# Tema 1: Evolución de la arquitectura de los sistemas paralelos y de sus modelos de programación

## Perspectiva histórica y tendencias en arquitecturas paralelas

**Asignatura: Arquitectura de Sistemas Paralelos**

Profesor: Francisco Javier Gómez Arribas
Departamento de Tecnología Electrónica y de las Comunicaciones

UNIVERSIDAD AUTONOMA DE MADRID

Escuela Politécnica Superior

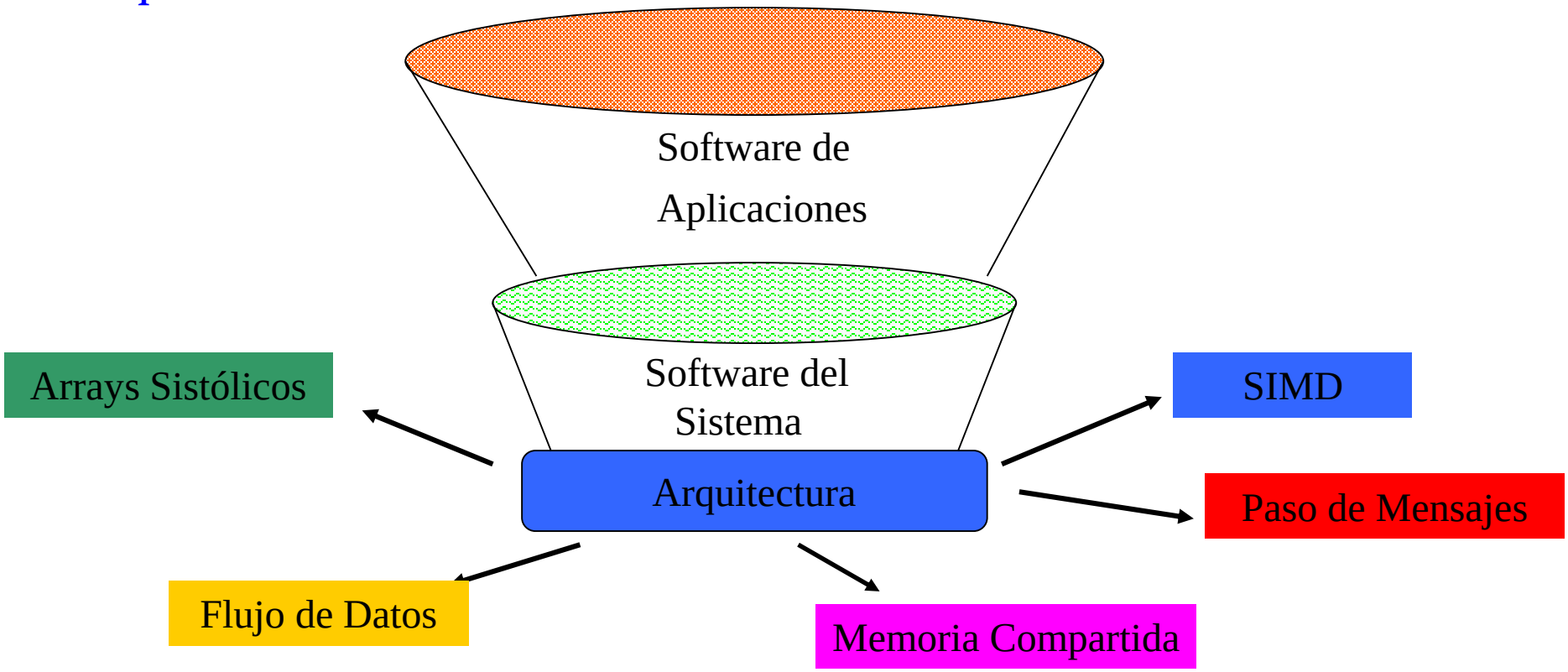
# Contenidos

- **Introducción a la computación paralela**
  - **Motivación y Objetivos**
  - **Aplicaciones de la computación paralela**
- **Arquitecturas para procesamiento en paralelo**
  - **Clasificación**
  - **Arquitecturas**
- **Evolución de sistemas de computación paralela**
  - **Integración, Ley de Moore, Limitaciones Tecnológicas, Mejoras Arquitectura de procesador, Mejora de Interconexión**
  - **Top 500. Ejemplos de SuperOrdenadores**
  - **Métricas**

# Evolución de las Arquitecturas Paralelas

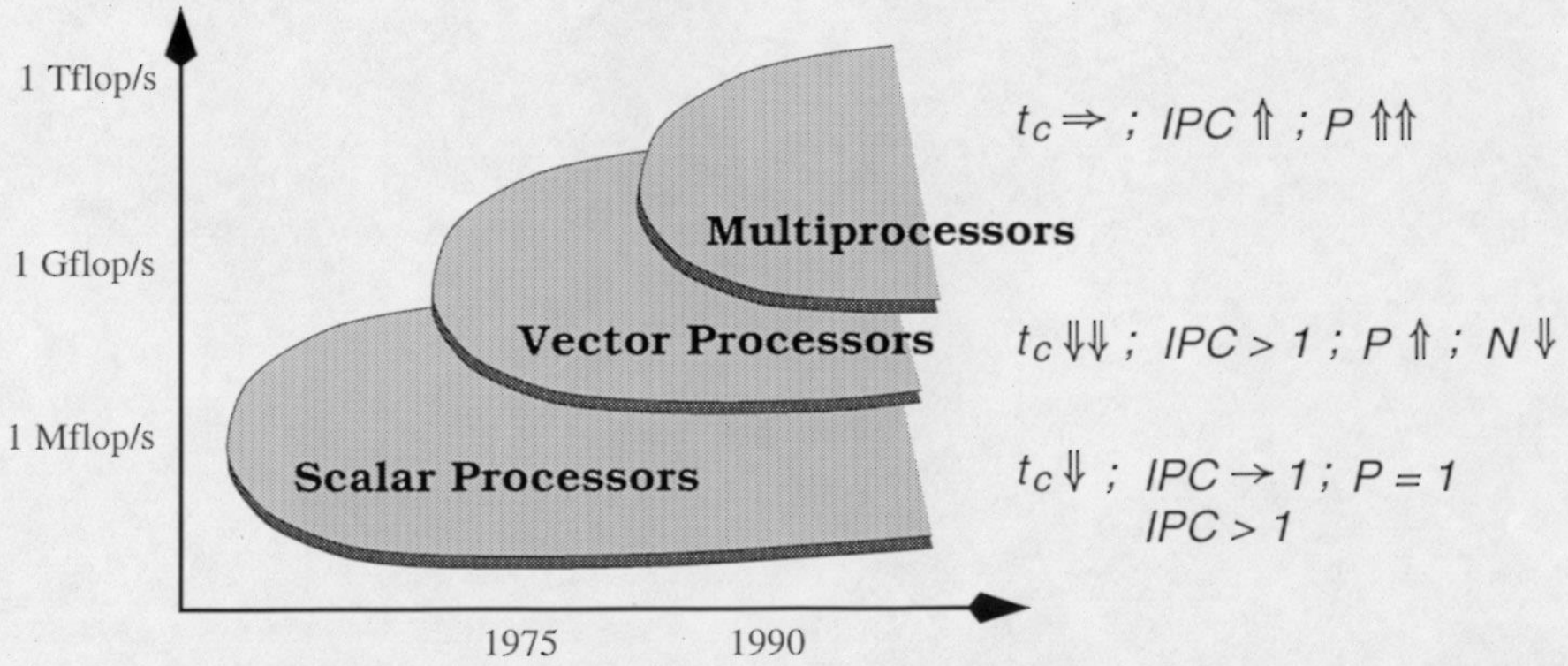
## Evolución Histórica:

- **La incertidumbre arquitectural con desarrollos divergentes ha caracterizado la evolución de las arquitecturas paralelas y ha paralizado el desarrollo del software paralelo**

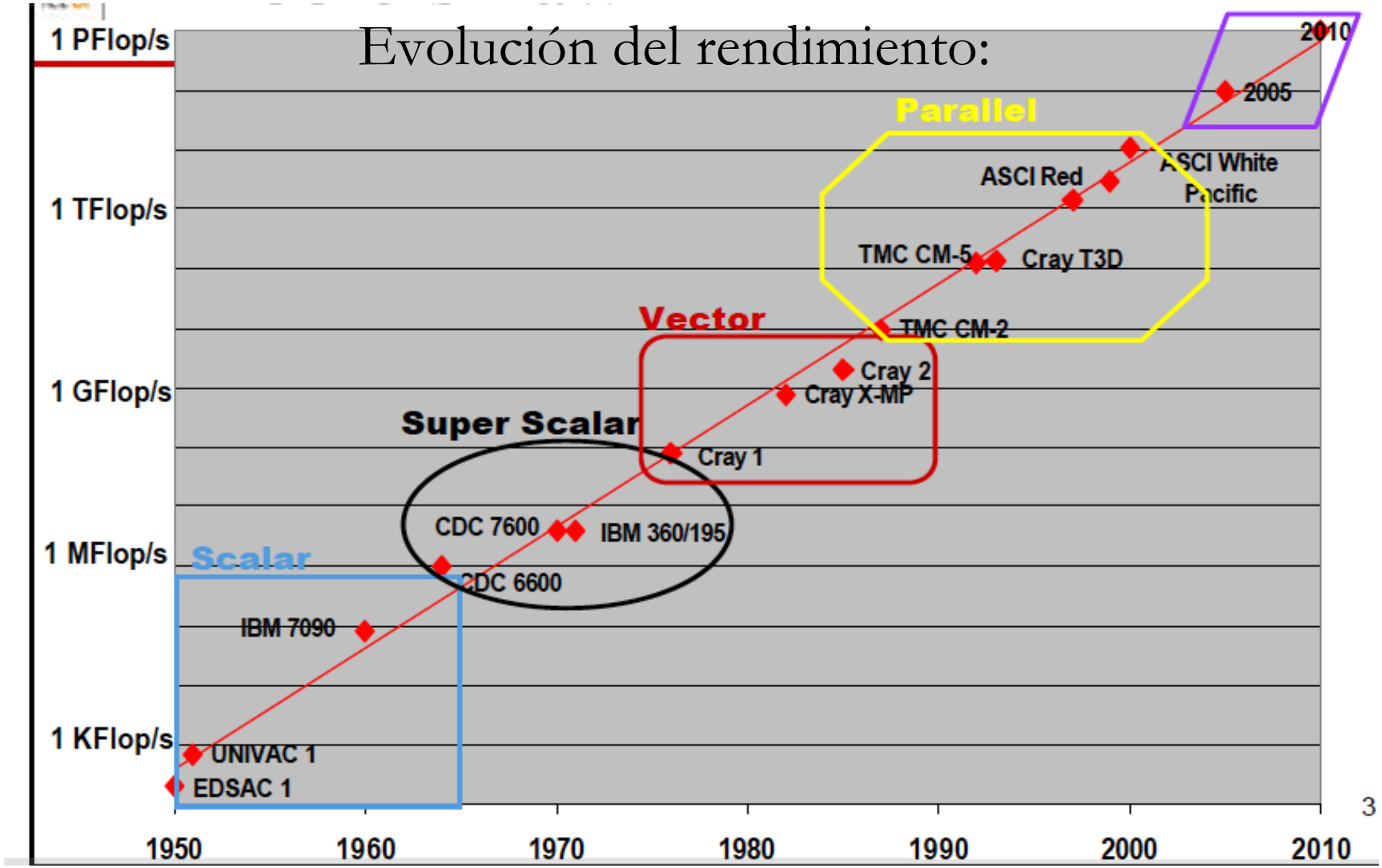


# Architectural Evolution

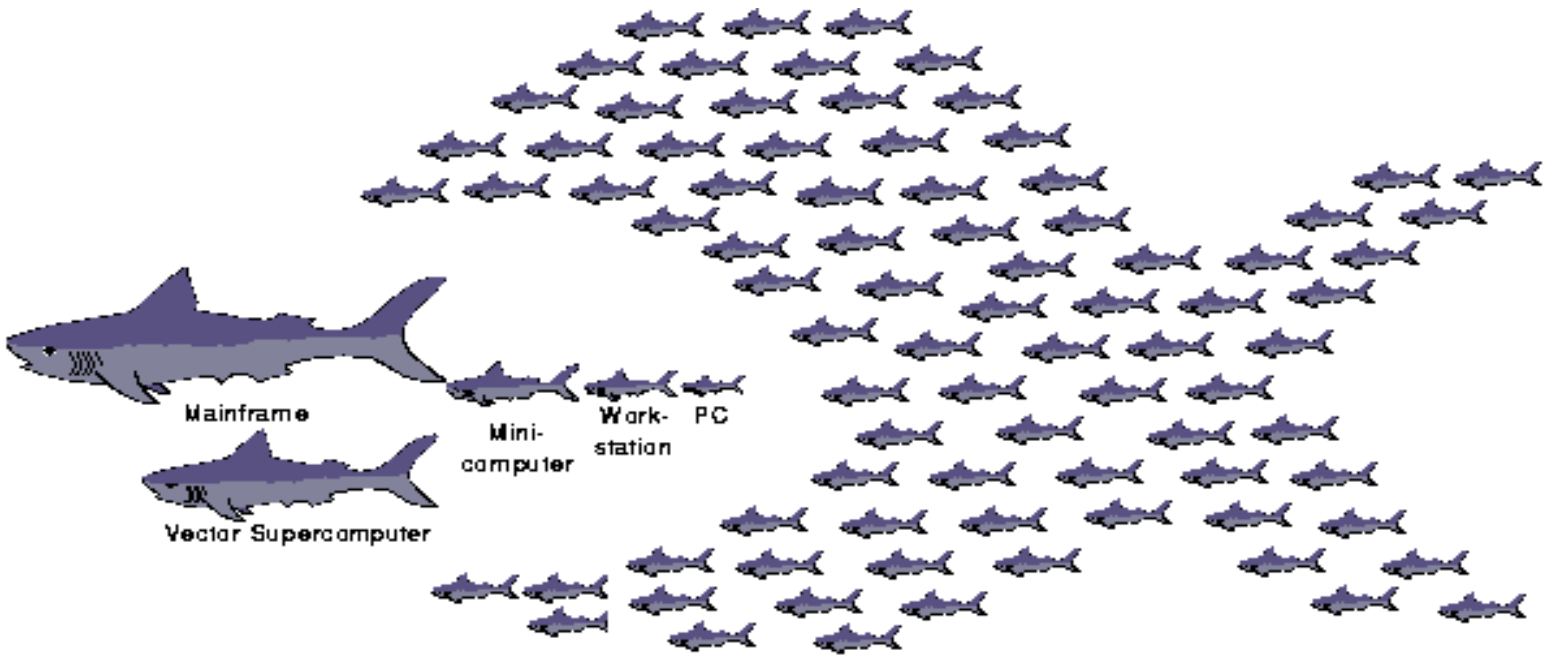
$$T = \frac{N}{P} * \frac{1}{IPC} * t_c$$



# Evolución histórica de los sistemas de computación paralela



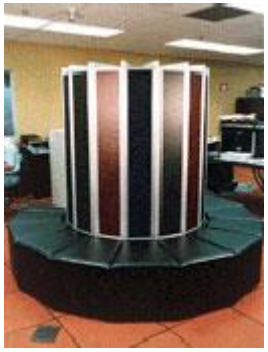
# Algunas ideas de Gordon Bell (4/10/1997)

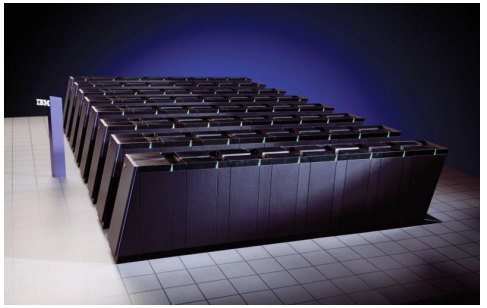



now.cs.berkeley.edu/

# Evolución de las Arquitecturas Paralelas

| | |
|---|---|
| Vector Processor | 1976 |
| | (CRAY-1) |
| Parallel Processors | 1985 |
| | (CM-1)(CM5) Thinking Machines |
| MPU ClusterGrid | 1997 |
| ***(Multiple Process Unit)*** | (ASCI-RED9) |
| **MPP massively Parallel** | **2008/ 2010** |
| **Processing** | (DARPA-HPCS machines |
| | BlueGene/LBG/C64) |





# Metricas: TOP500

**Es el listado de las 500 computadoras paralelas más potentes, reportadas a nivel internacional. Se publica regularmente desde el 93, dos veces al año (Junio y Noviembre).**

**El test utilizado para medir el rendimiento es el LINPACK, introducido por Jack Dongarra y consiste en la solución de un SEL denso, utilizando la factorización LU con pivote parcial, excluyendo el uso del algoritmo de multiplicación rápida de matrices. La complejidad del algoritmo es $2/3n^3 + O(n^2)$ operaciones en punto flotante.**

# TOP500 : Noviembre 2004


| | |
|---|---|
| **Rank** | Position within the TOP500 ranking |
| **Manufacturer** | Manufacturer or vendor |
| **Computer** | Type indicated by manufacturer or vendor |
| **Installation Site** | Customer |
| **Location** | Location and country |
| **Year** | Year of installation/last major update |
| **Installation Area** | Field of Application |
| **Processors** | Number of processors |
| $R_{max}$ | Maximal LINPACK performance achieved |
| $R_{peak}$ | Theoretical peak performance |
| $N_{max}$ | Problem size for achieving Rmax |
| $N_{1/2}$ | Problem size for achieving half of Rmax |

http://www.top500.org/

List for November 2004

$R_{max}$ and $R_{peak}$ values are in GFlops. For more details about other fields, please click on the button "Explanation of the Fields"

EXPLANATION OF THE FIELDS

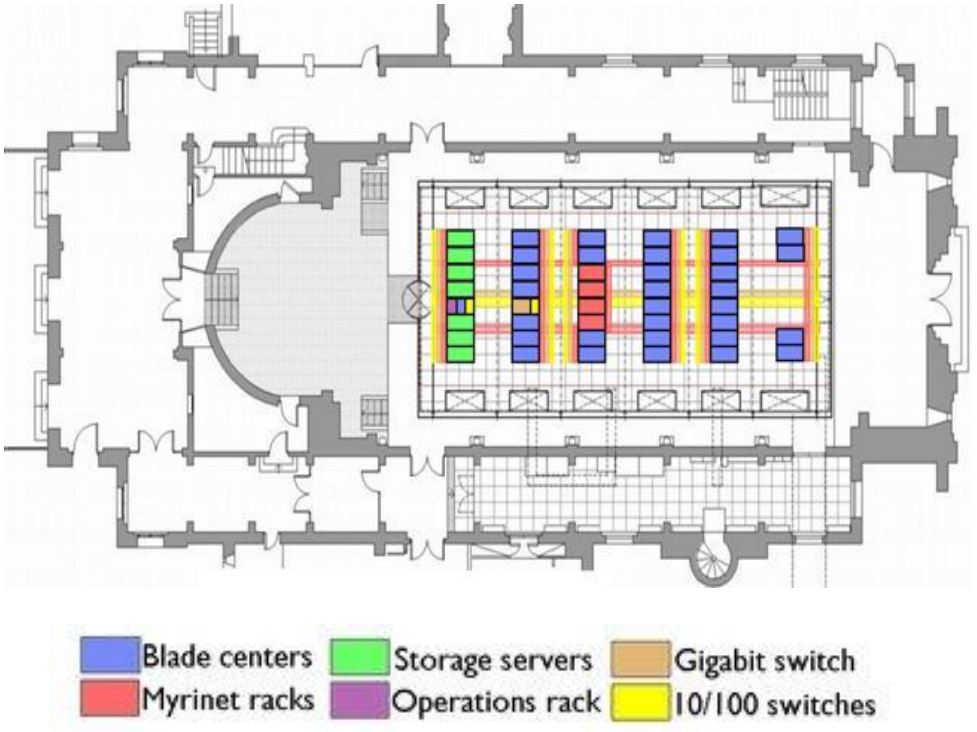
1-100 | 101-200 | 201-300 | 301-400 | 401-500

| Rank | Site<br>Country/Year | Computer / Processors<br>Manufacturer | Computer Family<br>Model | Inst. type<br>Installation Area | $R_{max}$<br>$R_{peak}$ | $N_{max}$<br>$n_{half}$ |
|---|---|---|---|---|---|---|
| 1 | IBM/DOE<br>United States/2004 | *BlueGene/L beta-System*<br>**BlueGene/L DD2 beta-System (0.7 GHz PowerPC 440)** / 32768<br>IBM | **IBM BlueGene/L**<br>BlueGene/L | **Research** | 70720<br>91750 | 933887 |
| 2 | NASA/Ames Research Center/NAS<br>United States/2004 | *Columbia*<br>**SGI Altix 1.5 GHz, Voltaire Infiniband** / 10160<br>SGI | **SGI Altix**<br>SGI Altix 1.5 GHz, Infiniband | **Research** | 51870<br>60960 | 1.29024e+06 |
| 3 | The Earth Simulator Center<br>Japan/2002 | **Earth-Simulator** / 5120<br>NEC | **NEC Vector**<br>SX6 | **Research** | 35860<br>40960 | 1.0752e+06<br>266240 |
| 4 | Barcelona Supercomputer Center<br>Spain/2004 | *MareNostrum*<br>**eServer BladeCenter JS20 (PowerPC970 2.2 GHz), Myrinet** / 3564<br>IBM | **IBM Cluster**<br>JS20 CLuster, Myrinet | **Academic** | 20530<br>31363 | 812592 |
| 5 | Lawrence Livermore National Laboratory<br>United States/2004 | *Thunder*<br>**Intel Itanium2 Tiger4 1.4GHz - Quadrics** / 4096<br>California Digital Corporation | **NOW - Intel Itanium**<br>Itanium2 Tiger4 Cluster - Quadrics | **Research** | 19940<br>22938 | 975000<br>110000 |
| 6 | Los Alamos National Laboratory<br>United States/2002 | *ASCI Q*<br>**ASCI Q - AlphaServer SC45, 1.25 GHz** / 8192<br>HP | **HP AlphaServer**<br>SC Alpha-Server-Cluster | **Research** | 13880<br>20480 | 633000<br>225000 |
| 7 | Virginia Tech<br>United States/2004 | *System X*<br>**1100 Dual 2.3 GHz Apple XServe/Mellanox Infiniband 4X/Cisco GigE** / 2200<br>Self-made | **NOW - PowerPC**<br>XServe Cluster | **Academic** | 12250<br>20240 | 620000 |

# MareNostrum: Barcelona Supercomputer Center


**MareNostrum** (2004, 2006)

- **Peak Performance of 94,21 Teraflops**
- **10240 IBM Power PC 970MP processors at 2.3 GHz (2560 JS21 blades)**
- **20 TB of main memory**
- **280 + 90 TB of disk storage**
- **Interconnection networks:**
  - **Myrinet and Gigabit Ethernet**
- **Linux: SuSe Distribution**



# TOP500

http:/www.top500.org/

## TOP500 List - June 2006 (1-100)

$R_{max}$ and $R_{peak}$ values are in GFlops. For more details about other fields, description.

| | |
|---|---|
| **Rank** | Position within the TOP500 ranking |
| **Manufacturer** | Manufacturer or vendor |
| **Computer** | Type indicated by manufacturer or vendor |
| **Installation Site** | Customer |
| **Location** | Location and country |
| **Year** | Year of installation/last major update |
| **Installation Area** | Field of Application |
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| $N_{1/2}$ | Problem size for achieving half of Rmax |

| Rank | Site | Computer | Processors | Year | $R_{max}$ | $R_{peak}$ |
|---|---|---|---|---|---|---|
| 1 | DOE/NNSA/LLNL<br>United States | BlueGene/L - eServer Blue Gene Solution<br>IBM | 131072 | 2005 | 280600 | 367000 |
| 2 | IBM Thomas J. Watson Research Center<br>United States | BGW - eServer Blue Gene Solution<br>IBM | 40960 | 2005 | 91290 | 114688 |
| 3 | DOE/NNSA/LLNL<br>United States | ASC Purple - eServer pSeries p5 575 1.9 GHz<br>IBM | 12208 | 2006 | 75760 | 92781 |
| 4 | NASA/Ames Research Center/NAS<br>United States | Columbia - SGI Altix 1.5 GHz, Voltaire Infiniband<br>SGI | 10160 | 2004 | 51870 | 60960 |
| 5 | Commissariat a l'Energie Atomique (CEA)<br>France | Tera-10 - NovaScale 5160, Itanium2 1.6 GHz, Quadrics<br>Bull SA | 8704 | 2006 | 42900 | 55705.6 |
| 6 | Sandia National Laboratories<br>United States | Thunderbird - PowerEdge 1850, 3.6 GHz, Infiniband<br>Dell | 9024 | 2006 | 38270 | 64972.8 |
| 7 | GSIC Center, Tokyo Institute of Technology<br>Japan | TSUBAME Grid Cluster - Sun Fire X64 Cluster, Opteron 2.4/2.6 GHz, Infiniband<br>NEC/Sun | 10368 | 2006 | 38180 | 49868.8 |
| 8 | Forschungszentrum Juelich (FZJ)<br>Germany | JUBL - eServer Blue Gene Solution<br>IBM | 16384 | 2006 | 37330 | 45875 |
| 9 | Sandia National Laboratories<br>United States | Red Storm Cray XT3, 2.0 GHz<br>Cray Inc. | 10880 | 2005 | 36190 | 43520 |
| 10 | The Earth Simulator Center<br>Japan | Earth-Simulator<br>NEC | 5120 | 2002 | 35860 | 40960 |
| 11 | Barcelona Supercomputer Center<br>Spain | MareNostrum - JS20 Cluster, PPC 970, 2.2 GHz, Myrinet<br>IBM | 4800 | 2005 | 27910 | 42144 |
| 12 | ASTRON/University Groningen<br>Netherlands | Stella - eServer Blue Gene Solution<br>IBM | 12288 | 2005 | 27450 | 34406.4 |

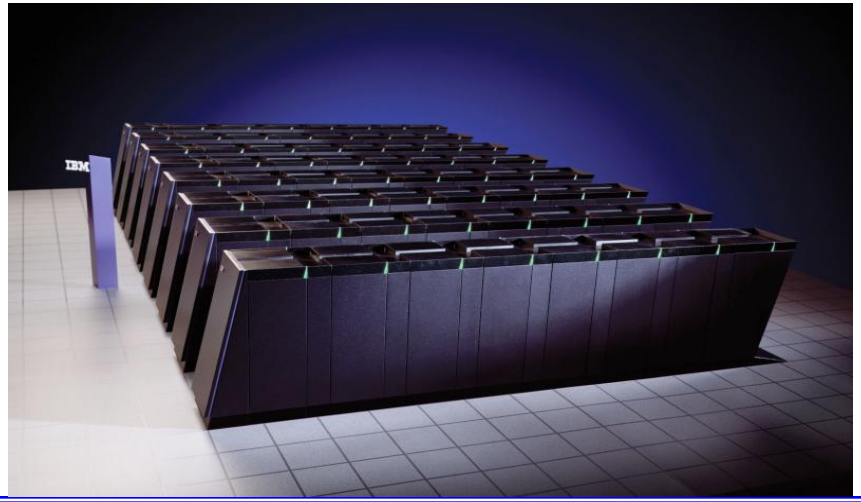
# IBM Roadmap (2008-…)

- **IBM BlueGene/L Project (360TFLOPS 2005)**
  **High density parallel processor**
  **65,536 CPU chips in 64 racks 131,072 processors**
- **IBM BlueGene/C64 Project (1.1 PFlops, 2008)**

**http://www.tomshardware.com/news/bluegene-supercomputer-doe-argonne,12159.html**

**(10 PFlops, 20xx)**

**(x100 en 2020) powered by "100s of millions of cores".**



IBM Blue Gene/L

# TOP500 : Noviembre 2009

http:/www.top500.org/

| | |
|---|---|
| **Rank** | Position within the TOP500 ranking |
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| **Computer** | Type indicated by manufacturer or vendor |
| **Installation Site** | Customer |
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TOP500 List - November 2009 (1-100) | TOP500 Supe...

## TOP500 List - November 2009 (1-100)

$R_{max}$ and $R_{peak}$ values are in TFlops. For more details about other fields, check the TOP500 description.

Power data in KW for entire system

next

| Rank | Site | Computer/Year Vendor | Cores | $R_{max}$ | $R_{peak}$ | Power |
|---|---|---|---|---|---|---|
| 1 | Oak Ridge National Laboratory<br>United States | Jaguar - Cray XT5-HE Opteron Six Core 2.6 GHz / 2009<br>Cray Inc. | 224162 | 1759.00 | 2331.00 | 6950.60 |
| 2 | DOE/NNSA/LANL<br>United States | Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband / 2009<br>IBM | 122400 | 1042.00 | 1375.78 | 2345.50 |
| 3 | National Institute for Computational Sciences/University of Tennessee<br>United States | Kraken XT5 - Cray XT5-HE Opteron Six Core 2.6 GHz / 2009<br>Cray Inc. | 98928 | 831.70 | 1028.85 | |
| 4 | Forschungszentrum Juelich (FZJ)<br>Germany | JUGENE - Blue Gene/P Solution / 2009<br>IBM | 294912 | 825.50 | 1002.70 | 2268.00 |
| 5 | National SuperComputer Center in Tianjin/NUDT<br>China | Tianhe-1 - NUDT TH-1 Cluster, Xeon E5540/E5450, ATI Radeon HD 4870 2, Infiniband / 2009<br>NUDT | 71680 | 563.10 | 1206.19 | |
| 6 | NASA/Ames Research Center/NAS<br>United States | Pleiades - SGI Altix ICE 8200EX, Xeon QC 3.0 GHz/Nehalem EP 2.93 Ghz / 2009<br>SGI | 56320 | 544.30 | 673.26 | 2348.00 |
| 7 | DOE/NNSA/LLNL<br>United States | BlueGene/L - eServer Blue Gene Solution / 2007<br>IBM | 212992 | 478.20 | 596.38 | 2329.60 |
| 8 | Argonne National Laboratory<br>United States | Blue Gene/P Solution / 2007<br>IBM | 163840 | 458.61 | 557.06 | 1260.00 |
| 9 | Texas Advanced Computing Center/Univ. of Texas<br>United States | Ranger - SunBlade x6420, Opteron QC 2.3 Ghz, Infiniband / 2008<br>Sun Microsystems | 62976 | 433.20 | 579.38 | 2000.00 |
| 10 | Sandia National Laboratories / National Renewable Energy Laboratory<br>United States | Red Sky - Sun Blade x6275, Xeon X55xx 2.93 Ghz, Infiniband / 2009<br>Sun Microsystems | 41616 | 423.90 | 487.74 | |
| 11 | DOE/NNSA/LLNL<br>United States | Dawn - Blue Gene/P Solution / 2009<br>IBM | 147456 | 415.70 | 501.35 | 1134.00 |

# TOP500 : Noviembre 2010

## China Grabs Supercomputing Leadership Spot in Latest Ranking of World's Top 500 Supercomputers

**THU, 2010-11-11 22:42** MANNHEIM, Germany; BERKELEY, Calif.; and KNOXVILLE, Tenn.—The 36th edition of the closely watched TOP500 list of the world's most powerful supercomputers confirms the rumored takeover of the top spot by the **Chinese Tianhe-1A** system at the National Supercomputer Center in Tianjin, achieving a performance level of 2.57 petaflop/s (quadrillions of calculations per second).

News of the Chinese system's performance emerged in late October. As a result, the former number one system — the Cray XT5 "Jaguar" system at the U.S. Department of Energy's (DOE) Oak Ridge Leadership Computing Facility in Tennessee — is now ranked in second place. Jaguar achieved 1.75 petaflop/s running Linpack, the TOP500 benchmark application

# TOP500

http:/www.top500.org/

| | |
|---|---|
| **Rank** | Position within the TOP500 ranking |
| **Manufacturer** | Manufacturer or vendor |
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| **Installation Site** | Customer |
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## TOP500 List - November 2010 (1-100)

$R_{max}$ and $R_{peak}$ values are in TFlops. For more details about other fields, check the TOP500 description.

Power data in KW for entire system

| Rank | Site | Computer/Year Vendor | Cores | $R_{max}$ | $R_{peak}$ | Power |
|---|---|---|---|---|---|---|
| 1 | National Supercomputing Center in Tianjin<br>China | Tianhe-1A - NUDT TH MPP, X5670 2.93Ghz 6C, NVIDIA GPU, FT-1000 8C / 2010<br>NUDT | 186368 | 2566.00 | 4701.00 | 4040.00 |
| 2 | DOE/SC/Oak Ridge National Laboratory<br>United States | Jaguar - Cray XT5-HE Opteron 6-core 2.6 GHz / 2009<br>Cray Inc. | 224162 | 1759.00 | 2331.00 | 6950.60 |
| 3 | National Supercomputing Centre in Shenzhen (NSCS)<br>China | Nebulae - Dawning TC3600 Blade, Intel X5650, NVidia Tesla C2050 GPU / 2010<br>Dawning | 120640 | 1271.00 | 2984.30 | 2580.00 |
| 4 | GSIC Center, Tokyo Institute of Technology<br>Japan | TSUBAME 2.0 - HP ProLiant SL390s G7 Xeon 6C X5670, Nvidia GPU, Linux/Windows / 2010<br>NEC/HP | 73278 | 1192.00 | 2287.63 | 1398.61 |
| 5 | DOE/SC/LBNL/NERSC<br>United States | Hopper - Cray XE6 12-core 2.1 GHz / 2010<br>Cray Inc. | 153408 | 1054.00 | 1288.63 | 2910.00 |
| 6 | Commissariat a l'Energie Atomique (CEA)<br>France | Tera-100 - Bull bullx super-node S6010/S6030 / 2010<br>Bull SA | 138368 | 1050.00 | 1254.55 | 4590.00 |
| 7 | DOE/NNSA/LANL<br>United States | Roadrunner - BladeCenter QS22/LS21 Cluster, PowerXCell 8i 3.2 Ghz / Opteron DC 1.8 GHz, Voltaire Infiniband / 2009<br>IBM | 122400 | 1042.00 | 1375.78 | 2345.50 |
| 8 | National Institute for Computational Sciences/University of Tennessee<br>United States | Kraken XT5 - Cray XT5-HE Opteron 6-core 2.6 GHz / 2009<br>Cray Inc. | 98928 | 831.70 | 1028.85 | 3090.00 |
| 9 | Forschungszentrum Juelich (FZJ)<br>Germany | JUGENE - Blue Gene/P Solution / 2009<br>IBM | 294912 | 825.50 | 1002.70 | 2268.00 |
| 10 | DOE/NNSA/LANL/SNL<br>United States | Cielo - Cray XE6 8-core 2.4 GHz / 2010<br>Cray Inc. | 107152 | 816.60 | 1028.66 | 2950.00 |
| 11 | NASA/Ames Research Center/NAS<br>United States | Pleiades - SGI Altix ICE 8200EX/8400EX, Xeon HT QC 3.0/Xeon Westmere 2.93 Ghz, Infiniband / 2010<br>SGI | 81920 | 772.70 | 973.29 | 3096.00 |
| 12 | DOE/NNSA/LLNL<br>United States | BlueGene/L - eServer Blue Gene Solution / 2007<br>IBM | 212992 | 478.20 | 596.38 | 2329.60 |

# TOP500 Junio 2012

## Lawrence Livermore's Sequoia Supercomputer owers above the Rest in Latest TOP500 List

MANNHEIM, Germany; BERKELEY, Calif.; and KNOXVILLE, Tenn..—For the first time since November 2009, a United States supercomputer sits atop the TOP500 list of the world's top supercomputers. Named Sequoia, the IBM BlueGene/Q system installed at the Department of Energy's Lawrence Livermore National Laboratory achieved an impressive 16.32 petaflop/s on the Linpack benchmark using 1,572,864 cores


| | NAME | SPECS | SITE | COUNTRY | CORES | $R_{max}$ Pflop/s |
|---|---|---|---|---|---|---|
| 1 | **Sequoia** | IBM BlueGene/Q, Power BQC 16C 1.60 GHz, Custom interconnect | DOE / NNSA / LLNL | USA | 1,572,864 | 16.33 |
| 2 | **K computer** | Fujitsu SPARC64 VIIIfx 2.0GHz, Tofu interconnect | RIKEN AICS | Japan | 705,024 | 10.51 |
| 3 | **Mira** | IBM BlueGene/Q, Power BQC 16C 1.60 GHz, Custom interconnect | DOE / SC / ANL | USA | 786,432 | 8.153 |
| 4 | **SuperMUC** | IBM iDataPlex DX360M4, Xeon E5-2680 8C 2.70GHz, Infiniband QDR | Leibniz Rechenzentrum | Germany | 147,456 | 2.897 |
| 5 | **Tianhe-1A** | NUDT YH MPP, Xeon X5670 6C 2.93 GHz, NVIDIA 2050 | NUDT/NSCC/Tianjin | China | 186,368 | 2.566 |

# TOP500

http:/www.top500.org/

## TOP500 List - June 2006 (1-100)

$R_{max}$ and $R_{peak}$ values are in GFlops. For more details about other fields, c
description.

| | |
|---|---|
| **Rank** | Position within the TOP500 ranking |
| **Manufacturer** | Manufacturer or vendor |
| **Computer** | Type indicated by manufacturer or vendor |
| **Installation Site** | Customer |
| **Location** | Location and country |
| **Year** | Year of installation/last major update |
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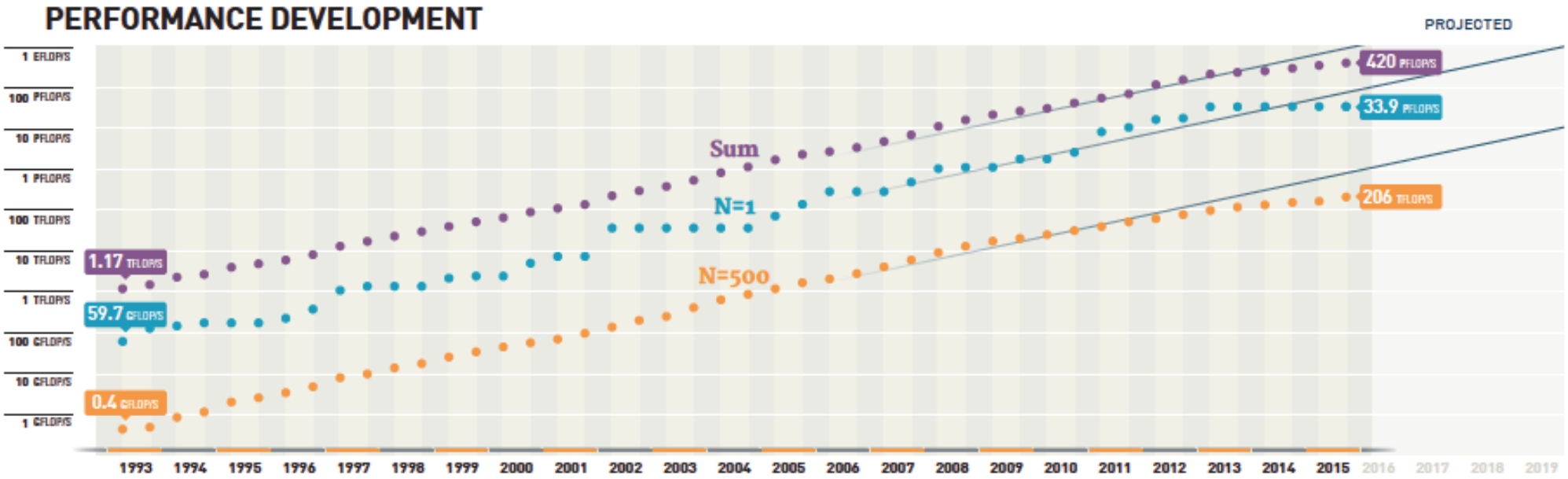
| $N_{1/2}$ | Problem size for achieving half of Rmax |

| Rank | Site | Computer | Processors | Year | $R_{max}$ | $R_{peak}$ |
|---|---|---|---|---|---|---|
| 1 | DOE/NNSA/LLNL<br>United States | BlueGene/L - eServer Blue Gene Solution<br>IBM | 131072 | 2005 | 280600 | 367000 |
| 2 | IBM Thomas J. Watson Research Center<br>United States | BGW - eServer Blue Gene Solution<br>IBM | 40960 | 2005 | 91290 | 114688 |
| 3 | DOE/NNSA/LLNL<br>United States | ASC Purple - eServer pSeries p5 575 1.9 GHz<br>IBM | 12208 | 2006 | 75760 | 92781 |
| 4 | NASA/Ames Research Center/NAS<br>United States | Columbia - SGI Altix 1.5 GHz, Voltaire Infiniband<br>SGI | 10160 | 2004 | 51870 | 60960 |
| 5 | Commissariat a l'Energie Atomique (CEA)<br>France | Tera-10 - NovaScale 5160, Itanium2 1.6 GHz, Quadrics<br>Bull SA | 8704 | 2006 | 42900 | 55705.6 |
| 6 | Sandia National Laboratories<br>United States | Thunderbird - PowerEdge 1850, 3.6 GHz, Infiniband<br>Dell | 9024 | 2006 | 38270 | 64972.8 |
| 7 | GSIC Center, Tokyo Institute of Technology<br>Japan | TSUBAME Grid Cluster - Sun Fire X64 Cluster, Opteron 2.4/2.6 GHz, Infiniband<br>NEC/Sun | 10368 | 2006 | 38180 | 49868.8 |
| 8 | Forschungszentrum Juelich (FZJ)<br>Germany | JUBL - eServer Blue Gene Solution<br>IBM | 16384 | 2006 | 37330 | 45875 |
| 9 | Sandia National Laboratories<br>United States | Red Storm Cray XT3, 2.0 GHz<br>Cray Inc. | 10880 | 2005 | 36190 | 43520 |
| 10 | The Earth Simulator Center<br>Japan | Earth-Simulator<br>NEC | 5120 | 2002 | 35860 | 40960 |
| 11 | Barcelona Supercomputer Center<br>Spain | MareNostrum - JS20 Cluster, PPC 970, 2.2 GHz, Myrinet<br>IBM | 4800 | 2005 | 27910 | 42144 |
| 12 | ASTRON/University Groningen<br>Netherlands | Stella - eServer Blue Gene Solution<br>IBM | 12288 | 2005 | 27450 | 34406.4 |

# TOP500 Nov2015

| | NAME | SPECS | SITE | COUNTRY | CORES | RMAX PFLOP/S | POWER MW |
|---|---|---|---|---|---|---|---|
| 1 | Tianhe-2 (Milkyway-2) | Intel Ivy Bridge (12C 2.2 GHz) & Xeon Phi (57C 1.1 GHz), Custom interconnect | NUDT | China | 3,120,000 | 33.9 | 17.8 |
| 2 | Titan | Cray XK7, Opteron 6274 (16C 2.2 GHz) + Nvidia Kepler GPU, Custom interconnect | DOE/SC/ORNL | USA | 560,640 | 17.6 | 8.2 |
| 3 | Sequoia | IBM BlueGene/Q, Power BQC (16C 1.60 GHz), Custom interconnect | DOE/NNSA/LLNL | USA | 1,572,864 | 17.2 | 7.9 |
| 4 | K computer | Fujitsu SPARC64 VIIIfx (8C 2.0 GHz), Custom interconnect | RIKEN AICS | Japan | 705,024 | 10.5 | 12.7 |
| 5 | Mira | IBM BlueGene/Q, Power BQC (16C 1.60 GHz), Custom interconnect | DOE/SC/ANL | USA | 786,432 | 8.59 | 3.95 |



# www.top500.org Nov 2019

| Rank | Site | System | Cores | Rmax (TFlop/s) | Rpeak (TFlop/s) | Power (kW) |
|---|---|---|---|---|---|---|
| 1 | DOE/SC/Oak Ridge National Laboratory<br>United States | **Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband<br>IBM | 2,414,592 | 148,600.0 | 200,794.9 | 10,096 |
| 2 | DOE/NNSA/LLNL<br>United States | **Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband<br>IBM / NVIDIA / Mellanox | 1,572,480 | 94,640.0 | 125,712.0 | 7,438 |
| 3 | National Supercomputing Center in Wuxi<br>China | **Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway<br>NRCPC | 10,649,600 | 93,014.6 | 125,435.9 | 15,371 |
| 4 | National Super Computer Center in Guangzhou<br>China | **Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000<br>NUDT | 4,981,760 | 61,444.5 | 100,678.7 | 18,482 |
| 5 | Texas Advanced Computing Center/Univ. of Texas<br>United States | **Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR<br>Dell EMC | 448,448 | 23,516.4 | 38,745.9 | |
| 6 | Swiss National Supercomputing Centre (CSCS)<br>Switzerland | **Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100<br>Cray/HPE | 387,872 | 21,230.0 | 27,154.3 | 2,384 |

**Los sistemas HPC actuales explotan el paralelismo interconectando nodos homogéneos.**

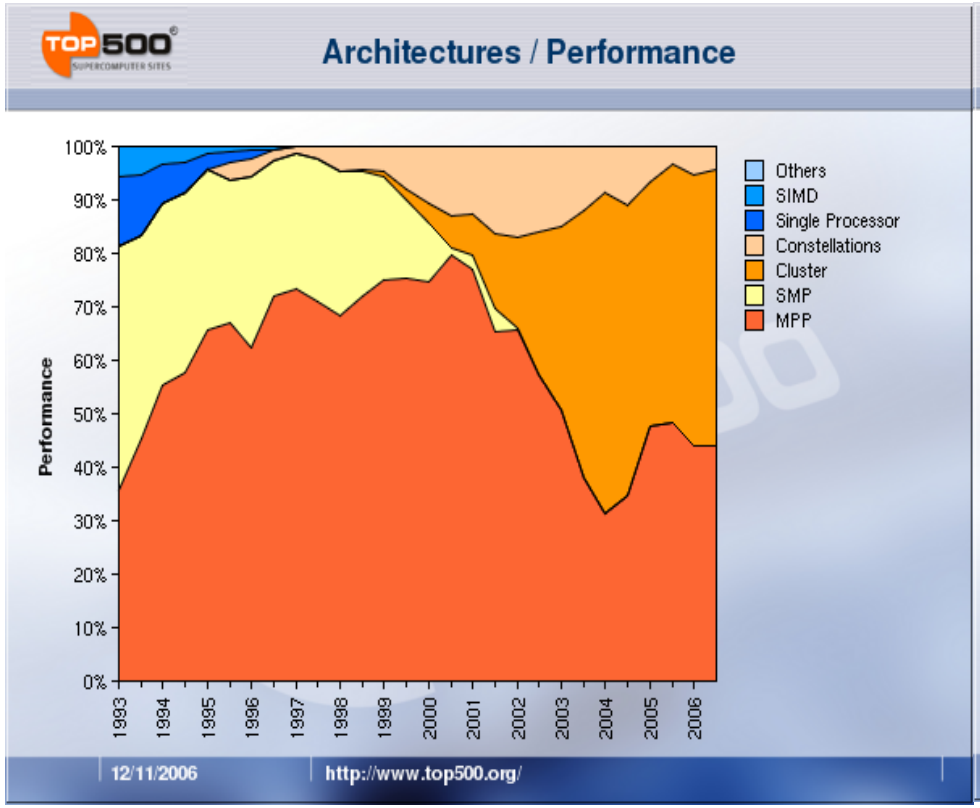
**En muchos casos la arquitectura del nodo es heterogénea:**

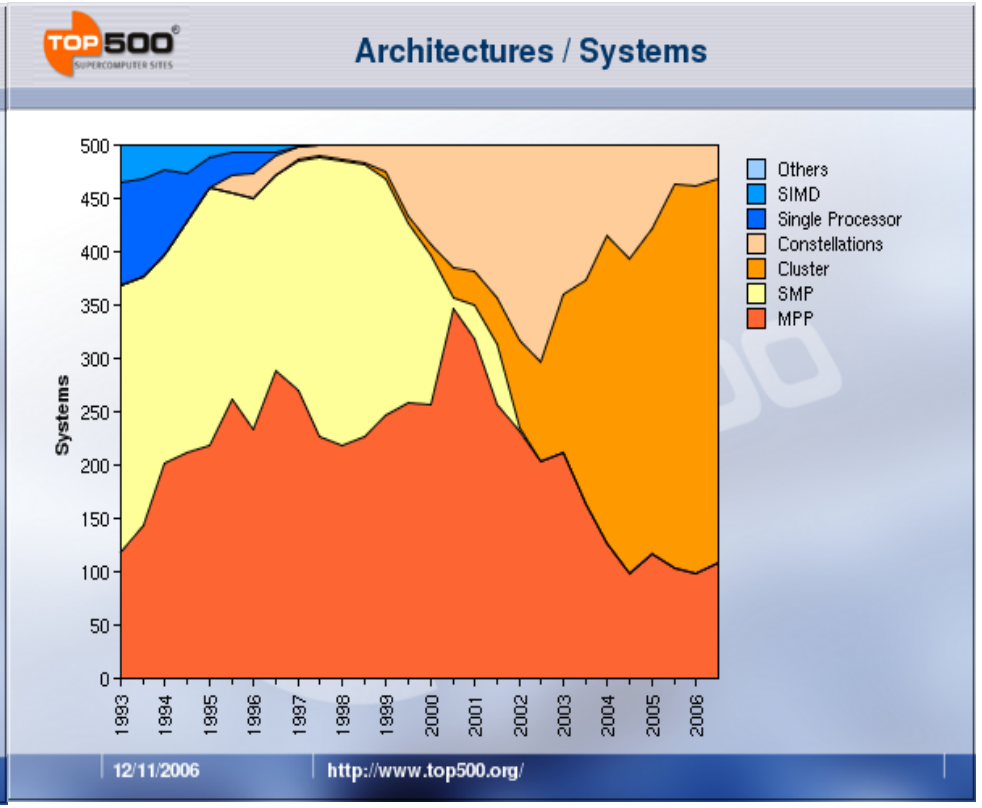
- **Coprocesador GPU**
- **Coprocesador XeonPhi**


TOP500
Performance Development
100 PFlops
10 PFlops
1 PFlops
100 TFlops
10 TFlops
1 TFlops
100 GFlops
10 GFlops
1 GFlops
100 MFlops
Performance
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
1.12 TF
59.7 GF
0.42 GF
27951.30 TF
1759.00 TF
20051 GF
#1
#500
Sum
13/11/2009
http://www.top500.org/

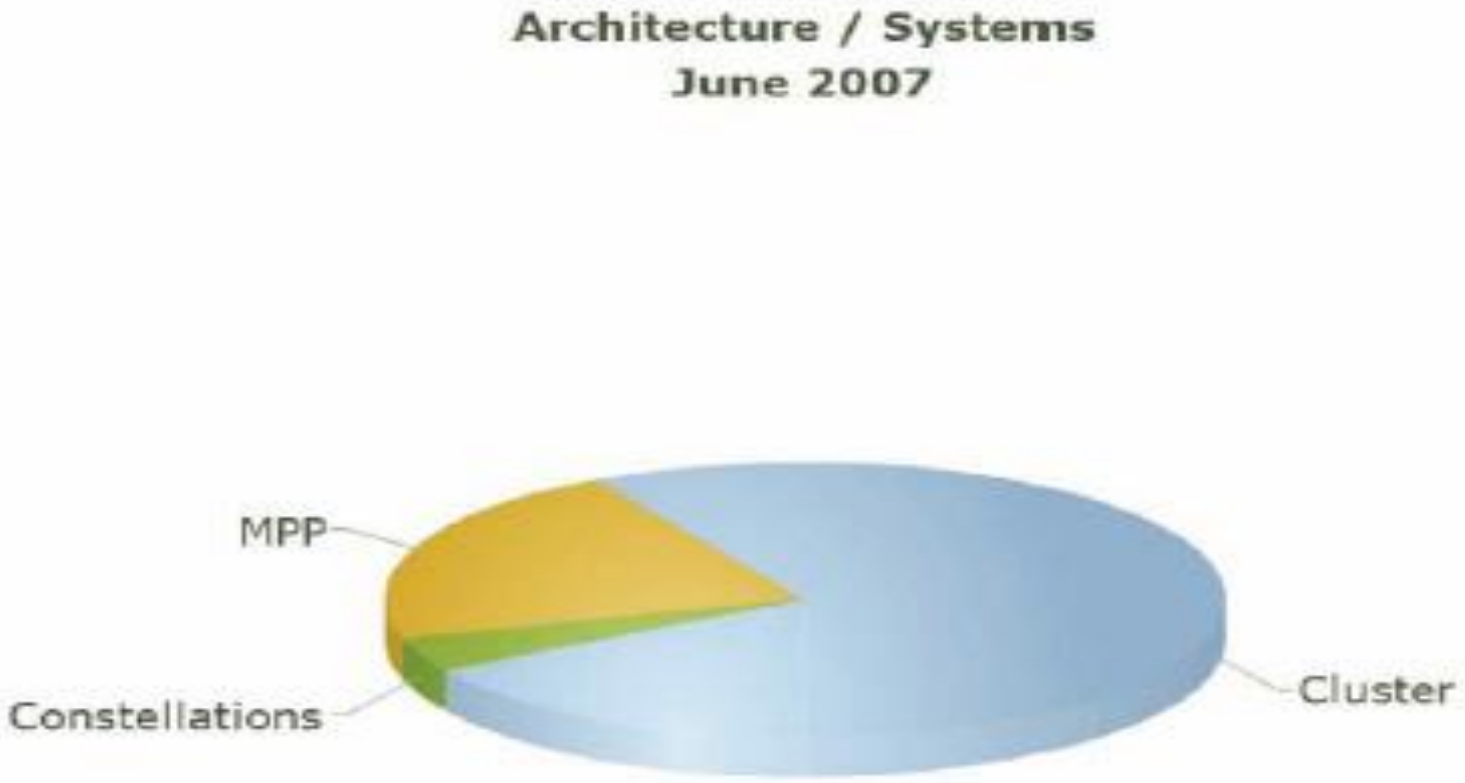
# Cluster se impone en top500:Tendencia desde 2007

http://www.top500.org/



# some numbers: Top500 (cont'd)




**cluster:** #nodes > #processors/node

**constellation:** #nodes < #processors/node

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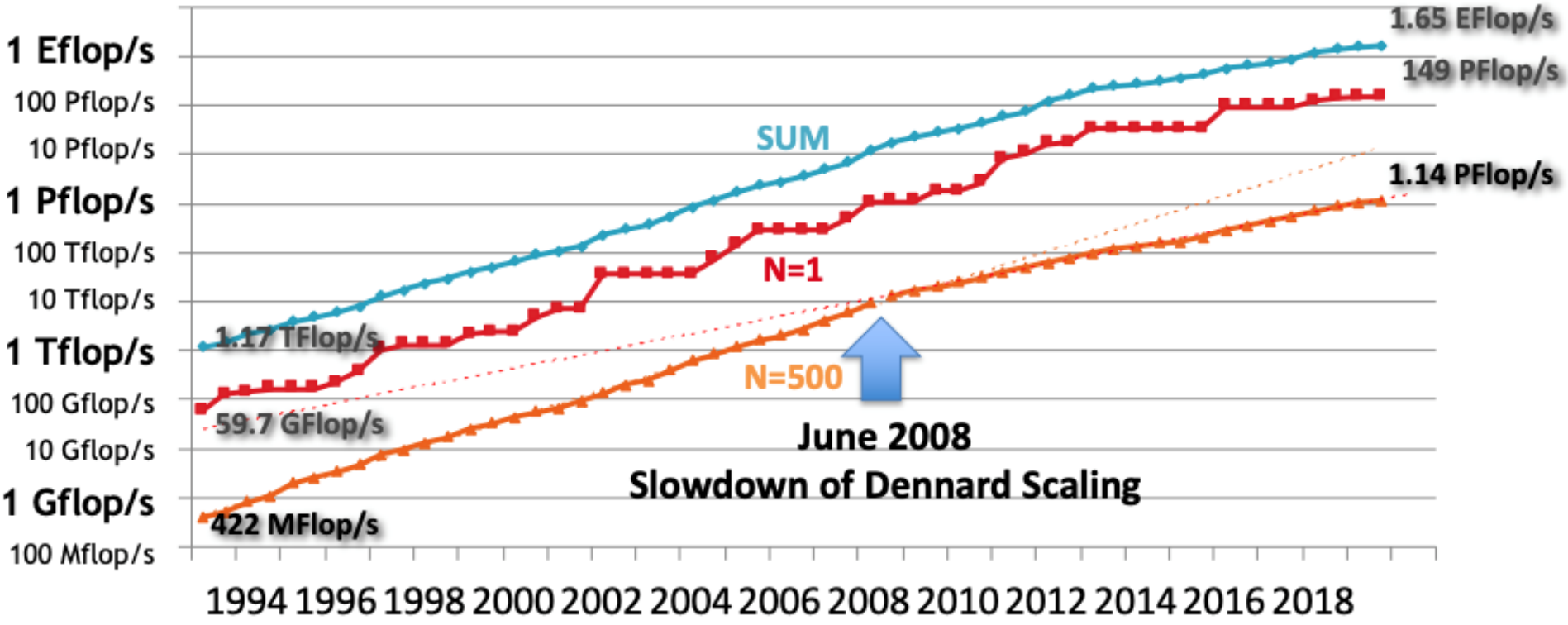
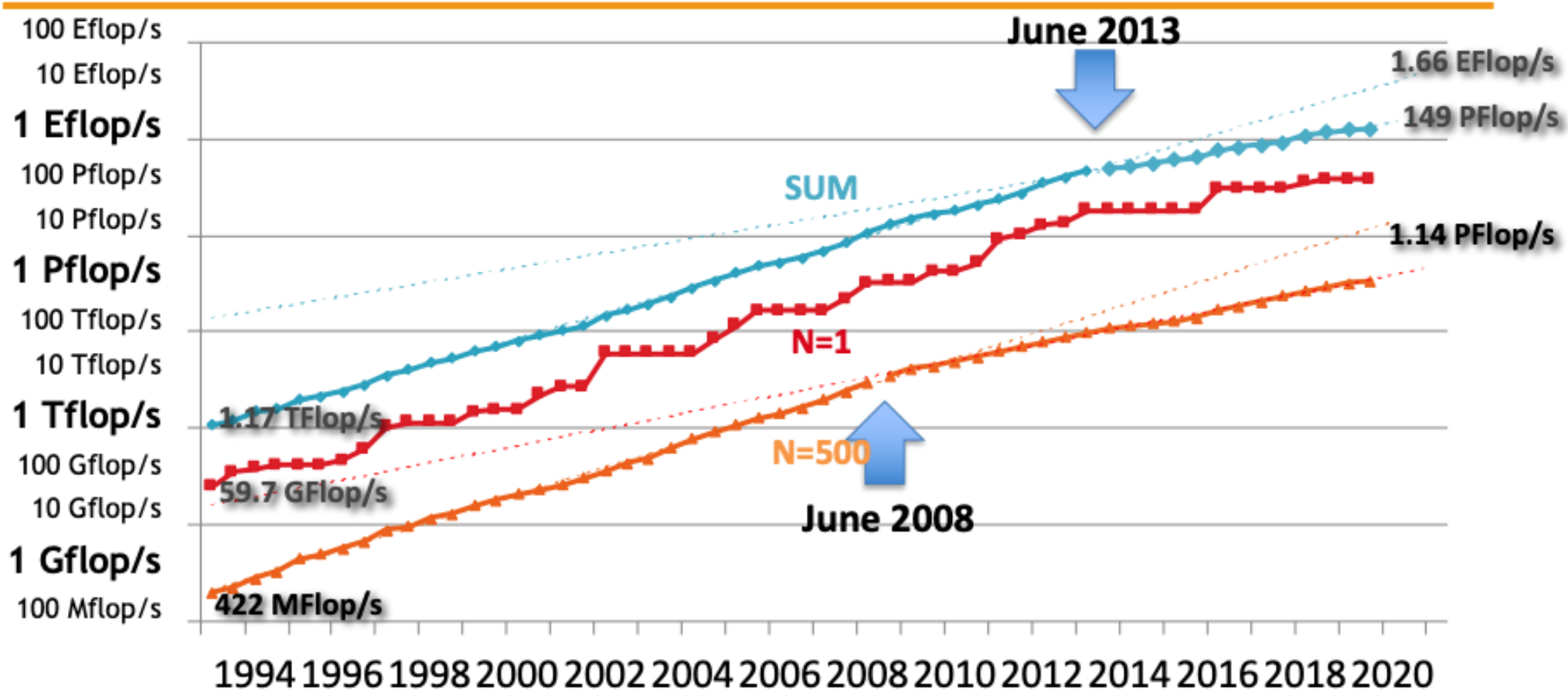
# PERFORMANCE DEVELOPMENT

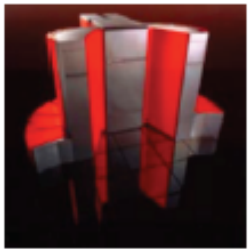


# PERFORMANCE DEVELOPMENT



# Looking at the Gordon Bell Prize

(Recognize outstanding achievement in high-performance computing applications and encourage development of parallel processing )

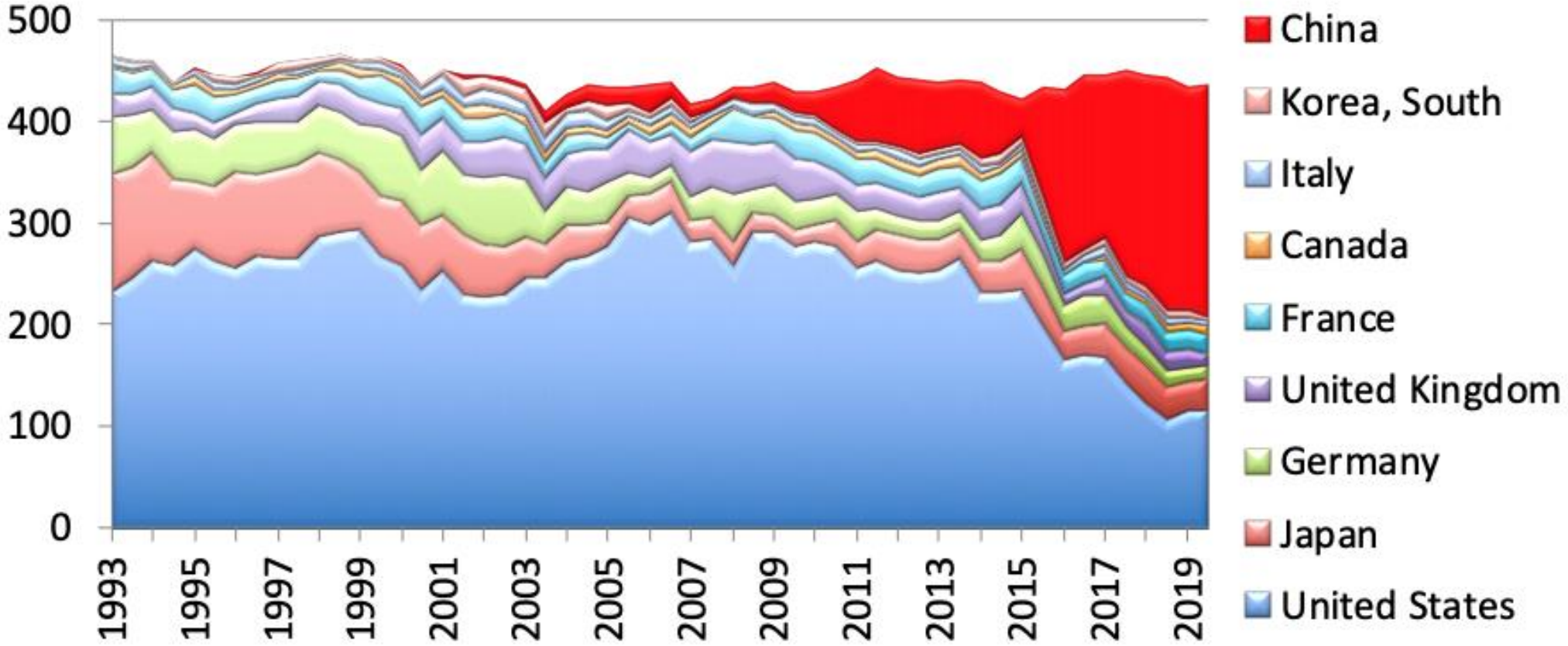


- 1 GFlop/s; 1988; Cray Y-MP; 8 Processors
  - Static finite element analysis

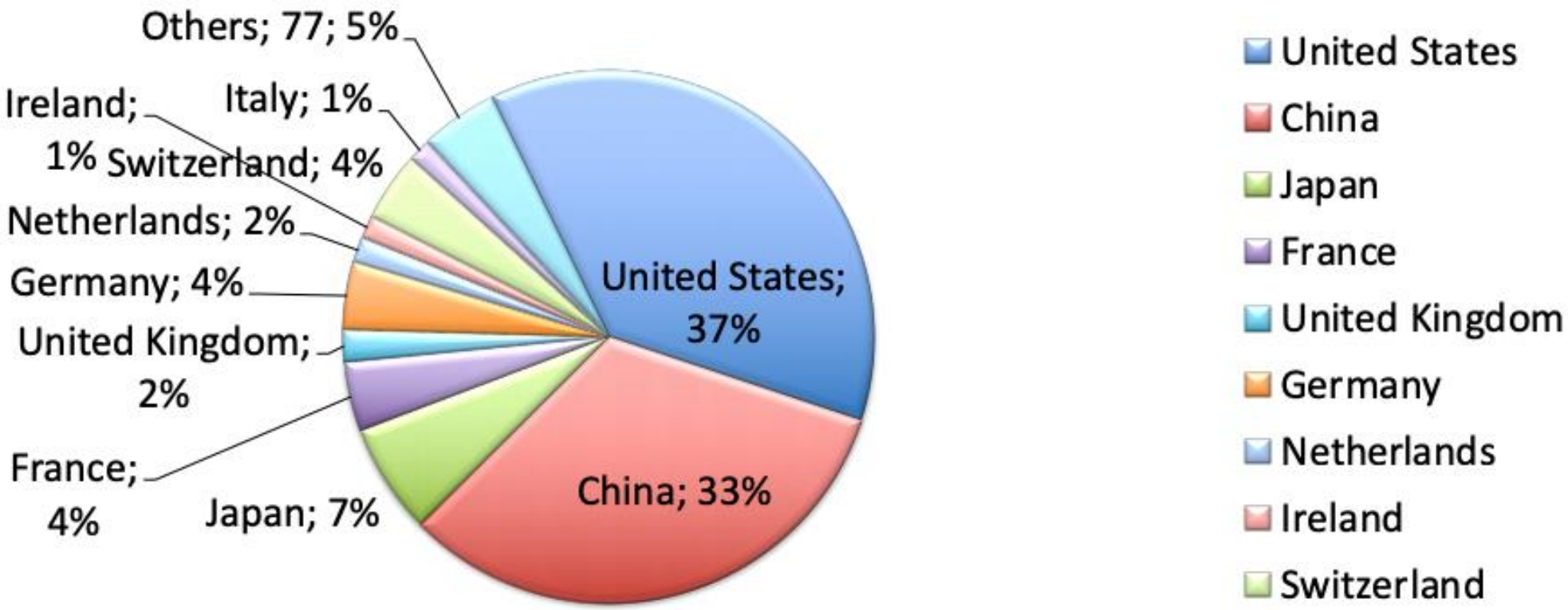
- 1 TFlop/s; 1998; Cray T3E; 1024 Processors
  - Modeling of metallic magnet atoms, using a variation of the locally self-consistent multiple scattering method.

- 1 PFlop/s; 2008; Cray XT5; $1.5 \times 10^5$ Processors
  - Superconductive materials
- 1 EFlop/s; ~2018; ?; $1 \times 10^7$ Processors ($10^9$ threads)

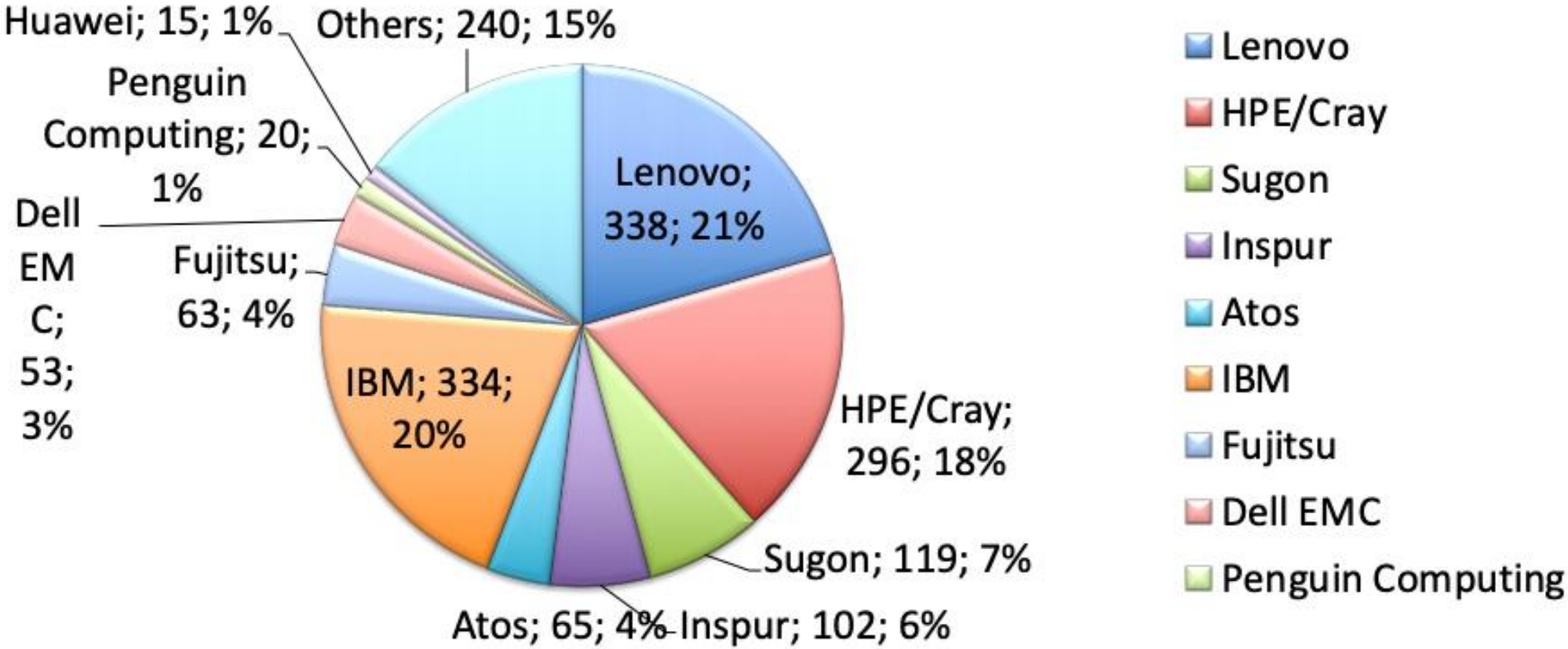
# COUNTRIES


500
400
300
200
100
0
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
China
Korea, South
Italy
Canada
France
United Kingdom
Germany
Japan
United States

# COUNTRIES / PERFORMANCE SHARE

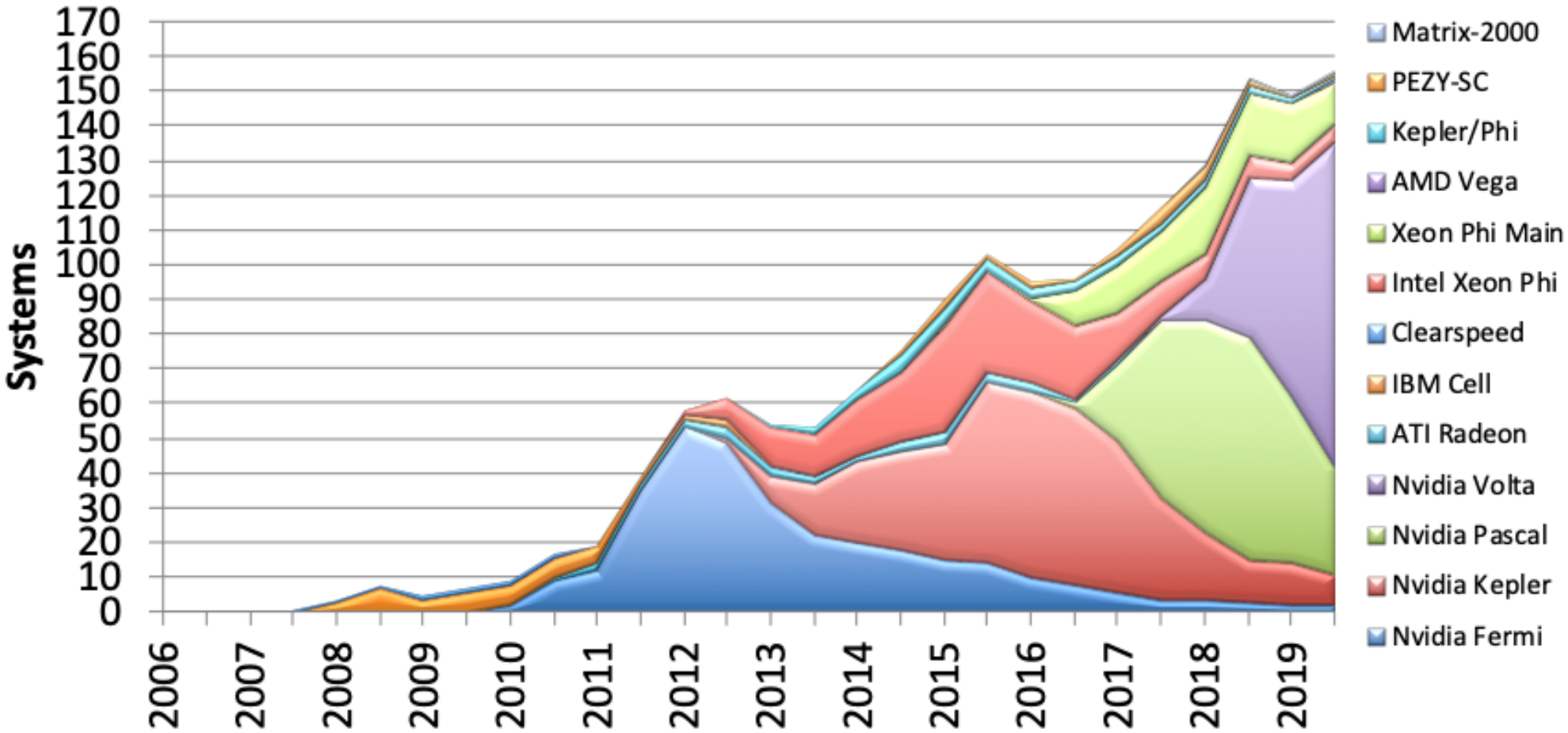


# VENDORS / PERFORMANCE SHARE




Sum of Pflop/s, % of whole list

# ACCELERATORS



# ENERGY EFFICIENCY