departamento de informática
FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

The Panorama of Parallel and High Performance Computing

Concurrency and Parallelism — 2017-18

Master in Computer Science

(Mestrado Integrado em Eng. Informática)

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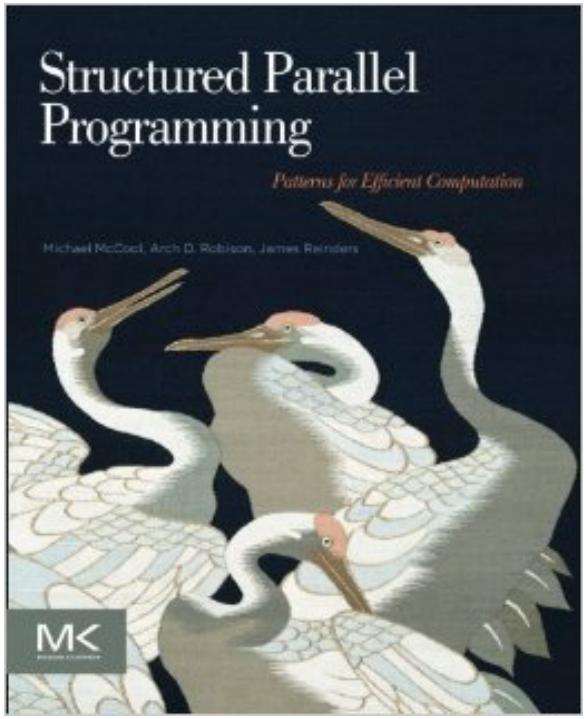
Slides based in: https://computing.llnl.gov/tutorials/parallel_comp/

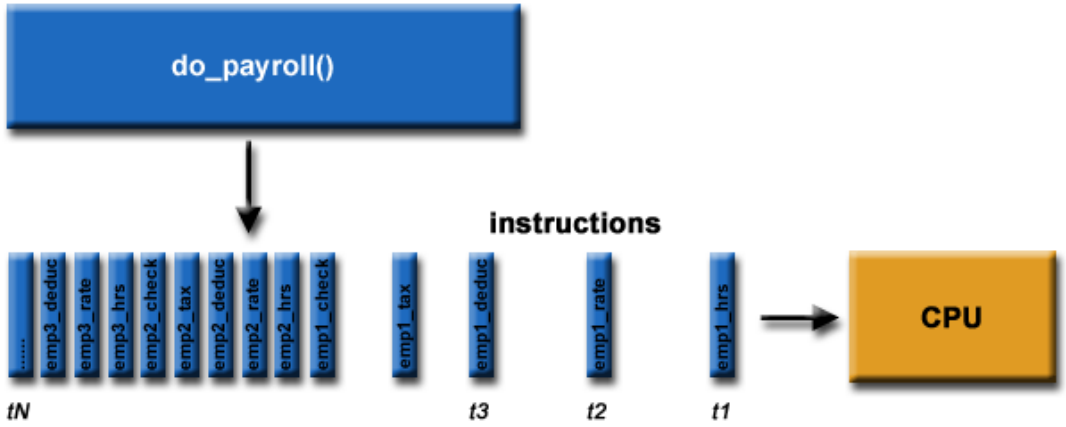
Bibliograpy

- **Chapter 1 of book**
  McCool M., Arch M., Reinders J.;
  Structured Parallel Programming: Patterns for Efficient Computation;
  Morgan Kaufmann (2012);
  ISBN: 978-0-12-415993-8



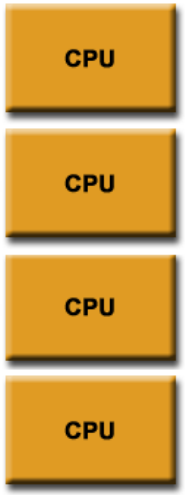
What is Parallel Computing?

- Traditionally, software has been written for serial computation:
  - To be run on a single computer having a single Central Processing Unit (CPU)
  - A problem is broken into a discrete series of instructions
  - Instructions are executed one after another (sequentially)
    - Only one instruction may execute at any moment in time



What is Parallel Computing?

- Is the simultaneous use of multiple compute resources to solve a computational problem:
  - To be executed using multiple processors



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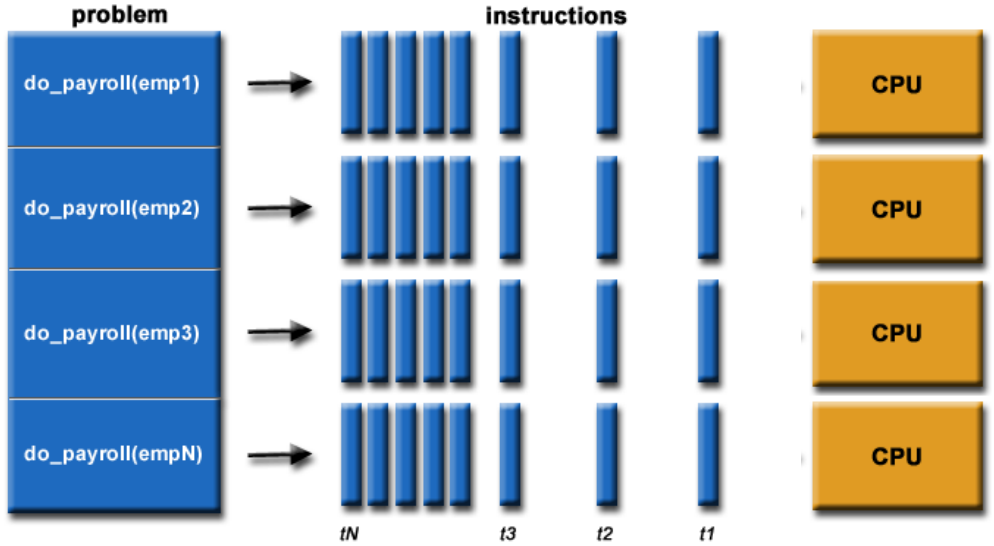

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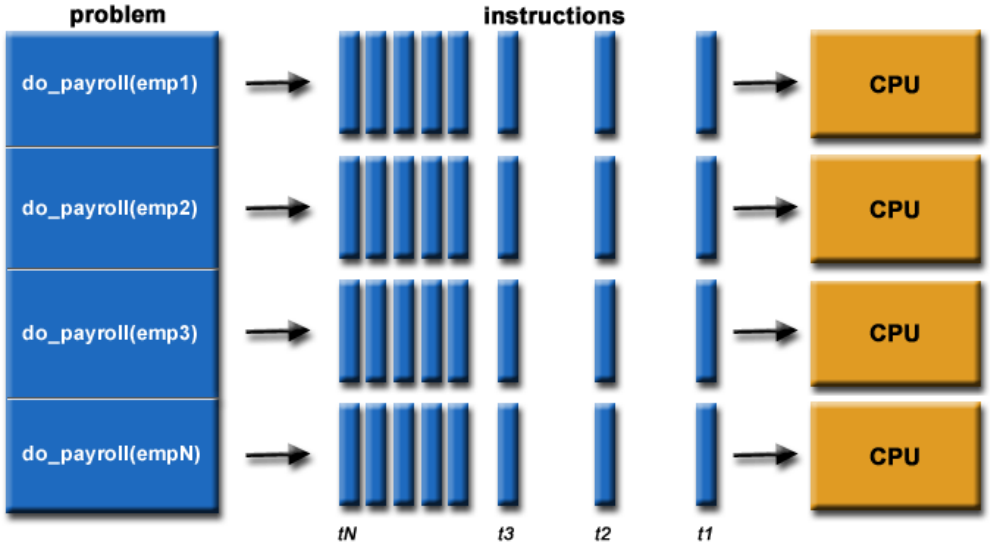

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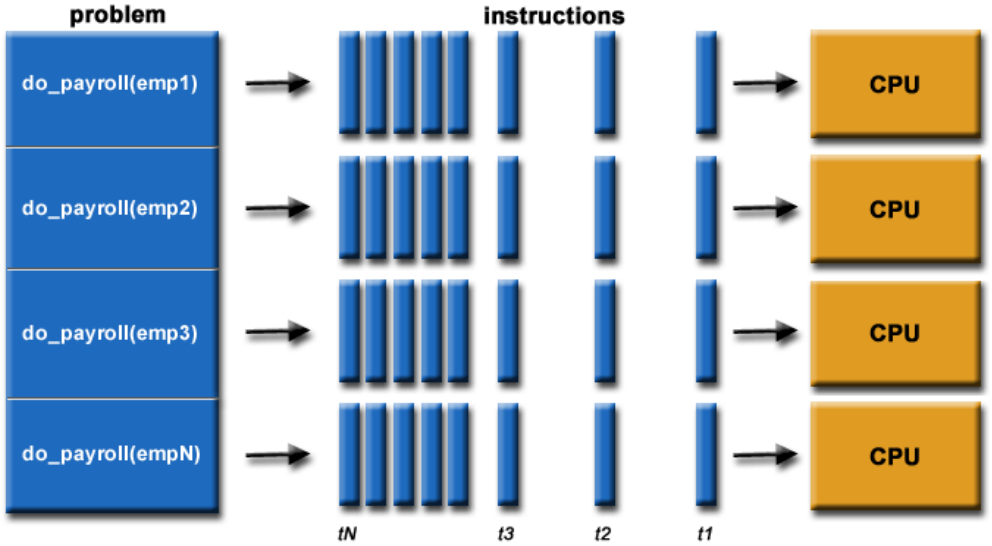
  - An overall control/coordination mechanism is employed



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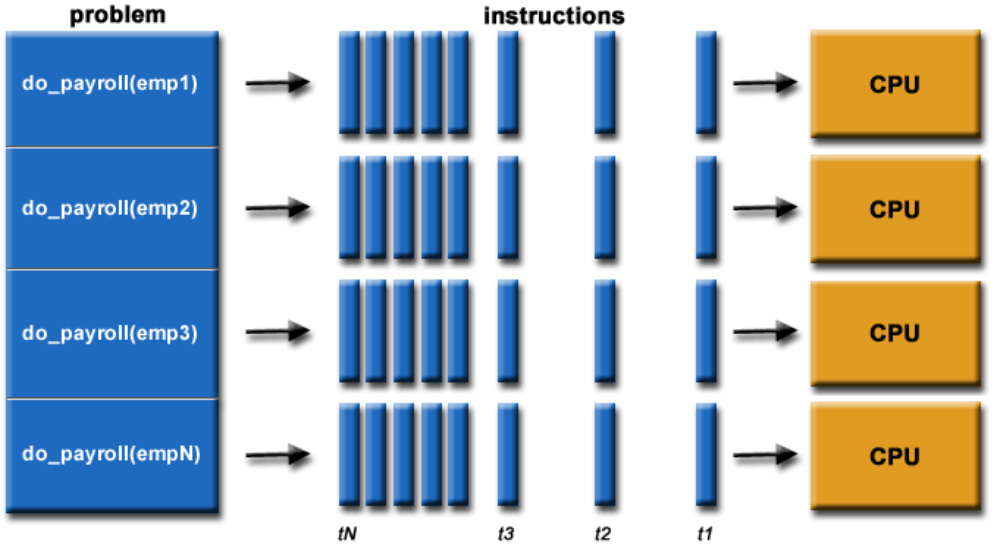
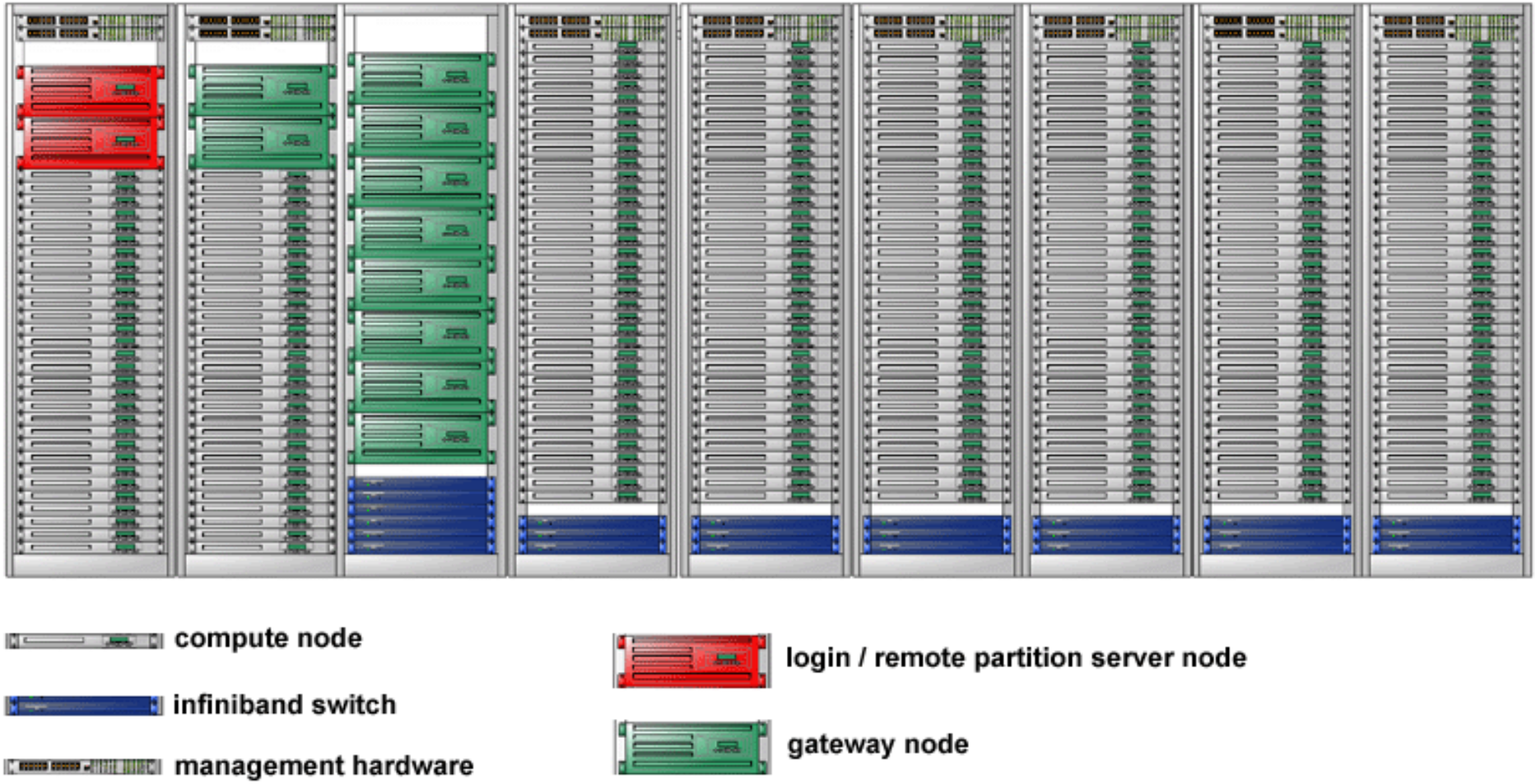


What is Parallel Computing?

- 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 computing resources might be:
  - A single computer with multiple processors
  - An arbitrary number of computers connected by a network (real or virtual systems)
  - A combination of both

What is Parallel Computing?

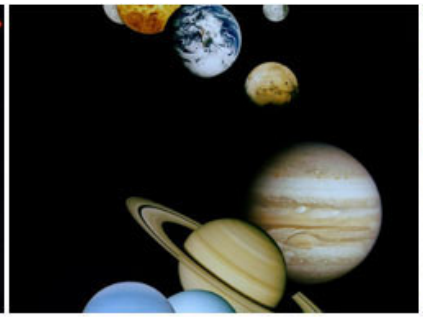


The Real World is Massively Parallel

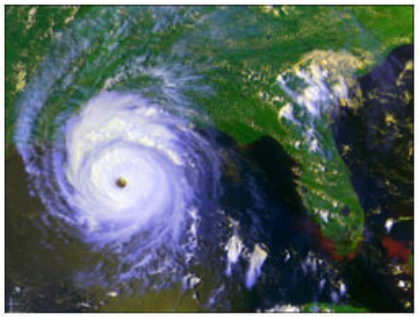
- In the natural world, many complex, interrelated events are happening at the same time, yet within a temporal sequence.
- Compared to serial computing, parallel computing is much better suited for modeling, simulating and understanding complex, real world phenomena.
- For example, imagine modeling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

The Real World is Massively Parallel

Galaxy Formation



Planetary Movments



Climate Change

Rush Hour Traffic

Plate Tectonics

Weather

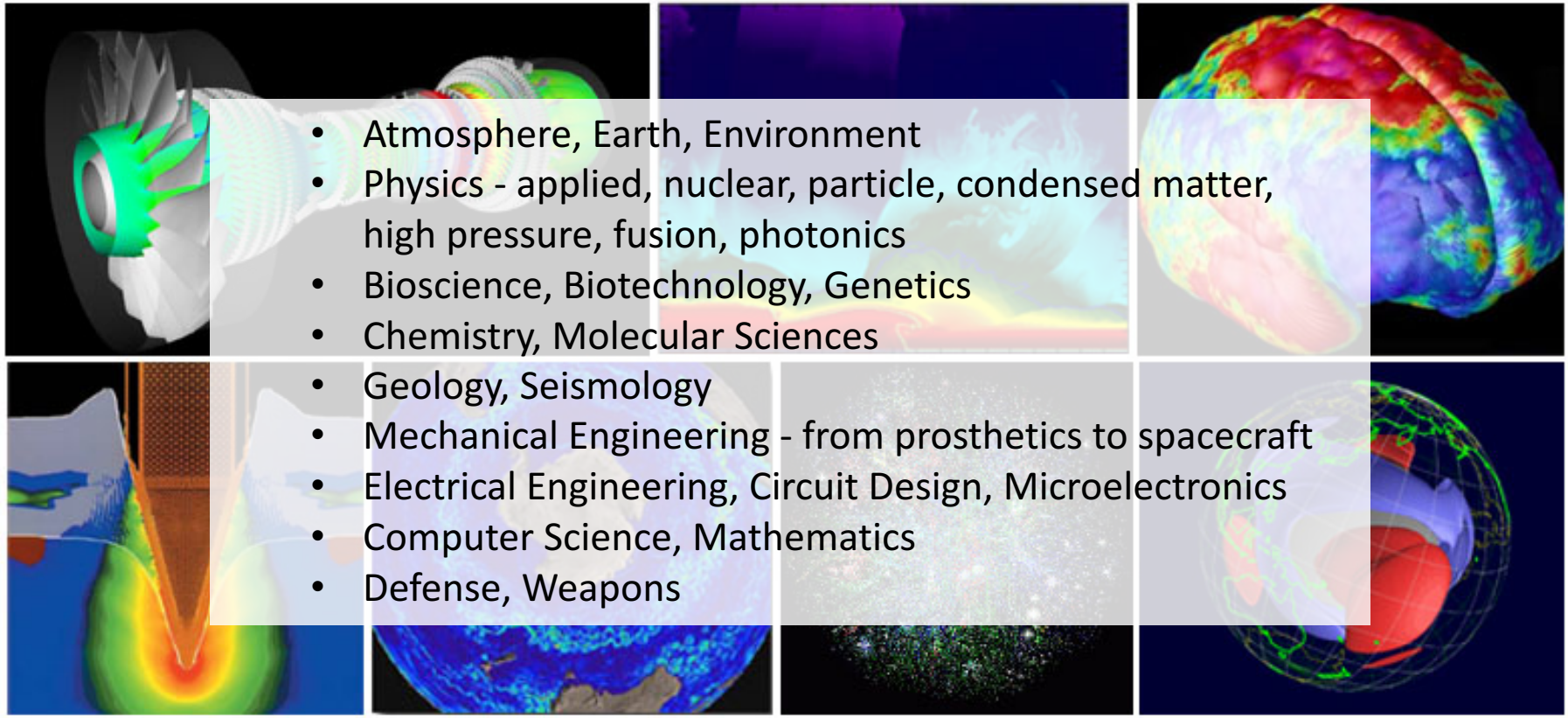
Auto Assembly

Jet Construction

Drive-thru Lunch

Uses for Parallel Computing

- Modeling 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

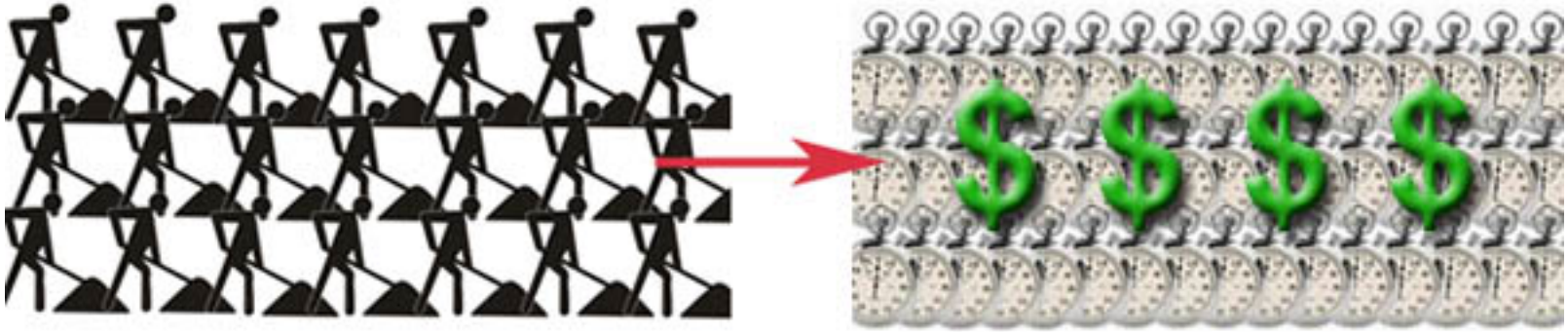
Uses for Parallel Computing

- Industrial and Commercial

- 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

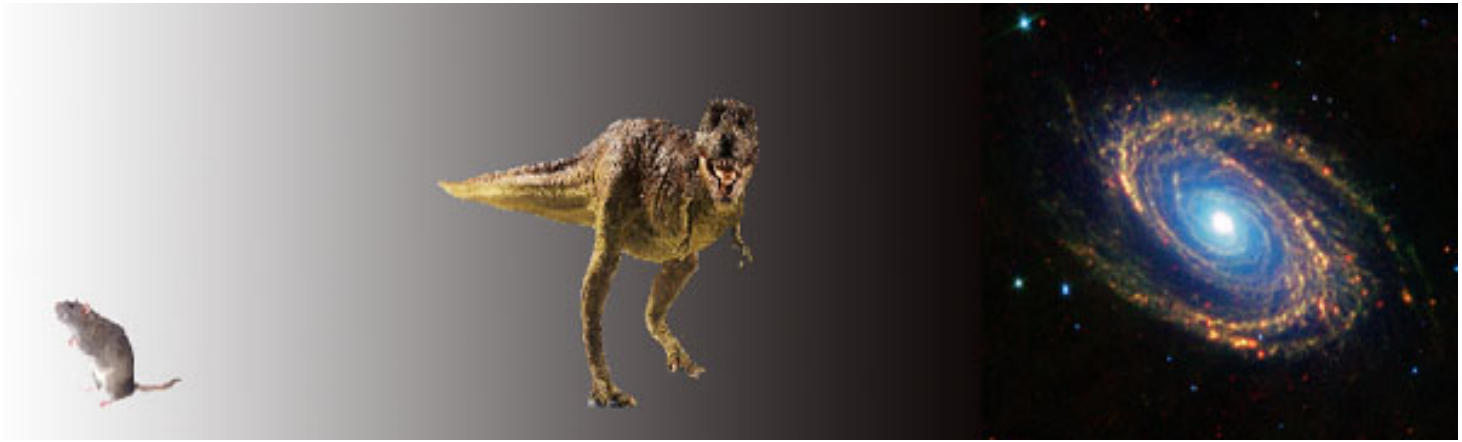
Why Use Parallel Computing?

- 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.



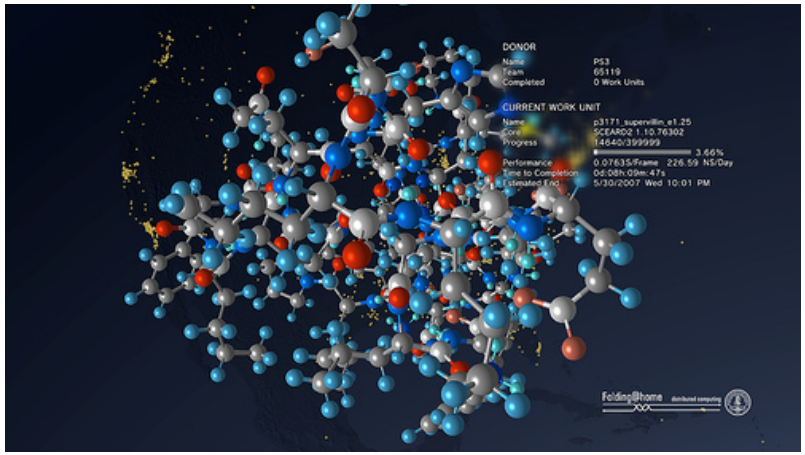
Why Use Parallel Computing?

- Solve larger problems
  - Many problems are so large and/or complex that it is impractical or impossible to solve them on a single computer. For example:
    - "Grand Challenge" (en.wikipedia.org/wiki/Grand_Challenge) problems requiring PetaFLOPS and PetaBytes of computing resources.
    - Web search engines/databases processing millions of transactions per second.



Why Use Parallel Computing?

- Use of non-local resources
  - Using compute resources on a wide area network, or even the Internet when local compute resources are scarce. For example:
    - SETI@home (setiathome.berkeley.edu) over 1.6 million users, 4 million computers, in nearly every country in the world. Source: https://setiathome.berkeley.edu/stats.php (Sep, 2016).
    - Folding@home (folding.stanford.edu) uses over 320,000 computers globally (Sep, 2016)



Limits to serial computing

- Both physical and practical reasons pose significant constraints to simply building ever faster serial computers:
  - Transmission speeds
    - the speed of a serial computer is directly dependent upon how fast data can move through hardware. Absolute limits are the speed of light (30 cm/nanosecond) and the transmission limit of copper wire (9 cm/nanosecond). Increasing speeds requires increasing proximity of processing elements.
  - Limits to miniaturization
    - processor technology is allowing an increasing number of transistors to be placed on a chip. However, even with molecular or atomic-level components, a limit will be reached on how small components can be.

Limits to serial computing

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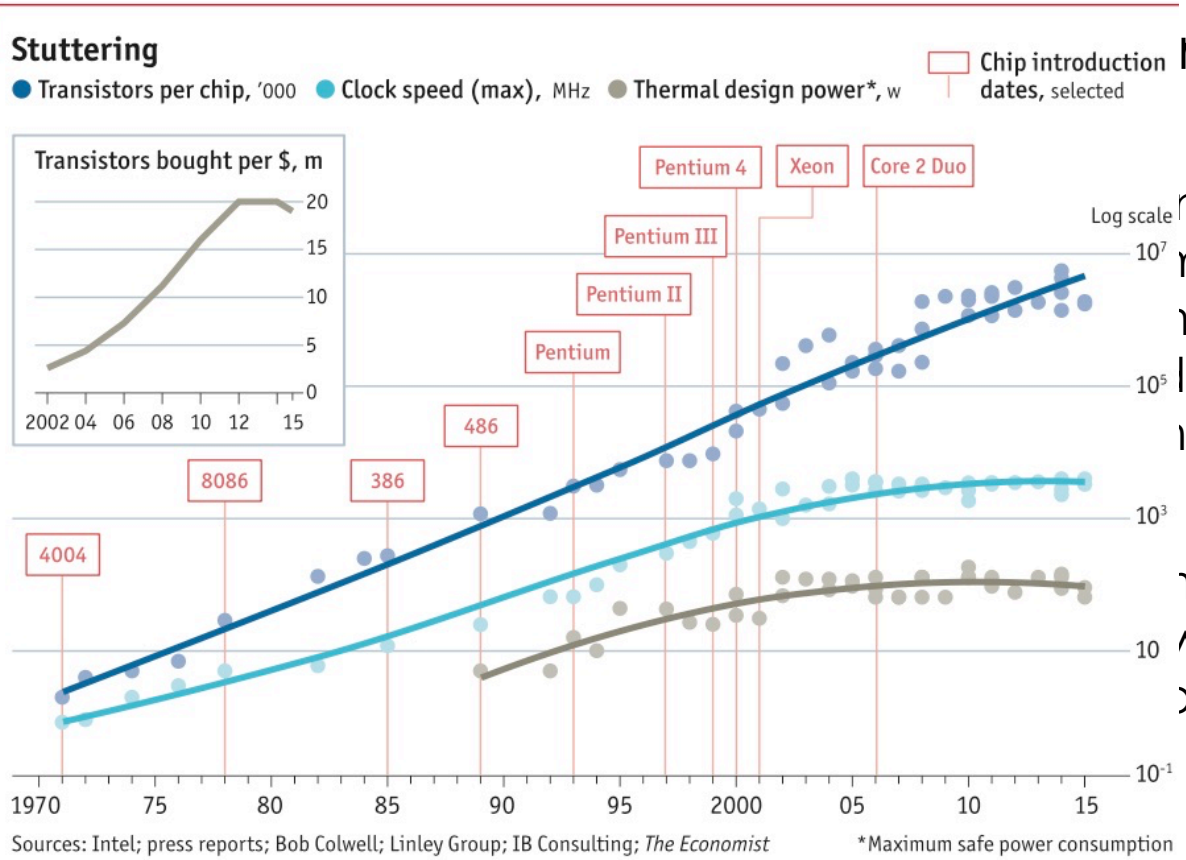
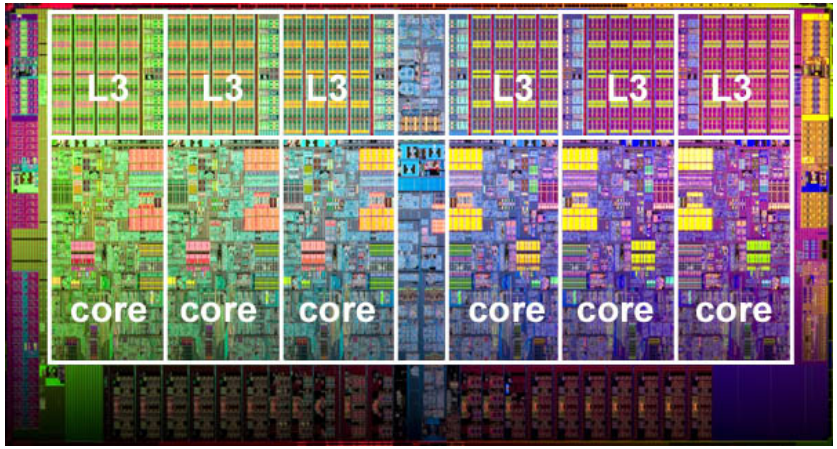


Limits to serial computing

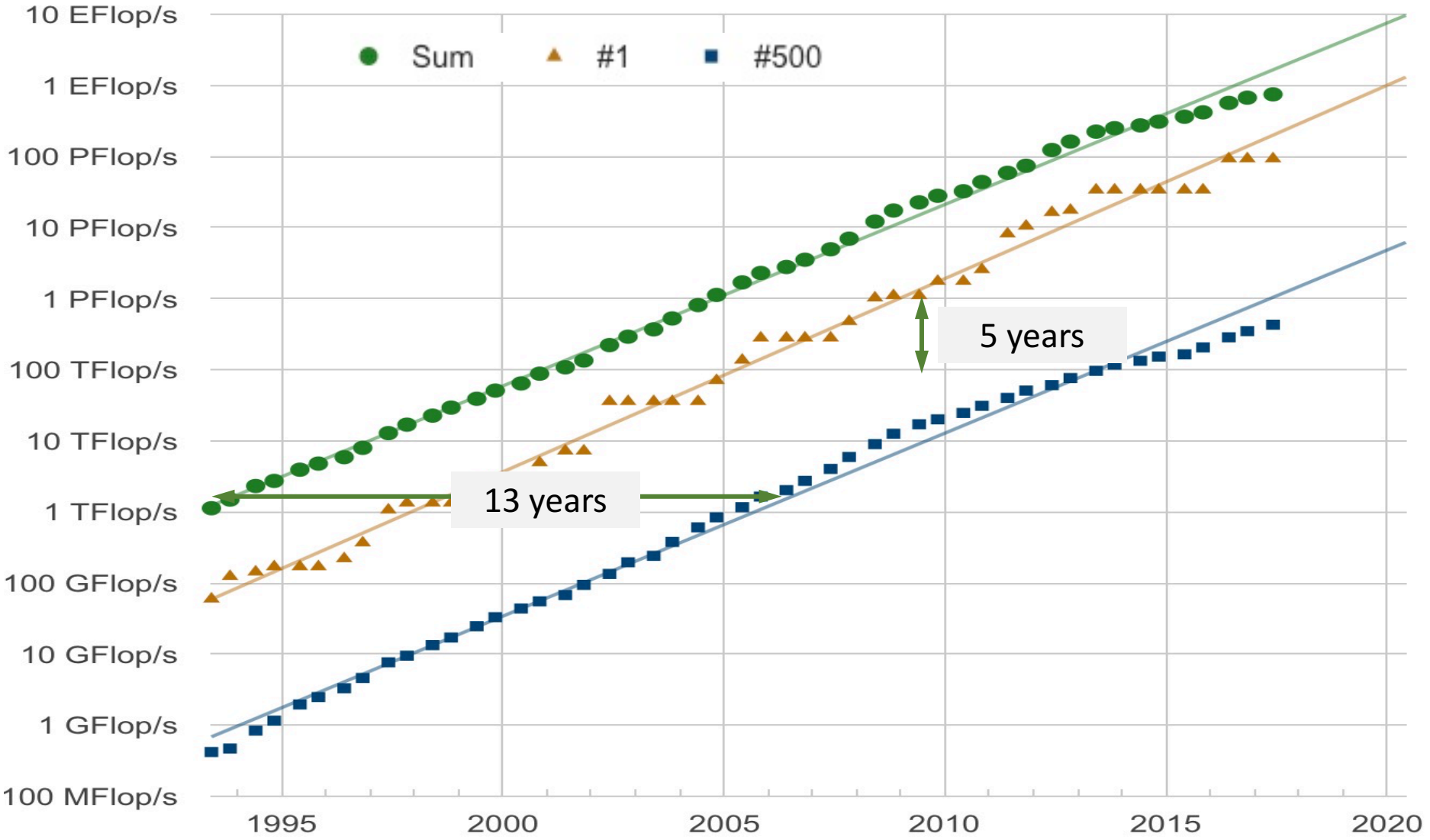
- Both physical and practical reasons pose significant constraints to simply building ever faster serial computers:
  - Economic limitations
    - it is increasingly expensive to make a single processor faster. Using a larger number of moderately fast commodity processors to achieve the same (or better) performance is less expensive.
  - Current computer architectures are increasingly relying upon hardware level parallelism to improve performance:
    - Multiple execution units
    - Pipelined instructions
    - Multi-core



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 1000x increase in supercomputer performance, with no end currently in sight.
- The race is already on for Exascale Computing! (10^{18} FLOPS)

Performance development



Top500.org

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
2	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P , NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.7	54,902.4	17,808
3	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	361,760	19,590.0	25,326.3	2,272
4	**Titan** - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209
5	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom , IBM DOE/NNSA/LLNL United States	1,572,864	17,173.2	20,132.7	7,890

Sunway TaihuLight System

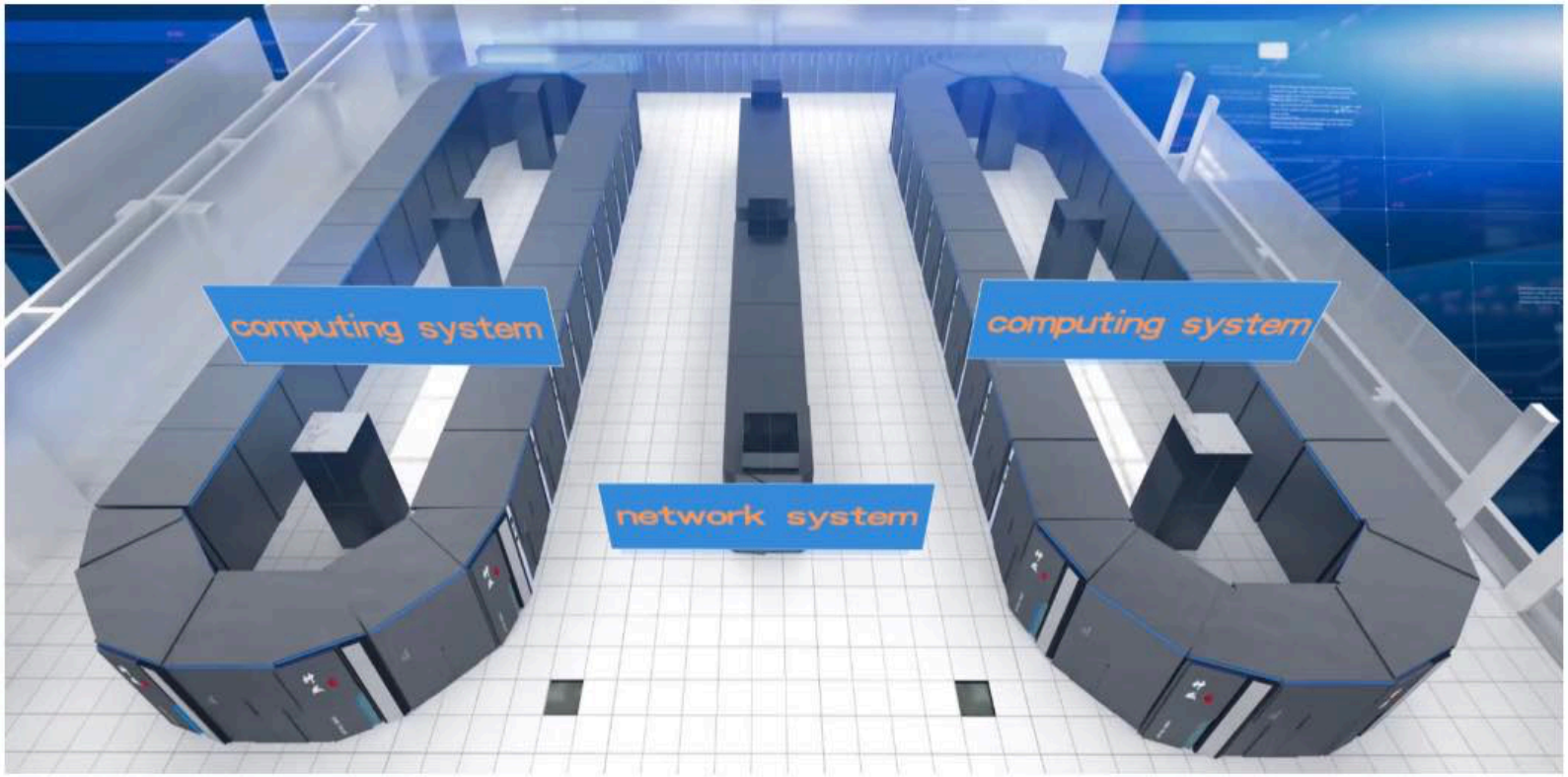
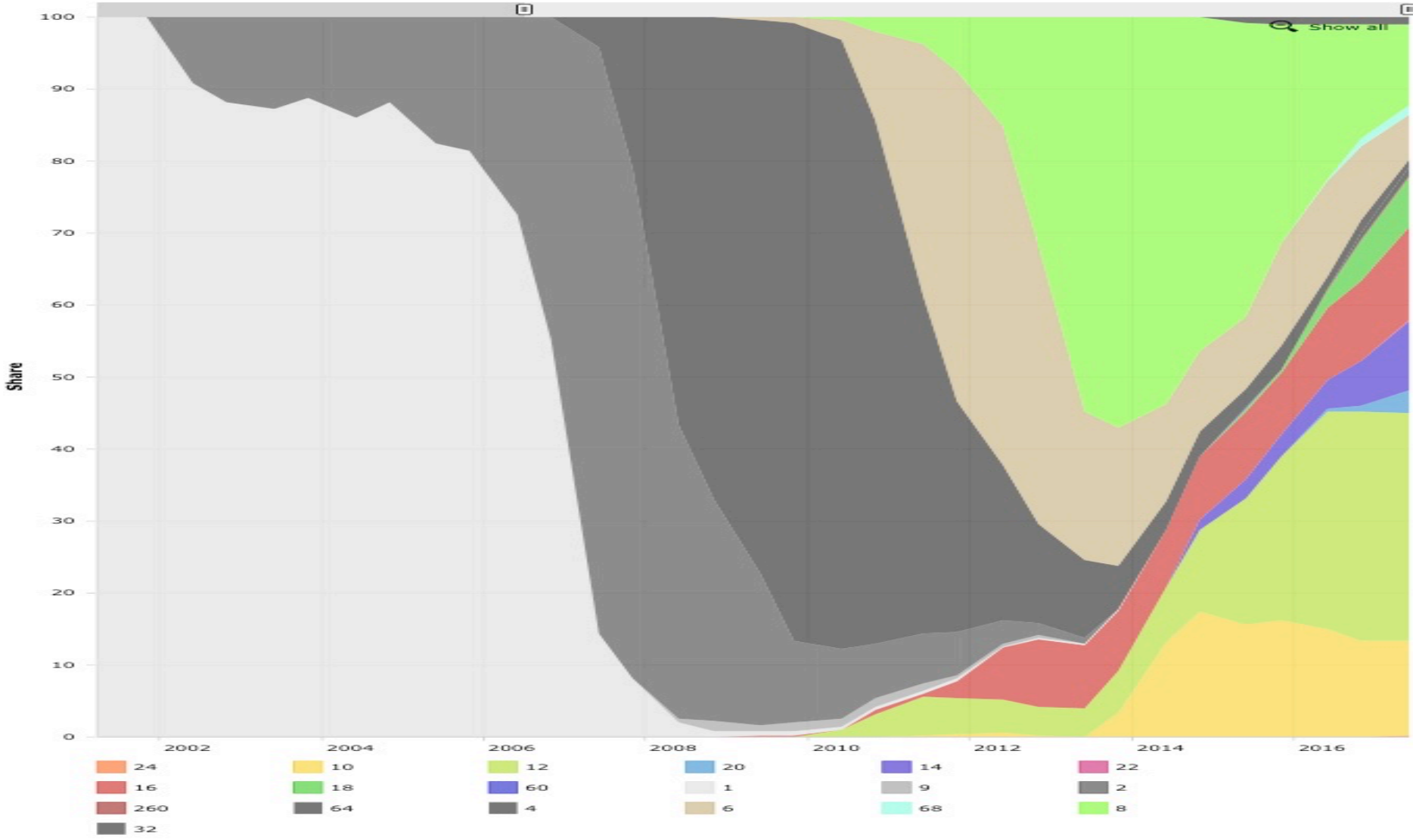
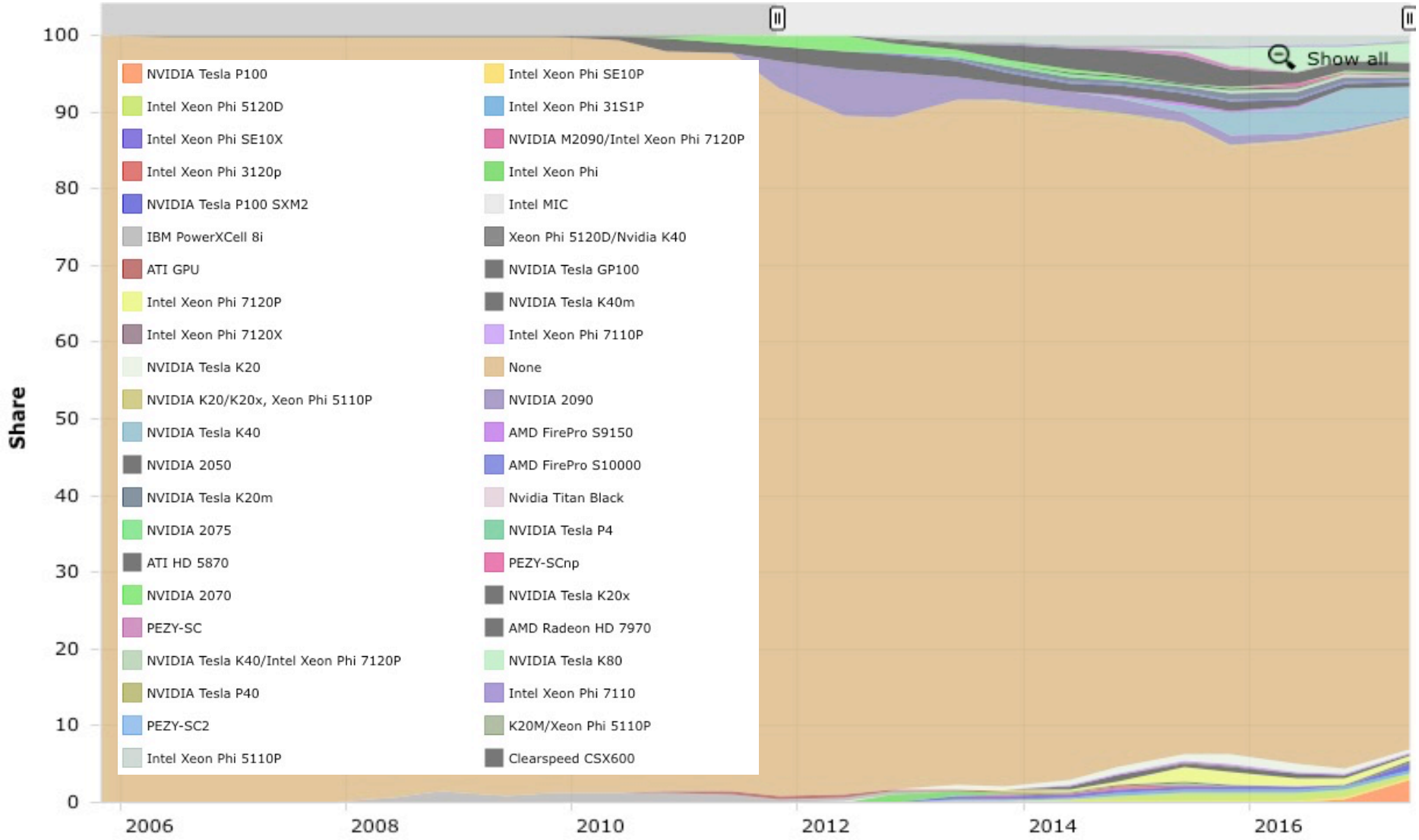


Figure 4: Overview of the Sunway TaihuLight System

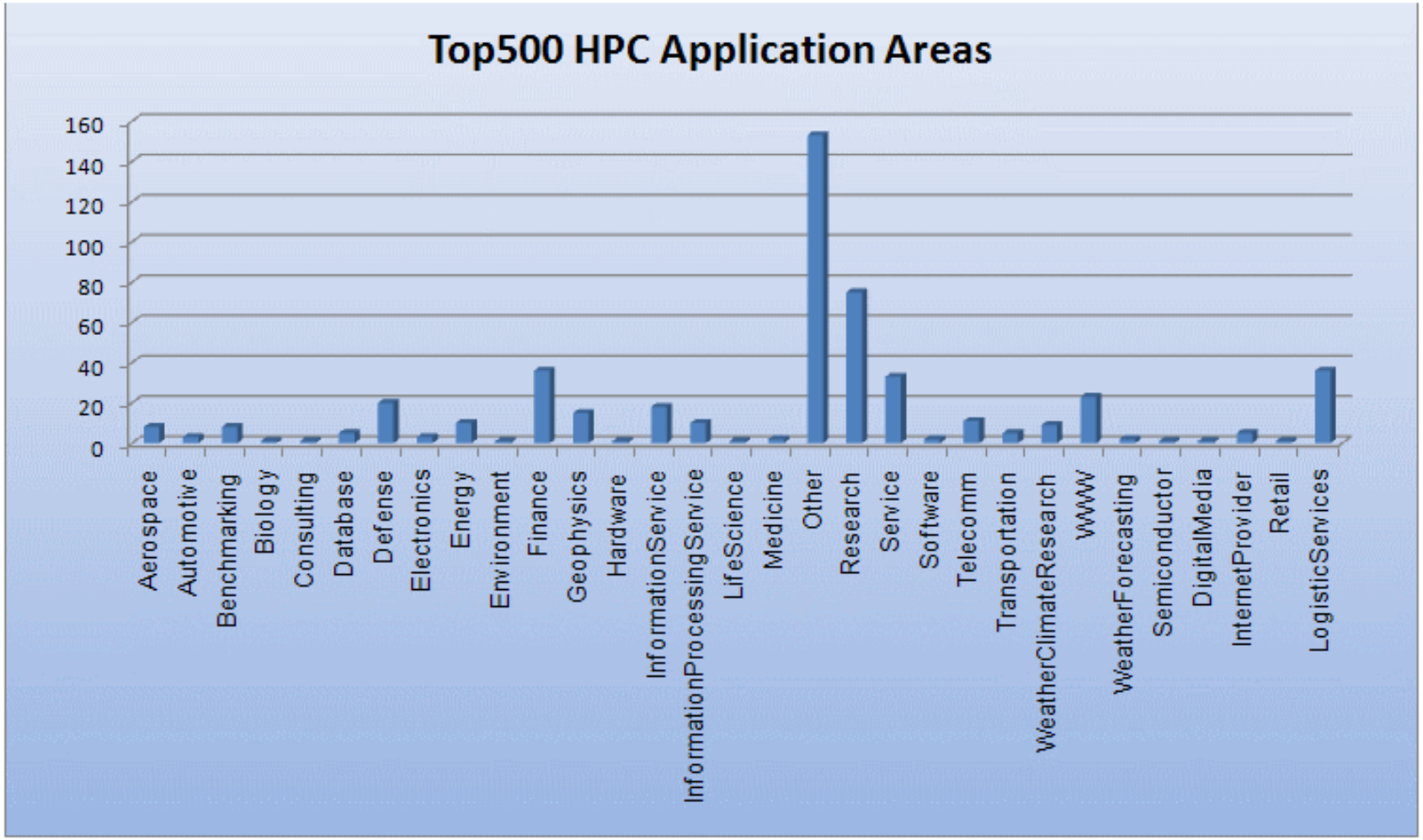
Cores per socket



Accelerators



The Future


Top500 HPC Application Areas
160
140
120
100
80
60
40
20
0
Aerospace
Automotive
Benchmarking
Biology
Consulting
Database
Defense
Electronics
Energy
Environment
Finance
Geophysics
Hardware
InformationService
InformationProcessingService
LifeScience
Medicine
Other
Research
Service
Software
Telecomm
Transportation
WeatherClimateResearch
WWW
WeatherForecasting
Semiconductor
DigitalMedia
InternetProvider
Retail
LogisticServices

The END