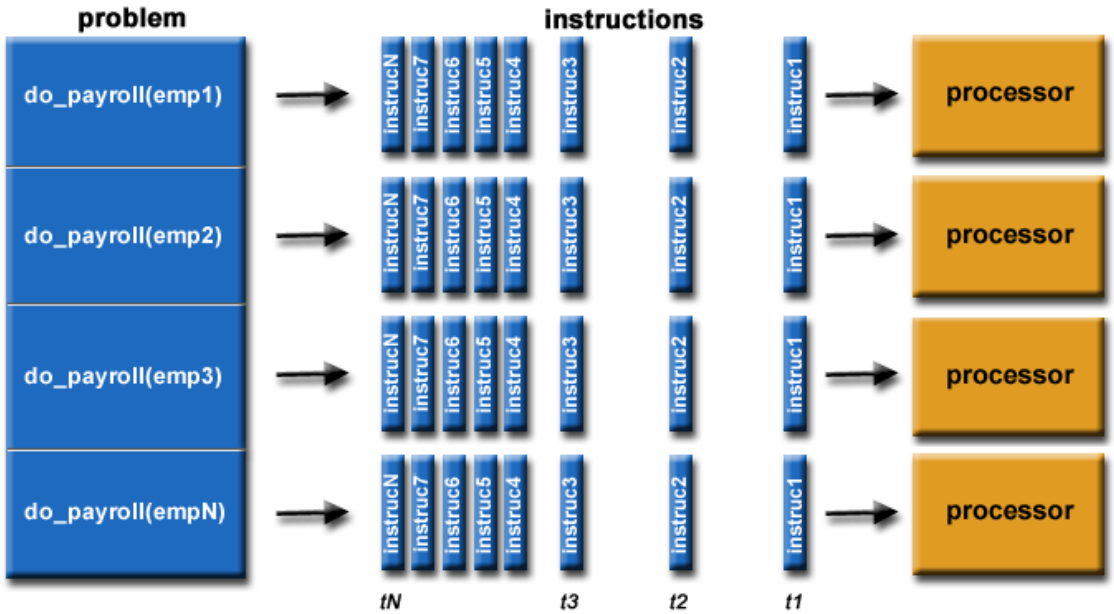
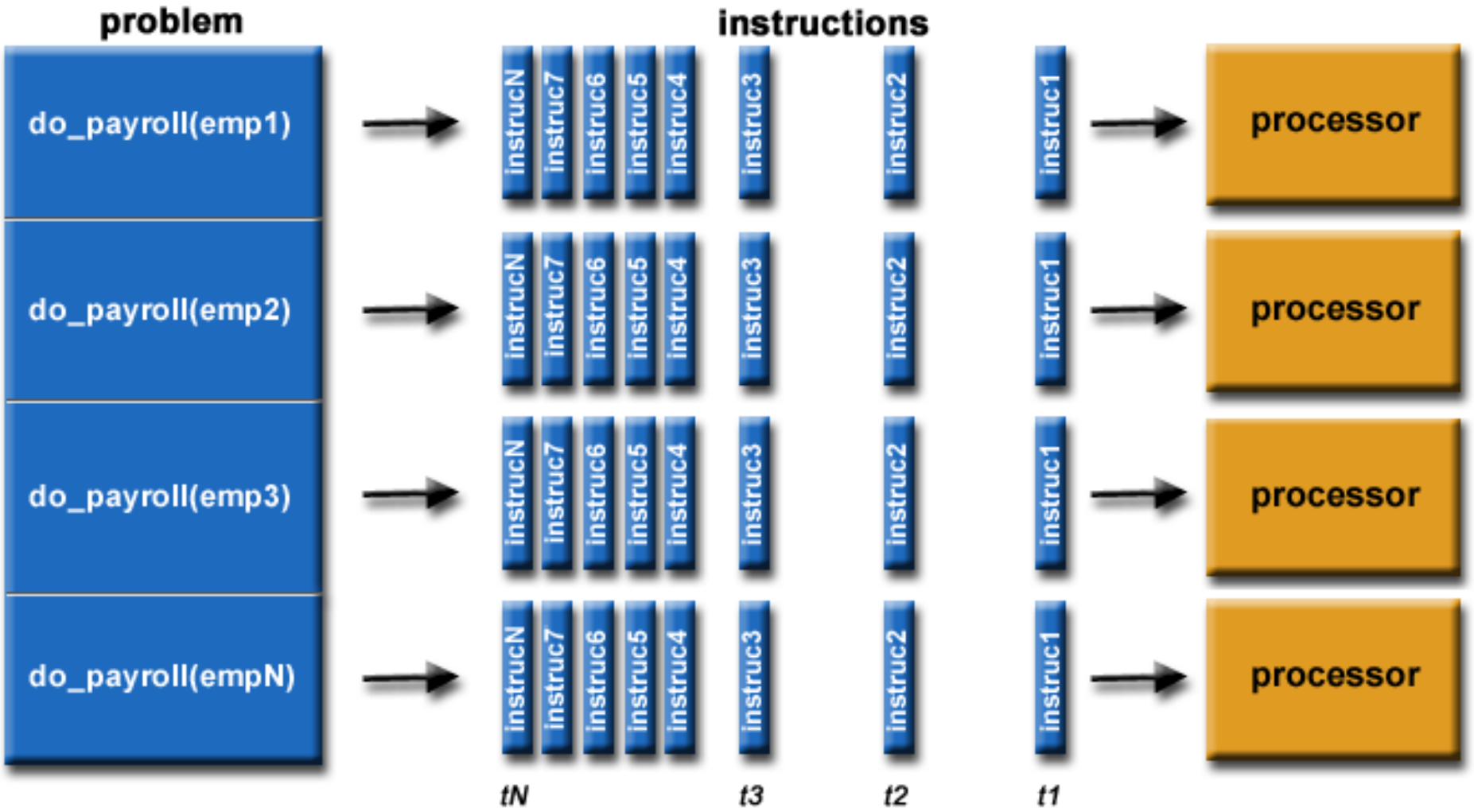


Figure 3: Parallel computing

What is Parallel Computing? 4/4

For example:



What is Parallel Computing? 4/4

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.

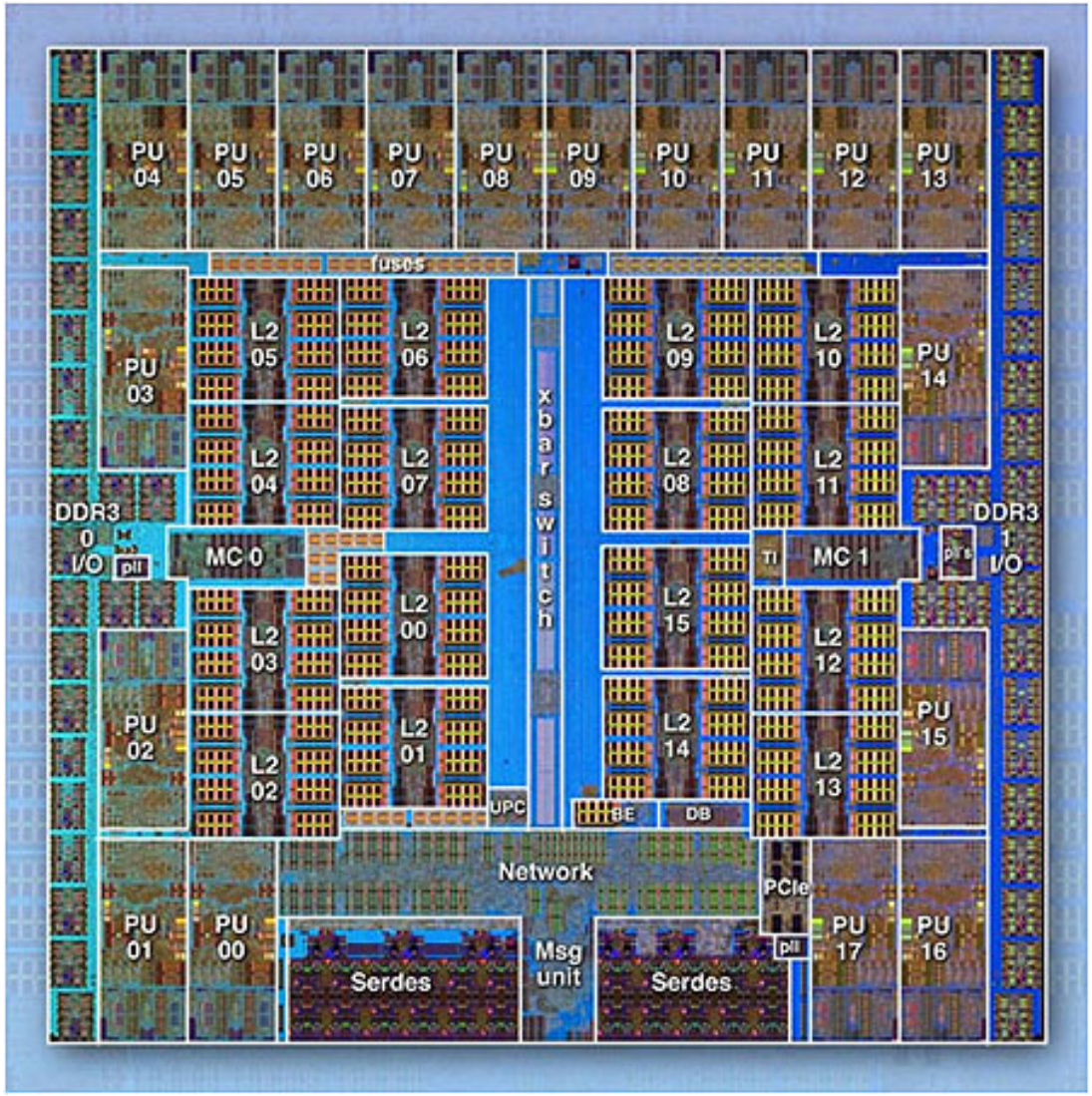
The compute resources are typically:

- A single computer with multiple processors/cores
- An arbitrary number of such computers connected by a network

Parallel Computers:

1. 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

Parallel Computers:



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

Parallel Computers:

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

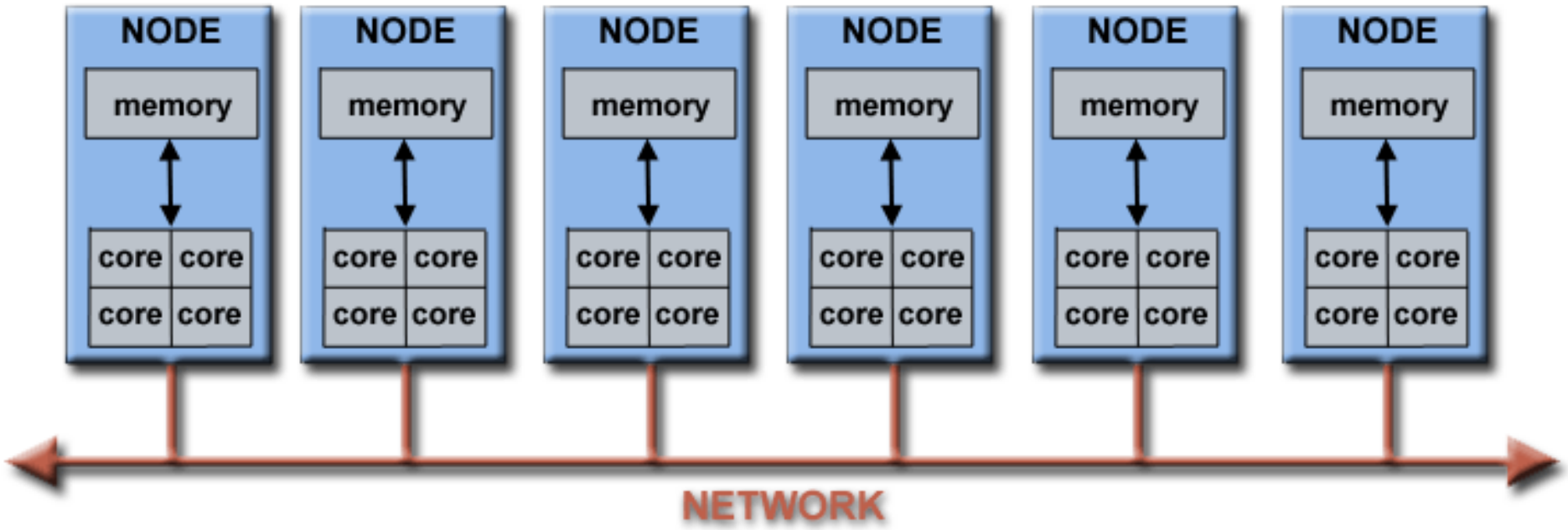
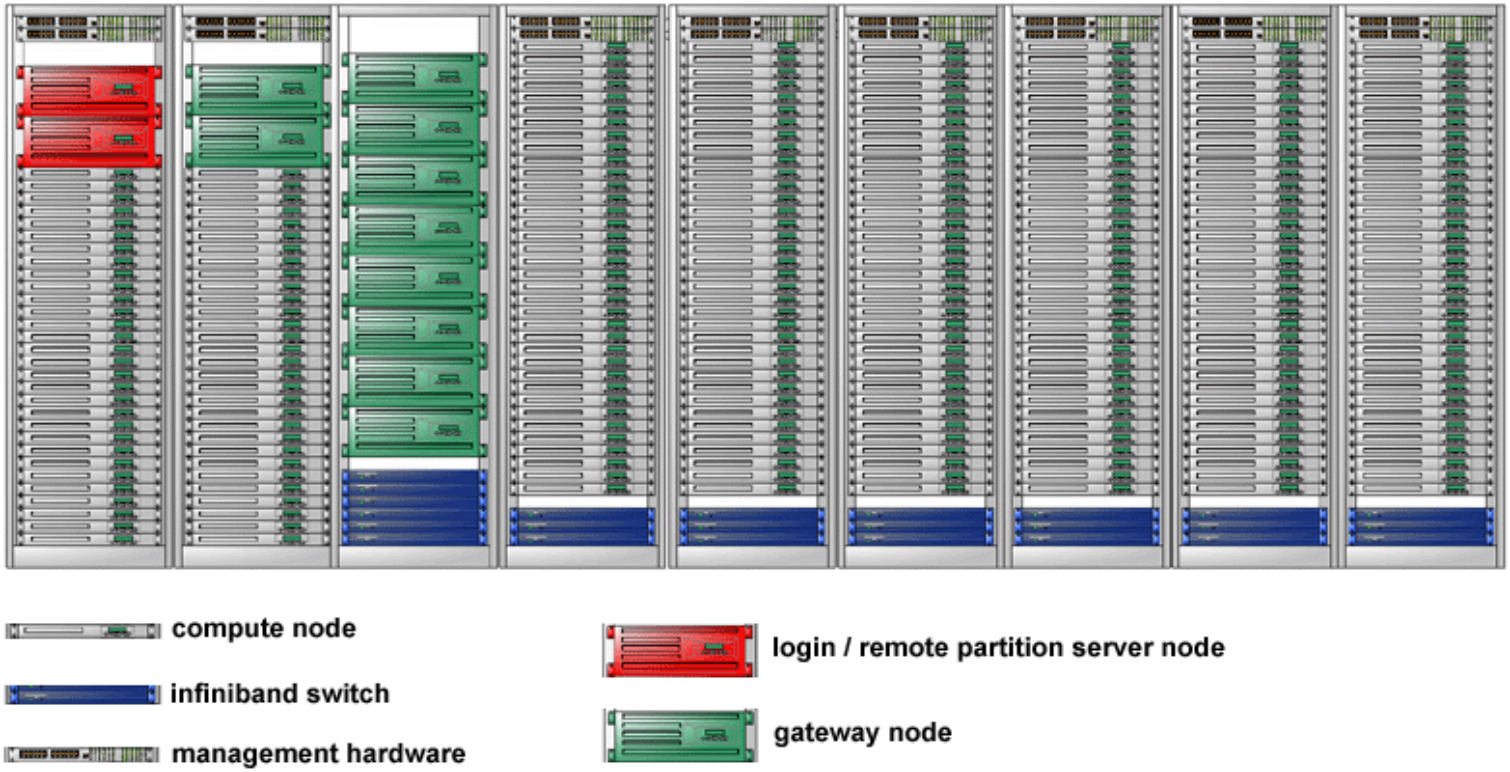


Figure 6: Computing nodes

Parallel Computers:

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

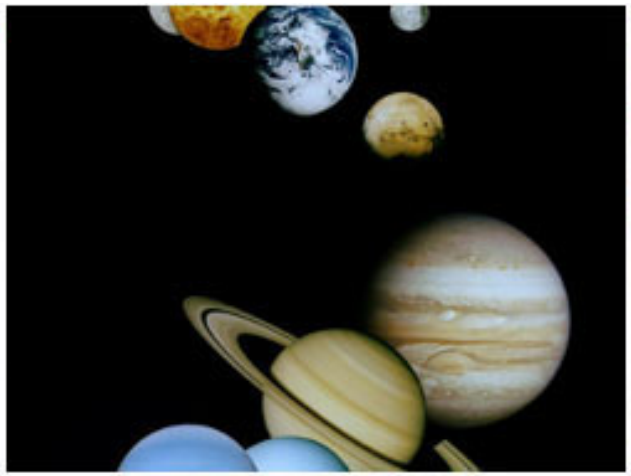


Why Use Parallel Computing?

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

Why Use Parallel Computing?

Rush Hour Traffic

Plate Tectonics

Weather

Auto Assembly

Jet Construction

Drive-thru Lunch

Why Use Parallel Computing?

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.

Why Use Parallel Computing?

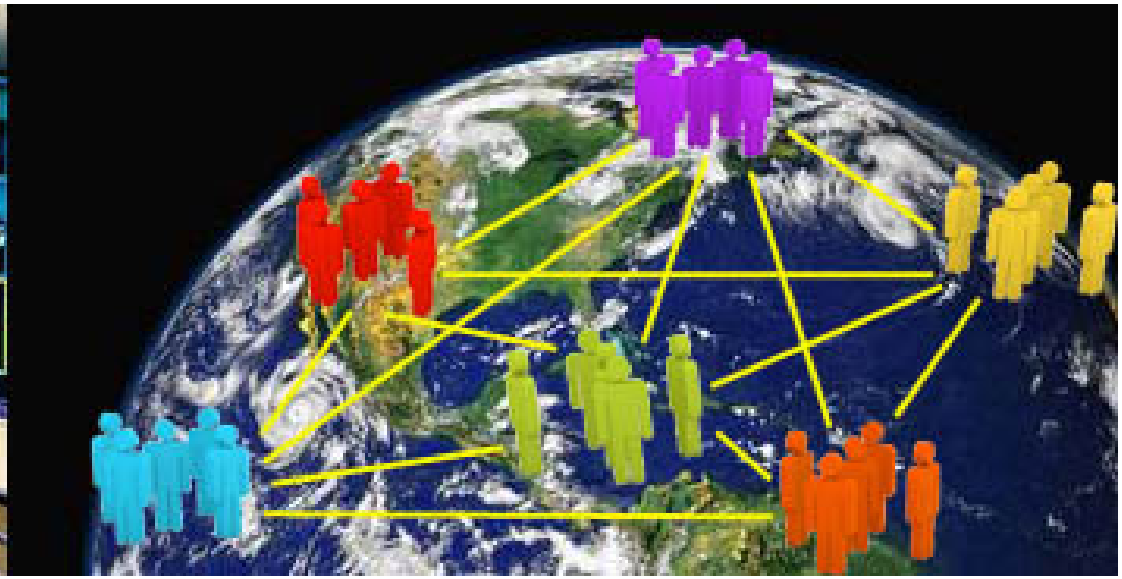
SOLVE LARGER / MORE COMPLEX PROBLEMS:

- 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

Why Use Parallel Computing?

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".



Why Use Parallel Computing?

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).

Why Use Parallel Computing?

TAKE ADVANTAGE OF NON-LOCAL RESOURCES:

- Example: Folding@home (folding.stanford.edu) uses over 160,000 computers globally (June, 2015)

Why Use Parallel Computing?

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.

Why Use Parallel Computing?

MAKE BETTER USE OF UNDERLYING PARALLEL HARDWARE:

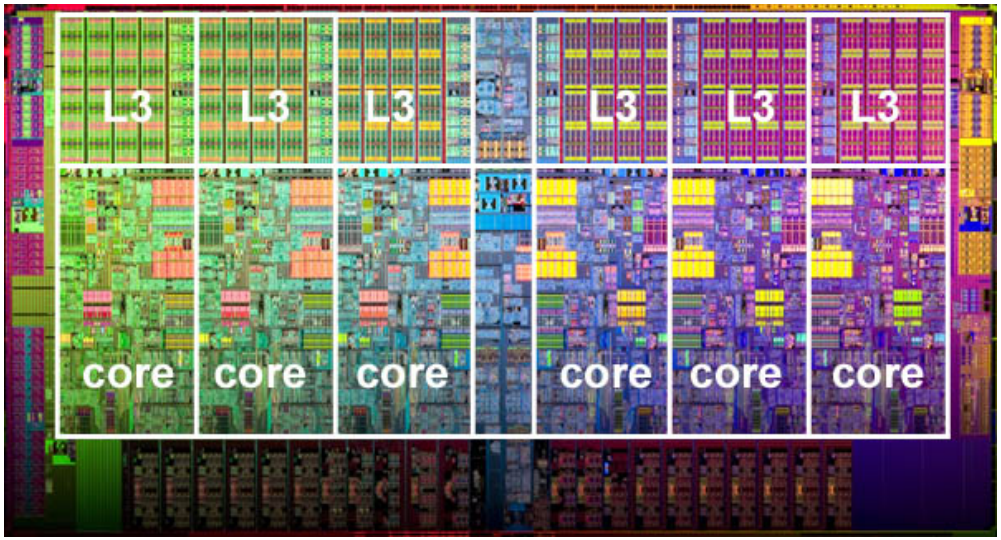


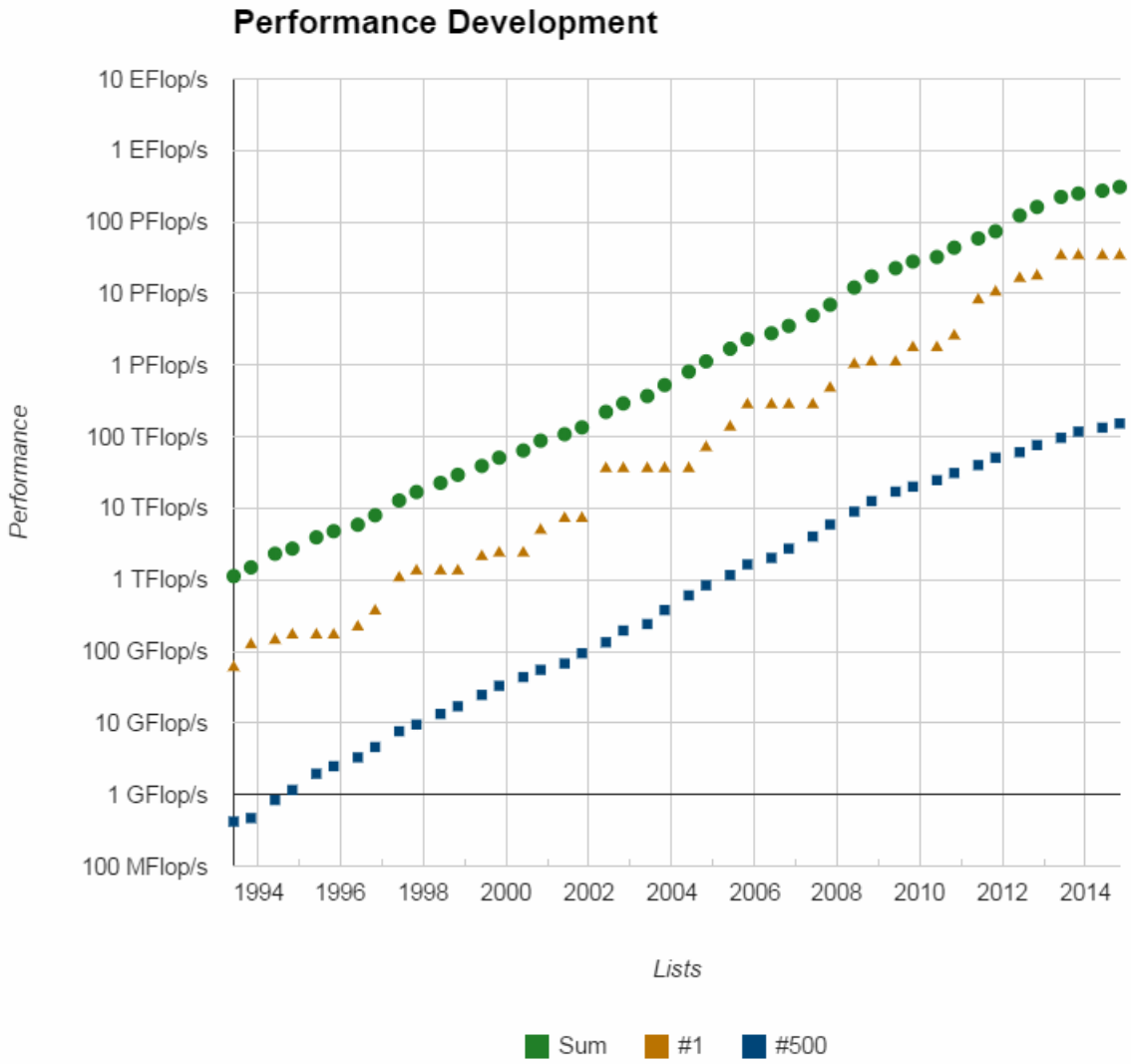
Figure 8: Intel Xeon processor with 6 cores and 6 L3 cache units

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

The Future

Source: [Top500.org](http://top500.org)



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,
- Mechanical Engineering
- Environment
- prosthetics to spacecraft
- Physics - applied, nuclear,
- Electrical Engineering,
- particle, condensed matter,
- high pressure, fusion,
- Circuit Design,
- Microelectronics
- photonics
- Defense, Weapons
- Computer Science, Mathematics
- Bioscience, Biotechnology,
- Genetics
- Chemistry, Molecular Sciences
- Geology, Seismology

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SCIENCE AND ENGINEERING

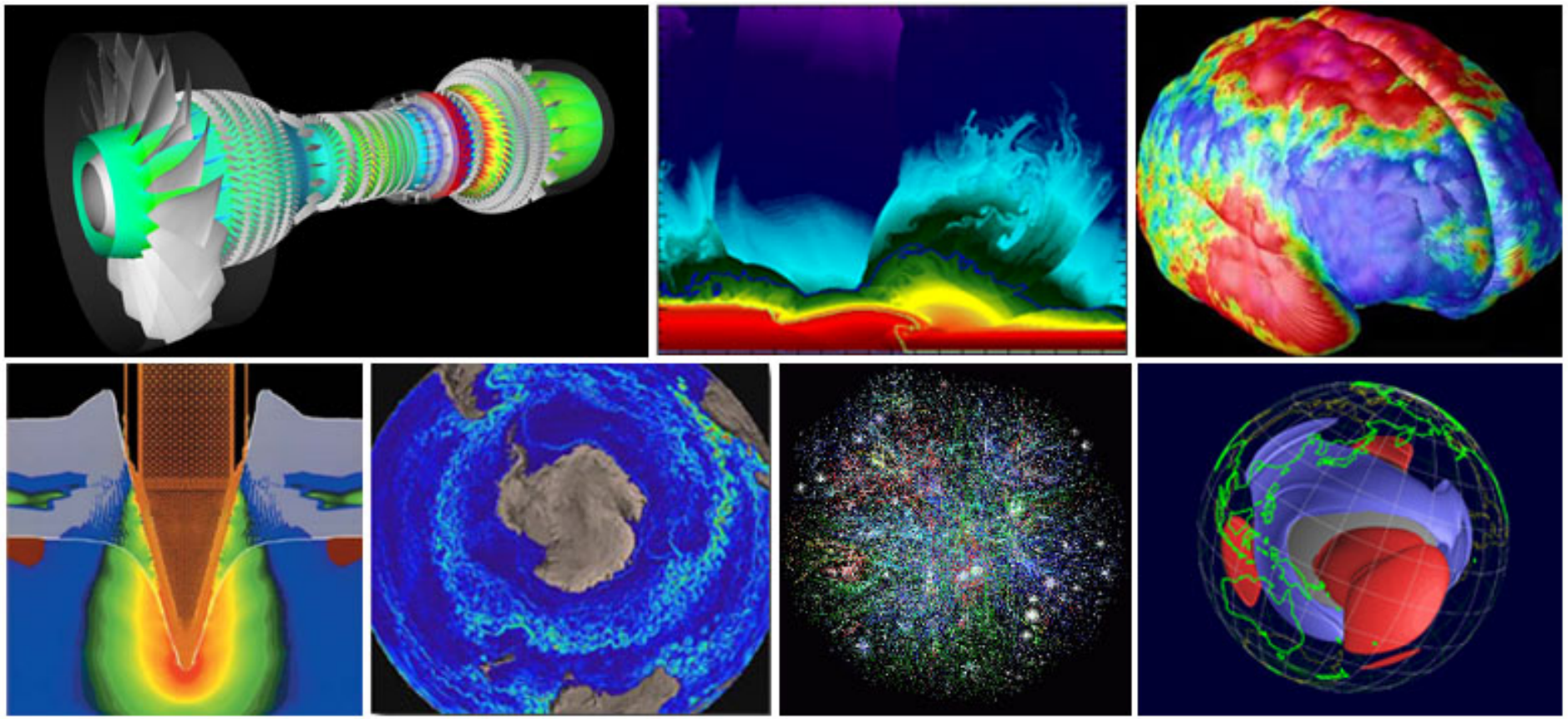

Figure 10: Science and engineering

Who is Using Parallel Computing?

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
- Financial and economic modeling
- Oil exploration
- Management of national and multi-national corporations
- Web search engines, web based business services
- Advanced graphics and virtual reality, particularly in the entertainment industry
- Pharmaceutical design
- Medical imaging and diagnosis
- Networked video and multi-media technologies
- Collaborative work environments

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INDUSTRIAL AND COMMERCIAL

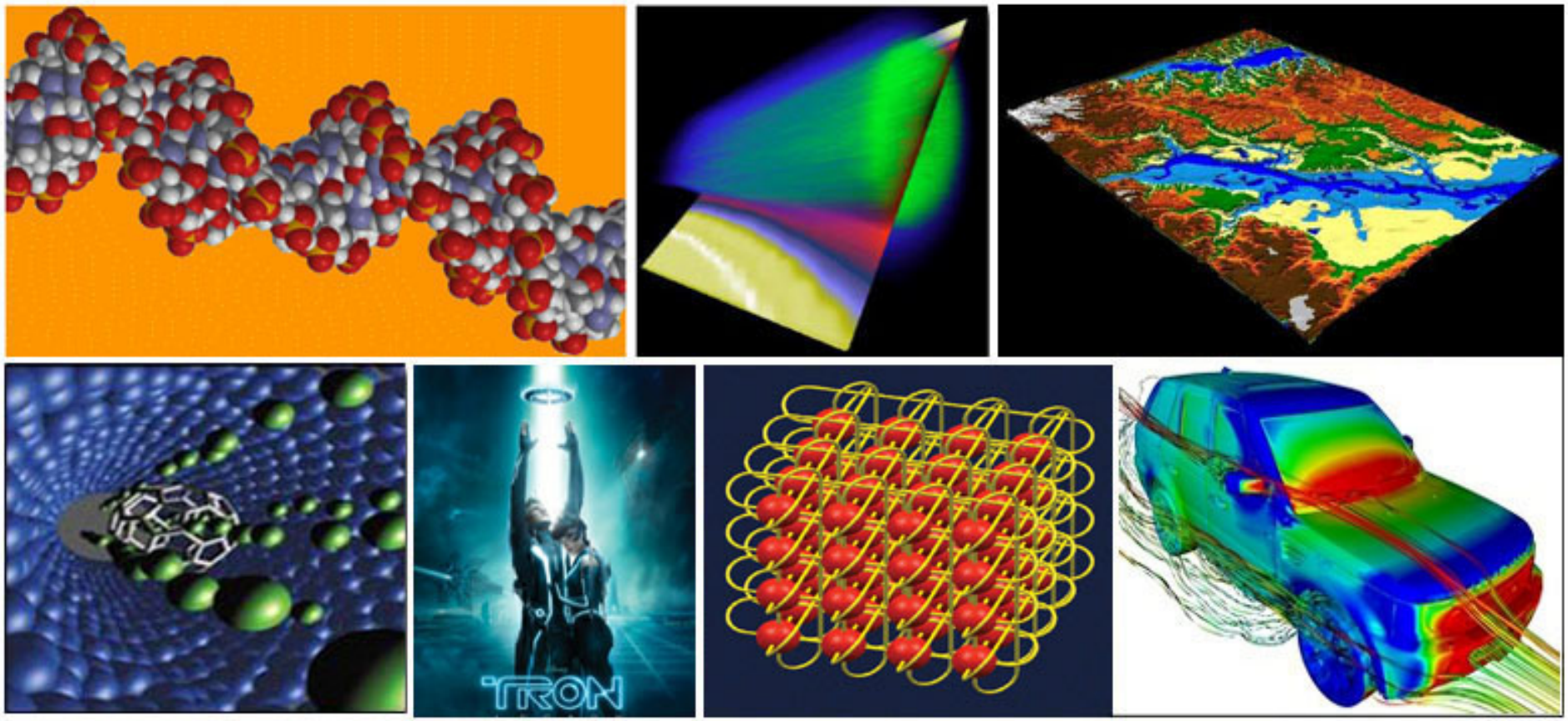
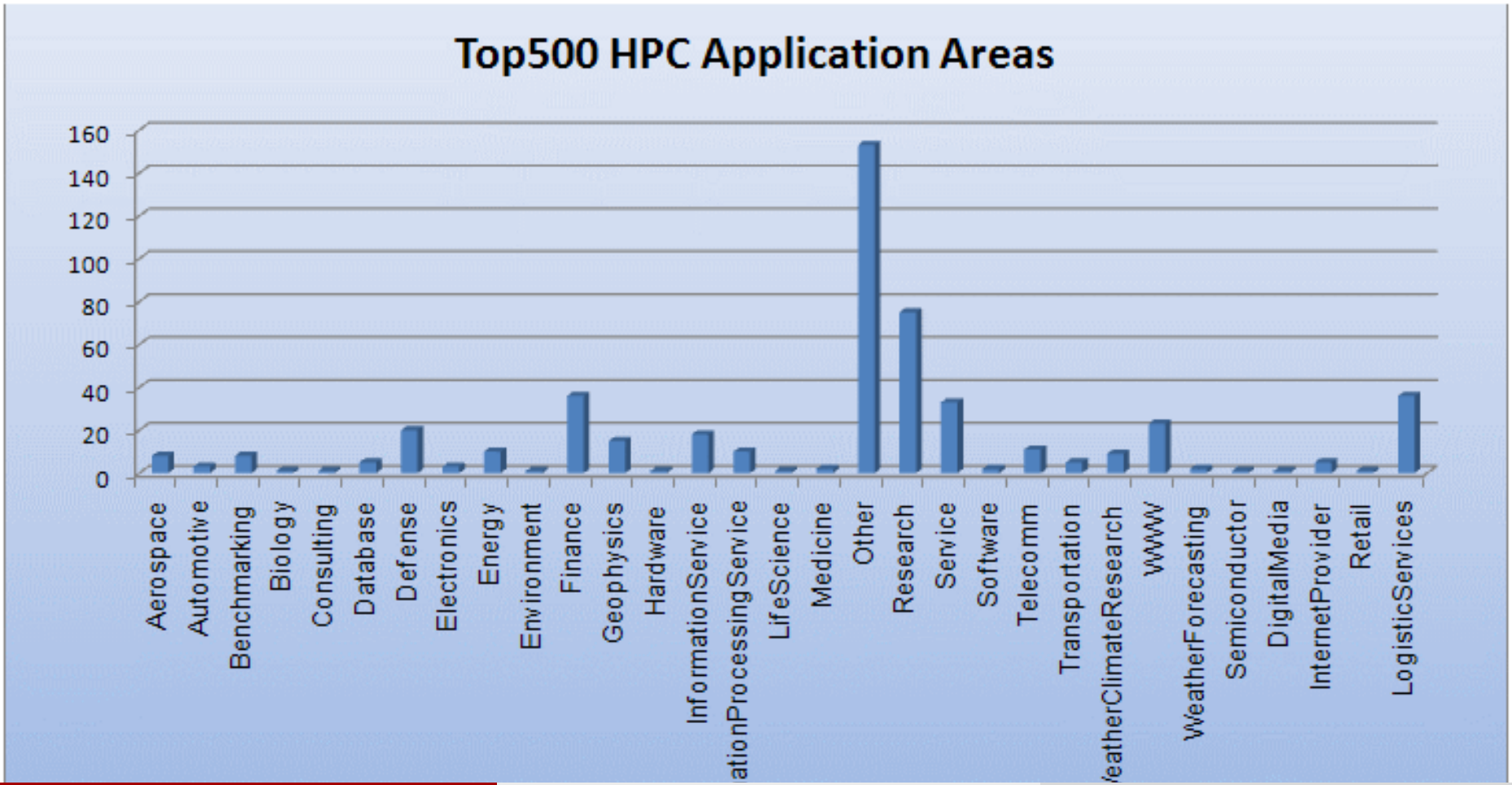


Figure 11: Industrial and commercial

Who is Using Parallel Computing?

GLOBAL APPLICATIONS

Parallel computing is now being used extensively around the world, in a wide variety of applications. Source: Top500.org



References