[Template:Redirect](/wiki/Template:Redirect" \o "Template:Redirect) [Template:Use dmy dates](/wiki/Template:Use_dmy_dates) [300px|thumb|](/wiki/File:IBM_Blue_Gene_P_supercomputer.jpg)[IBM's](/wiki/IBM) [Blue Gene/P](/wiki/Blue_Gene) supercomputer at [Argonne National Laboratory](/wiki/Argonne_National_Laboratory) runs over 250,000 processors using normal data center air conditioning, grouped in 72 racks/cabinets connected by a high-speed optical network[[1]](#cite_note-1)

A **supercomputer** is a computer with a high-level computational capacity compared to a general-purpose computer. Performance of a supercomputer is measured in [floating-point](/wiki/Floating-point) operations per second ([FLOPS](/wiki/FLOPS)) instead of [million instructions per second](/wiki/Million_instructions_per_second) (MIPS). As of 2015, there are supercomputers which can perform up to quadrillions of FLOPS.[[2]](#cite_note-2) Supercomputers were introduced in the 1960s, made initially, and for decades primarily, by [Seymour Cray](/wiki/Seymour_Cray) at [Control Data Corporation](/wiki/Control_Data_Corporation) (CDC), [Cray Research](/wiki/Cray_Research) and subsequent companies bearing his name or monogram. While the supercomputers of the 1970s used only a few [processors](/wiki/Central_processing_unit), in the 1990s machines with thousands of processors began to appear and, by the end of the 20th century, [massively parallel](/wiki/Massively_parallel_(computing)) supercomputers with tens of thousands of "off-the-shelf" processors were the norm.<ref name=Hoffman>[Template:Cite book](/wiki/Template:Cite_book)</ref><ref name=Jouppi>[Template:Cite book](/wiki/Template:Cite_book)</ref>

As of June 2016 the fastest supercomputer in the world is the [Sunway TaihuLight](/wiki/Sunway_TaihuLight), with a Linpack benchmark of 93 petaFLOPS(PFLOPS), exceeding the previous record holder, [Tianhe-2](/wiki/Tianhe-2), by around 59 PFLOPS.

Supercomputers play an important role in the field of [computational science](/wiki/Computational_science), and are used for a wide range of computationally intensive tasks in various fields, including [quantum mechanics](/wiki/Quantum_mechanics), [weather forecasting](/wiki/Weather_forecasting), [climate research](/wiki/Climate_research), [oil and gas exploration](/wiki/Oil_and_gas_exploration), [molecular modeling](/wiki/Computational_chemistry) (computing the structures and properties of chemical compounds, biological [macromolecules](/wiki/Macromolecules), polymers, and crystals), and physical simulations (such as simulations of the early moments of the universe, airplane and spacecraft aerodynamics, the detonation of [nuclear weapons](/wiki/Nuclear_weapons), and [nuclear fusion](/wiki/Nuclear_fusion)). Throughout their history, they have been essential in the field of [cryptanalysis](/wiki/Cryptanalysis).[[3]](#cite_note-3) Systems with massive numbers of processors generally take one of the two paths: in one approach (e.g., in [distributed computing](/wiki/Distributed_computing)), hundreds or thousands of discrete computers (e.g., [laptops](/wiki/Laptop)) distributed across a network (e.g., the [Internet](/wiki/Internet)) devote some or all of their time to solving a common problem; each individual computer (client) receives and completes many small tasks, reporting the results to a central server which integrates the task results from all the clients into the overall solution.<ref name=Prodan>[Template:Cite book](/wiki/Template:Cite_book)</ref>[[4]](#cite_note-4) In another approach, thousands of dedicated processors are placed in proximity to each other (e.g., in a [computer cluster](/wiki/Computer_cluster)); this saves considerable time moving data around and makes it possible for the processors to work together (rather than on separate tasks), for example in [mesh](/wiki/Mesh_networking) and [hypercube](/wiki/Grid_network) [architectures](/wiki/Computer_architecture).

The use of [multi-core processors](/wiki/Multi-core_processor) combined with [centralization](/wiki/Centralized_computing) is an emerging trend; one can think of this as a small cluster (the multicore processor in a [smartphone](/wiki/Smartphone), [tablet](/wiki/Tablet_computer), laptop, etc.) that both depends upon and contributes to [the cloud](/wiki/Cloud_computing).[[5]](#cite_note-5)[[6]](#cite_note-6)

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## History[[edit](/index.php?title=(none)&action=edit&section=1)]

[Template:Main](/wiki/Template:Main) [thumb|A](/wiki/File:Cray-1-deutsches-museum.jpg) [Cray-1](/wiki/Cray-1) preserved at the [Deutsches Museum](/wiki/Deutsches_Museum) The history of supercomputing goes back to the 1960s, with the [Atlas](/wiki/Atlas_(computer)) at the [University of Manchester](/wiki/Victoria_University_of_Manchester) and a series of computers at [Control Data Corporation](/wiki/Control_Data_Corporation) (CDC), designed by [Seymour Cray](/wiki/Seymour_Cray). These used innovative designs and parallelism to achieve superior computational peak performance.[[7]](#cite_note-7) The [Atlas](/wiki/Atlas_(computer)) was a joint venture between [Ferranti](/wiki/Ferranti) and the Manchester University and was designed to operate at processing speeds approaching one microsecond per instruction, about one million instructions per second.[[8]](#cite_note-8) The first Atlas was officially commissioned on 7 December 1962 as one of the world's first supercomputers [Template:Snd](/wiki/Template:Snd) considered to be the most powerful computer in the world at that time by a considerable margin, and equivalent to four [IBM 7094s](/wiki/IBM_7094).[[9]](#cite_note-9) The [CDC 6600](/wiki/CDC_6600), released in 1964, was designed by Cray to be the fastest in the world. Cray switched from use of germanium to silicon transistors, which could run very fast, solving the overheating problem by introducing refrigeration.[[10]](#cite_note-10) Given that the 6600 outperformed all the other contemporary computers by about 10 times, it was dubbed a *supercomputer* and defined the supercomputing market when one hundred computers were sold at $8 million each.[[11]](#cite_note-11)[[12]](#cite_note-12)[[13]](#cite_note-13)[[14]](#cite_note-14) Cray left CDC in 1972 to form his own company, [Cray Research](/wiki/Cray).[[12]](#cite_note-12) Four years after leaving CDC, Cray delivered the 80 MHz [Cray 1](/wiki/Cray_1) in 1976, and it became one of the most successful supercomputers in history.[[15]](#cite_note-15)[[16]](#cite_note-16) The [Cray-2](/wiki/Cray-2) released in 1985 was an 8 processor [liquid cooled](/wiki/Computer_cooling) computer and [Fluorinert](/wiki/Fluorinert) was pumped through it as it operated. It performed at 1.9 [gigaflops](/wiki/Gigaflop) and was the world's second fastest after M-13 supercomputer in Moscow .[[17]](#cite_note-17)<ref name=Rupak>*Parallel Computational Fluid Dyynamics; Recent Advances and Future Directions* edited by Rupak Biswas 2010 ISBN 1-60595-022-X page 401</ref> The large amount of heat generated by a system may also have other effects, e.g. reducing the lifetime of other system components.[[28]](#cite_note-28) There have been diverse approaches to heat management, from pumping [Fluorinert](/wiki/Fluorinert) through the system, to a hybrid liquid-air cooling system or air cooling with normal [air conditioning](/wiki/Air_conditioning) temperatures.[[29]](#cite_note-29)[[30]](#cite_note-30) [thumb|right|The CPU share of](/wiki/File:Processor_families_in_TOP500_supercomputers.svg) [TOP500](/wiki/TOP500) Systems with a massive number of processors generally take one of two paths. In the [grid computing](/wiki/Grid_computing) approach, the processing power of many computers, organised as distributed, diverse administrative domains, is opportunistically used whenever a computer is available.[[31]](#cite_note-31) In another approach, a large number of processors are used in proximity to each other, e.g. in a [computer cluster](/wiki/Computer_cluster). In such a centralized [massively parallel](/wiki/Massively_parallel) system the speed and flexibility of the interconnect becomes very important and modern supercomputers have used various approaches ranging from enhanced [Infiniband](/wiki/Infiniband) systems to three-dimensional [torus interconnects](/wiki/Torus_interconnect).[[32]](#cite_note-32)[[33]](#cite_note-33) The use of [multi-core processors](/wiki/Multi-core_processor) combined with centralization is an emerging direction, e.g. as in the [Cyclops64](/wiki/Cyclops64) system.[[5]](#cite_note-5)[[6]](#cite_note-6) As the price, performance and energy efficiency of [general purpose graphic processors](/wiki/GPGPU) (GPGPUs) have improved,[[34]](#cite_note-34) a number of [petaflop](/wiki/Petaflop) supercomputers such as [Tianhe-I](/wiki/Tianhe-I) and [Nebulae](/wiki/Nebulae_(computer)) have started to rely on them.[[35]](#cite_note-35) However, other systems such as the [K computer](/wiki/K_computer) continue to use conventional processors such as [SPARC](/wiki/SPARC)-based designs and the overall applicability of [GPGPUs](/wiki/GPGPU) in general-purpose high-performance computing applications has been the subject of debate, in that while a GPGPU may be tuned to score well on specific benchmarks, its overall applicability to everyday algorithms may be limited unless significant effort is spent to tune the application towards it.[[36]](#cite_note-36)[[37]](#cite_note-37) However, GPUs are gaining ground and in 2012 the [Jaguar supercomputer](/wiki/Jaguar_supercomputer) was transformed into [Titan](/wiki/Titan_(supercomputer)) by retrofitting CPUs with GPUs.<ref name=PC>[Template:Cite web](/wiki/Template:Cite_web)</ref>[[38]](#cite_note-38)<ref name=TitanReg>[Template:Cite web](/wiki/Template:Cite_web)</ref>

High performance computers have an expected life cycle of about three years.[[39]](#cite_note-39) A number of "special-purpose" systems have been designed, dedicated to a single problem. This allows the use of specially programmed [FPGA](/wiki/Field-programmable_gate_array) chips or even custom [VLSI](/wiki/Very-large-scale_integration) chips, allowing better price/performance ratios by sacrificing generality. Examples of special-purpose supercomputers include [Belle](/wiki/Belle_(chess_machine)),[[40]](#cite_note-40) [Deep Blue](/wiki/IBM_Deep_Blue),[[41]](#cite_note-41) and [Hydra](/wiki/Hydra_(chess)),[[42]](#cite_note-42) for playing [chess](/wiki/Chess), [Gravity Pipe](/wiki/Gravity_Pipe) for astrophysics,[[43]](#cite_note-43) [MDGRAPE-3](/wiki/MDGRAPE-3) for protein structure computation molecular dynamics[[44]](#cite_note-44) and [Deep Crack](/wiki/Deep_Crack),[[45]](#cite_note-45) for breaking the [DES](/wiki/Data_Encryption_Standard) [cipher](/wiki/Cipher).

### Energy usage and heat management[[edit](/index.php?title=(none)&action=edit&section=3)]

[Template:See also](/wiki/Template:See_also) A typical supercomputer consumes large amounts of electrical power, almost all of which is converted into heat, requiring cooling. For example, [Tianhe-1A](/wiki/Tianhe-1A) consumes 4.04 [megawatts](/wiki/Megawatt) (MW) of electricity.[[46]](#cite_note-46) The cost to power and cool the system can be significant, e.g. 4 MW at $0.10/kWh is $400 an hour or about $3.5 million per year.

[thumb|left|An](/wiki/File:IBM_HS20_blade_server.jpg) [IBM HS20](/wiki/IBM_BladeCenter#HS20) [blade](/wiki/Blade_server) Heat management is a major issue in complex electronic devices, and affects powerful computer systems in various ways.[[47]](#cite_note-47) The [thermal design power](/wiki/Thermal_design_power) and [CPU power dissipation](/wiki/CPU_power_dissipation) issues in supercomputing surpass those of traditional [computer cooling](/wiki/Computer_cooling) technologies. The supercomputing awards for [green computing](/wiki/Green_computing) reflect this issue.[[48]](#cite_note-48)[[49]](#cite_note-49)[[50]](#cite_note-50) The packing of thousands of processors together inevitably generates significant amounts of [heat density](/wiki/Heat_density) that need to be dealt with. The [Cray 2](/wiki/Cray_2) was [liquid cooled](/wiki/Computer_cooling), and used a [Fluorinert](/wiki/Fluorinert) "cooling waterfall" which was forced through the modules under pressure.[[29]](#cite_note-29) However, the submerged liquid cooling approach was not practical for the multi-cabinet systems based on off-the-shelf processors, and in [System X](/wiki/System_X_(computing)) a special cooling system that combined air conditioning with liquid cooling was developed in conjunction with the [Liebert company](/wiki/Liebert_(company)).[[30]](#cite_note-30) In the [Blue Gene](/wiki/Blue_Gene) system, IBM deliberately used low power processors to deal with heat density.[[51]](#cite_note-51)On the other hand, the IBM [Power 775](/wiki/Power_775), released in 2011, has closely packed elements that require water cooling.[[52]](#cite_note-52) The IBM [Aquasar](/wiki/Aquasar) system, on the other hand uses *hot water cooling* to achieve energy efficiency, the water being used to heat buildings as well.[[53]](#cite_note-53)[[54]](#cite_note-54) The energy efficiency of computer systems is generally measured in terms of "FLOPS per [watt](/wiki/Watt)". In 2008, [IBM's Roadrunner](/wiki/IBM_Roadrunner) operated at 3.76 [MFLOPS/W](/wiki/Performance_per_watt).[[55]](#cite_note-55)[[56]](#cite_note-56) In November 2010, the [Blue Gene/Q](/wiki/IBM_Blue_Gene#Blue_Gene/Q) reached 1,684 MFLOPS/W.[[57]](#cite_note-57)[[58]](#cite_note-58) In June 2011 the top 2 spots on the [Green 500](/wiki/Green_500) list were occupied by [Blue Gene](/wiki/Blue_Gene) machines in New York (one achieving 2097 MFLOPS/W) with the [DEGIMA cluster](/wiki/DEGIMA_(computer_cluster)) in Nagasaki placing third with 1375 MFLOPS/W.[[59]](#cite_note-59) Because copper wires can transfer energy into a supercomputer with much higher power densities than forced air or circulating refrigerants can remove waste heat,[[60]](#cite_note-60)the ability of the cooling systems to remove waste heat is a limiting factor.[[61]](#cite_note-61)[[62]](#cite_note-62)[Template:As of](/wiki/Template:As_of), many existing supercomputers have more infrastructure capacity than the actual peak demand of the machine [Template:Snd](/wiki/Template:Snd) designers generally conservatively design the power and cooling infrastructure to handle more than the theoretical peak electrical power consumed by the supercomputer. Designs for future supercomputers are power-limited [Template:Snd](/wiki/Template:Snd) the [thermal design power](/wiki/Thermal_design_power) of the supercomputer as a whole, the amount that the power and cooling infrastructure can handle, is somewhat more than the expected normal power consumption, but less than the theoretical peak power consumption of the electronic hardware.[[63]](#cite_note-63)

## Software and system management[[edit](/index.php?title=(none)&action=edit&section=4)]

### Operating systems[[edit](/index.php?title=(none)&action=edit&section=5)]

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Since the end of the 20th century, [supercomputer operating systems](/wiki/Supercomputer_operating_systems) have undergone major transformations, based on the changes in [supercomputer architecture](/wiki/Supercomputer_architecture).[[64]](#cite_note-64) While early operating systems were custom tailored to each supercomputer to gain speed, the trend has been to move away from in-house operating systems to the adaptation of generic software such as [Linux](/wiki/Linux).[[65]](#cite_note-65) Since modern [massively parallel](/wiki/Massively_parallel) supercomputers typically separate computations from other services by using multiple types of [nodes](/wiki/Locale_(computer_hardware)), they usually run different operating systems on different nodes, e.g. using a small and efficient [lightweight kernel](/wiki/Lightweight_Kernel_Operating_System) such as [CNK](/wiki/CNK_operating_system) or [CNL](/wiki/Compute_Node_Linux) on compute nodes, but a larger system such as a [Linux](/wiki/Linux)-derivative on server and [I/O](/wiki/I/O) nodes.<ref name=EuroPar2004>*Euro-Par 2004 Parallel Processing: 10th International Euro-Par Conference* 2004, by Marco Danelutto, Marco Vanneschi and Domenico Laforenza ISBN 3-540-22924-8 pages 835</ref>[[66]](#cite_note-66)<ref name=Alam>*An Evaluation of the Oak Ridge National Laboratory Cray XT3* by Sadaf R. Alam etal *International Journal of High Performance Computing Applications* February 2008 vol. 22 no. 1 52–80</ref>

While in a traditional multi-user computer system [job scheduling](/wiki/Job_scheduling) is, in effect, a [tasking](/wiki/Task_scheduling) problem for processing and peripheral resources, in a massively parallel system, the job management system needs to manage the allocation of both computational and communication resources, as well as gracefully deal with inevitable hardware failures when tens of thousands of processors are present.[[67]](#cite_note-67) Although most modern supercomputers use the [Linux](/wiki/Linux) operating system, each manufacturer has its own specific Linux-derivative, and no industry standard exists, partly due to the fact that the differences in hardware architectures require changes to optimize the operating system to each hardware design.[[64]](#cite_note-64)[[68]](#cite_note-68)

### Software tools and message passing[[edit](/index.php?title=(none)&action=edit&section=6)]

[Template:Main](/wiki/Template:Main) [Template:See also](/wiki/Template:See_also) [thumb|Wide-angle view of the](/wiki/File:Wide-angle_view_of_the_ALMA_correlator.jpg) [ALMA](/wiki/Atacama_Large_Millimeter_Array) correlator.[[69]](#cite_note-69)

The parallel architectures of supercomputers often dictate the use of special programming techniques to exploit their speed. Software tools for distributed processing include standard [APIs](/wiki/Application_programming_interface) such as [MPI](/wiki/Message_Passing_Interface) and [PVM](/wiki/Parallel_Virtual_Machine), [VTL](/wiki/Virtual_tape_library), and [open source](/wiki/Open_source)-based software solutions such as [Beowulf](/wiki/Beowulf_(computing)).

In the most common scenario, environments such as [PVM](/wiki/Parallel_Virtual_Machine) and [MPI](/wiki/Message_Passing_Interface) for loosely connected clusters and [OpenMP](/wiki/OpenMP) for tightly coordinated shared memory machines are used. Significant effort is required to optimize an algorithm for the interconnect characteristics of the machine it will be run on; the aim is to prevent any of the CPUs from wasting time waiting on data from other nodes. [GPGPUs](/wiki/GPGPU) have hundreds of processor cores and are programmed using programming models such as [CUDA](/wiki/CUDA) or [OpenCL](/wiki/OpenCL).

Moreover, it is quite difficult to debug and test parallel programs. [Special techniques](/wiki/Testing_high-performance_computing_applications) need to be used for testing and debugging such applications.

## Distributed supercomputing[[edit](/index.php?title=(none)&action=edit&section=7)]

### Opportunistic approaches[[edit](/index.php?title=(none)&action=edit&section=8)]

[Template:Main](/wiki/Template:Main)

[thumb|Example architecture of a](/wiki/File:ArchitectureCloudLinksSameSite.png) [grid computing](/wiki/Grid_computing) system connecting many personal computers over the internet Opportunistic Supercomputing is a form of networked [grid computing](/wiki/Grid_computing) whereby a "super virtual computer" of many [loosely coupled](/wiki/Loose_coupling) volunteer computing machines performs very large computing tasks. Grid computing has been applied to a number of large-scale [embarrassingly parallel](/wiki/Embarrassingly_parallel) problems that require supercomputing performance scales. However, basic grid and [cloud computing](/wiki/Cloud_computing) approaches that rely on [volunteer computing](/wiki/Volunteer_computing) can not handle traditional supercomputing tasks such as fluid dynamic simulations.

The fastest grid computing system is the [distributed computing project](/wiki/Distributed_computing_project) [Folding@home](/wiki/Folding@home). F@h reported 43.1 PFLOPS of x86 processing power [Template:As of](/wiki/Template:As_of). Of this, 42.5 PFLOPS are contributed by clients running on various GPUs, and the rest from various CPU systems.[[70]](#cite_note-70) The [BOINC](/wiki/BOINC) platform hosts a number of distributed computing projects. [Template:As of](/wiki/Template:As_of), BOINC recorded a processing power of over 5.5 PFLOPS through over 480,000 active computers on the network[[71]](#cite_note-71) The most active project (measured by computational power), [MilkyWay@home](/wiki/MilkyWay@home), reports processing power of over 700 [teraFLOPS (TFLOPS)](/wiki/FLOPS) through over 33,000 active computers.[[72]](#cite_note-72) [Template:As of](/wiki/Template:As_of), [GIMPS's](/wiki/Great_Internet_Mersenne_Prime_Search) distributed [Mersenne Prime](/wiki/Mersenne_Prime) search achieved [as of 2015](/wiki/As_of_2015) about 60 TFLOPS through over 25,000 registered computers.[[73]](#cite_note-73) The [Internet PrimeNet Server](http://www.mersenne.org/primenet/) supports GIMPS's grid computing approach, one of the earliest and most successful grid computing projects, since 1997.

### Quasi-opportunistic approaches[[edit](/index.php?title=(none)&action=edit&section=9)]

[Template:Main](/wiki/Template:Main)

Quasi-opportunistic supercomputing is a form of [distributed computing](/wiki/Distributed_computing) whereby the “super virtual computer” of many networked geographically disperse computers performs computing tasks that demand huge processing power.<ref name=Kravtsov>[Template:Cite web](/wiki/Template:Cite_web)</ref> Quasi-opportunistic supercomputing aims to provide a higher quality of service than [opportunistic grid computing](/wiki/Grid_computing) by achieving more control over the assignment of tasks to distributed resources and the use of intelligence about the availability and reliability of individual systems within the supercomputing network. However, quasi-opportunistic distributed execution of demanding parallel computing software in grids should be achieved through implementation of grid-wise allocation agreements, co-allocation subsystems, communication topology-aware allocation mechanisms, fault tolerant message passing libraries and data pre-conditioning.[[74]](#cite_note-74)

## Performance measurement[[edit](/index.php?title=(none)&action=edit&section=10)]

### Capability vs capacity[[edit](/index.php?title=(none)&action=edit&section=11)]

Supercomputers generally aim for the maximum in *capability computing* rather than *capacity computing*. Capability computing is typically thought of as using the maximum computing power to solve a single large problem in the shortest amount of time. Often a capability system is able to solve a problem of a size or complexity that no other computer can, e.g. a very complex [weather simulation](/wiki/Weather_simulation) application.[[75]](#cite_note-75) Capacity computing, in contrast, is typically thought of as using efficient cost-effective computing power to solve a few somewhat large problems or many small problems.[[75]](#cite_note-75) Architectures that lend themselves to supporting many users for routine everyday tasks may have a lot of capacity, but are not typically considered supercomputers, given that they do not solve a single very complex problem.[[75]](#cite_note-75)

### Performance metrics[[edit](/index.php?title=(none)&action=edit&section=12)]

[Template:See also](/wiki/Template:See_also) [300px|thumb|Top supercomputer speeds:](/wiki/File:Supercomputing-rmax-graph2.svg) [*logscale*](/wiki/Logarithmic_scale) *speed* over 60 years In general, the speed of supercomputers is measured and [benchmarked](/wiki/Benchmark_(computing)) in "[FLOPS](/wiki/FLOPS)" (*FLoating point Operations Per Second*), and not in terms of "[MIPS](/wiki/Million_instructions_per_second)" (Million Instructions Per Second), as is the case with general-purpose computers.[[76]](#cite_note-76) These measurements are commonly used with an [SI prefix](/wiki/SI_prefix) such as [tera-](/wiki/Tera-), combined into the shorthand "TFLOPS" (1012 FLOPS, pronounced *teraflops*), or [peta-](/wiki/Peta-), combined into the shorthand "PFLOPS" (1015 FLOPS, pronounced *petaflops*.) "[Petascale](/wiki/Petascale)" supercomputers can process one quadrillion (1015) (1000 trillion) FLOPS. [Exascale](/wiki/Exascale_computing) is computing performance in the exaFLOPS (EFLOPS) range. An EFLOPS is one quintillion (1018) FLOPS (one million TFLOPS).

No single number can reflect the overall performance of a computer system, yet the goal of the Linpack benchmark is to approximate how fast the computer solves numerical problems and it is widely used in the industry.[[77]](#cite_note-77) The FLOPS measurement is either quoted based on the theoretical floating point performance of a processor (derived from manufacturer's processor specifications and shown as "Rpeak" in the TOP500 lists) which is generally unachievable when running real workloads, or the achievable throughput, derived from the [LINPACK benchmarks](/wiki/LINPACK_benchmarks) and shown as "Rmax" in the TOP500 list. The LINPACK benchmark typically performs [LU decomposition](/wiki/LU_decomposition) of a large matrix. The LINPACK performance gives some indication of performance for some real-world problems, but does not necessarily match the processing requirements of many other supercomputer workloads, which for example may require more memory bandwidth, or may require better integer computing performance, or may need a high performance I/O system to achieve high levels of performance.[[77]](#cite_note-77)

### The TOP500 list[[edit](/index.php?title=(none)&action=edit&section=13)]

[Template:Main](/wiki/Template:Main) [thumb|right|350px|Distribution of top 500 supercomputers among different countries, as of November 2015](/wiki/File:Supercomputer_Share_Top500_November2015.png) Since 1993, the fastest supercomputers have been ranked on the TOP500 list according to their [LINPACK benchmark](/wiki/LINPACK_benchmarks) results. The list does not claim to be unbiased or definitive, but it is a widely cited current definition of the "fastest" supercomputer available at any given time.

This is a recent list of the computers which appeared at the top of the TOP500 list,[[78]](#cite_note-78) and the "Peak speed" is given as the "Rmax" rating. For more historical data see [History of supercomputing](/wiki/History_of_supercomputing).

[500px|thumb|Top 20 Supercomputers in the World, as of June 2013](/wiki/File:Top20supercomputers.png)

|  |  |  |  |
| --- | --- | --- | --- |
| **Year** | **Supercomputer** | [**Peak speed (Rmax)**](/wiki/FLOPS) | **Location** |
| 2016 | [Sunway TaihuLight](/wiki/Sunway_TaihuLight) | align=right|93.01 PFLOPS | [Wuxi](/wiki/Wuxi), China |
| 2013 | [NUDT](/wiki/National_University_of_Defense_Technology) [Tianhe-2](/wiki/Tianhe-2) | align=right|33.86 PFLOPS | [Guangzhou](/wiki/Guangzhou), China |
| 2012 | [Cray](/wiki/Cray) [Titan](/wiki/Titan_(supercomputer)) | align=right|17.59 PFLOPS | [Oak Ridge](/wiki/Oak_Ridge,_Tennessee), U.S. |
| 2012 | [IBM](/wiki/IBM) [Sequoia](/wiki/IBM_Sequoia) | align=right|17.17 PFLOPS | [Livermore](/wiki/Livermore,_California), U.S. |
| 2011 | [Fujitsu](/wiki/Fujitsu) [K computer](/wiki/K_computer) | align=right|10.51 PFLOPS | [Kobe](/wiki/Kobe), Japan |
| 2010 | [Tianhe-IA](/wiki/Tianhe-I) | align=right|2.566 PFLOPS | [Tianjin](/wiki/Tianjin), China |
| 2009 | [Cray](/wiki/Cray) [Jaguar](/wiki/Jaguar_(computer)) | align=right|1.759 PFLOPS | [Oak Ridge](/wiki/Oak_Ridge_National_Laboratory), U.S. |
| 2008 | [IBM](/wiki/IBM) [Roadrunner](/wiki/IBM_Roadrunner) | align=right|1.026 PFLOPS | [Los Alamos](/wiki/Los_Alamos_National_Laboratory), U.S. |
| align=right|1.105 PFLOPS |
|  |  |  |  |

## Largest Supercomputer Vendors according to the total [http://www.top500.org/project/top500\_description/ Rmax] (GFLOPS) operated[[edit](/index.php?title=(none)&action=edit&section=14)]

Source : [TOP500](http://www.top500.org/statistics/list/)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Country/Vendor** | **System count** | **System share (%)** | **Rmax (GFLOPS)** | **Rpeak (GFLOPS)** | **Processor cores** |
| [Template:Flagicon](/wiki/Template:Flagicon) [IBM](/wiki/IBM) | 153 | 30.6 | 87,143,814 | 122,311,749 | 7,346,514 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Cray Inc.](/wiki/Cray_Inc.) | 62 | 12.4 | 68,198,477 | 97,027,365 | 3,583,180 |
| [Template:Flagicon](/wiki/Template:Flagicon) [HP](/wiki/Hewlett-Packard) | 179 | 35.8 | 44,855,405 | 73,630,508 | 3,747,812 |
| [Template:Flagicon](/wiki/Template:Flagicon) [NUDT](/wiki/NUDT) | 5 | 1 | 39,483,490 | 64,356,373 | 3,547,648 |
| [Template:Flagicon](/wiki/Template:Flagicon) [SGI](/wiki/Silicon_Graphics) | 23 | 4.6 | 14,741,773 | 17,963,102 | 813,376 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Fujitsu](/wiki/Fujitsu) | 8 | 1.6 | 13,719,473 | 14,981,840 | 915,974 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Bull](/wiki/Groupe_Bull) | 18 | 3.6 | 10,094,490 | 12,564,851 | 588,120 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Dell](/wiki/Dell) | 9 | 1.8 | 8,003,573 | 12,687,479 | 618,396 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Atipa Technologies](/wiki/Atipa_Technologies) | 3 | 0.6 | 3,044,976 | 4,163,712 | 214,584 |
| [Template:FlagiconTemplate:Flagicon](/wiki/Template:Flagicon) [NEC](/wiki/NEC)/[HP](/wiki/Hewlett-Packard) | 1 | 0.2 | 2,785,000 | 5,735,685 | 76,032 |
| [Template:Flagicon](/wiki/Template:Flagicon) [T-Platforms](/wiki/T-Platforms) | 2 | 0.4 | 2,750,900 | 4,276,082 | 115,780 |
| [Template:Flagicon](/wiki/Template:Flagicon) [RSC Group](/wiki/RSC_Group) | 4 | 0.8 | 1,492,512 | 2,399,433 | 99,200 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Dawning](/wiki/Dawning) | 2 | 0.4 | 1,451,600 | 3,217,772 | 151,360 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Hitachi](/wiki/Hitachi)/[Fujitsu](/wiki/Fujitsu) | 1 | 0.2 | 1,018,000 | 1,502,236 | 222,072 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Supermicro](/wiki/Supermicro) | 1 | 0.2 | 798,261 | 3,164,480 | 160,600 |
| [Template:Flagicon](/wiki/Template:Flagicon) [NRCPCET](/wiki/Sunway) | 1 | 0.2 | 795,900 | 1,070,160 | 137,200 |
| [Template:Flagicon](/wiki/Template:Flagicon) [ClusterVision](/wiki/ClusterVision) | 2 | 0.4 | 784,735 | 881,254 | 42,368 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Intel](/wiki/Intel) | 1 | 0.2 | 758,873 | 933,481 | 51,392 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Amazon](/wiki/Amazon.com) | 2 | 0.4 | 724,269 | 947,610 | 43,520 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Oracle](/wiki/Sun_Microsystems) | 2 | 0.4 | 708,300 | 804,835 | 68,672 |
| [Template:Flagicon](/wiki/Template:Flagicon) [MEGWARE](/wiki/MEGWARE) | 3 | 0.6 | 610,521 | 710,592 | 54,800 |
| [Template:Flagicon](/wiki/Template:Flagicon) [NEC](/wiki/NEC) | 3 | 0.6 | 578,987 | 709,520 | 21,296 |
| [Template:Flagicon](/wiki/Template:Flagicon) Adtech | 1 | 0.2 | 532,600 | 1,098,000 | 38,400 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Hitachi](/wiki/Hitachi) | 2 | 0.4 | 496,900 | 622,598 | 20,544 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [IPE](/wiki/Chinese_Academy_of_Sciences), [Nvidia](/wiki/Nvidia), [Tyan](/wiki/Tyan) | 1 | 0.2 | 496,500 | 1,012,650 | 29,440 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Itautec](/wiki/Itautec) | 2 | 0.4 | 411,800 | 920,830 | 27,776 |
| [Template:Flagicon](/wiki/Template:Flagicon) Netweb Technologies | 1 | 0.2 | 388,442 | 520,358 | 30,056 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Xenon Systems](/wiki/Xenon_Systems) | 1 | 0.2 | 335,300 | 472,498 | 6,875 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [AMD](/wiki/AMD), [ASUS](/wiki/ASUS), [FIAS](/wiki/Frankfurt_Institute_for_Advanced_Studies), [GSI](/wiki/GSI_Helmholtz_Centre_for_Heavy_Ion_Research) | 1 | 0.2 | 316,700 | 593,600 | 10,976 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [Clustervision/Supermicro](/wiki/Clustervision/Supermicro) | 1 | 0.2 | 299,300 | 588,749 | 44,928 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [Niagara Computers](/wiki/Niagara_Computers), [Supermicro](/wiki/Supermicro) | 1 | 0.2 | 289,500 | 348,660 | 5,310 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Inspur](/wiki/Inspur) | 1 | 0.2 | 196,234 | 262,560 | 8,412 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [HP](/wiki/Hewlett-Packard)/[WIPRO](/wiki/WIPRO) | 1 | 0.2 | 188,700 | 394,760 | 12,532 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Template:Flagicon](/wiki/Template:Flagicon) [PEZY Computing](/wiki/PEZY_Computing)/[Exascaler Inc.](/wiki/Exascaler_Inc.) | 1 | 0.2 | 178,107 | 395,264 | 262,784 |
| [Template:Flagicon](/wiki/Template:Flagicon) [Acer Group](/wiki/Acer_Group) | 1 | 0.2 | 177,100 | 231,859 | 26,244 |
|  |  |  |  |  |  |

## Applications[[edit](/index.php?title=(none)&action=edit&section=15)]

The stages of supercomputer application may be summarized in the following table:

|  |  |
| --- | --- |
| **Decade** | **Uses and computer involved** |
| 1970s | Weather forecasting, aerodynamic research ([Cray-1](/wiki/Cray-1)).[[79]](#cite_note-79) |
| 1980s | Probabilistic analysis,[[80]](#cite_note-80) radiation shielding modeling[[81]](#cite_note-81) ([CDC Cyber](/wiki/CDC_Cyber)). |
| 1990s | Brute force code breaking ([EFF DES cracker](/wiki/EFF_DES_cracker)).[[82]](#cite_note-82) |
| 2000s | 3D nuclear test simulations as a substitute for legal conduct [Nuclear Non-Proliferation Treaty](/wiki/Nuclear_Non-Proliferation_Treaty) ([ASCI Q](/wiki/ASCI_Q)).[[83]](#cite_note-83) |
| 2010s | Molecular Dynamics Simulation ([Tianhe-1A](/wiki/Tianhe-1A))[[84]](#cite_note-84) |

The IBM [Blue Gene](/wiki/Blue_Gene)/P computer has been used to simulate a number of artificial neurons equivalent to approximately one percent of a human cerebral cortex, containing 1.6 billion neurons with approximately 9 trillion connections. The same research group also succeeded in using a supercomputer to simulate a number of artificial neurons equivalent to the entirety of a rat's brain.[[85]](#cite_note-85) Modern-day weather forecasting also relies on supercomputers. The [National Oceanic and Atmospheric Administration](/wiki/National_Oceanic_and_Atmospheric_Administration) uses supercomputers to crunch hundreds of millions of observations to help make weather forecasts more accurate.[[86]](#cite_note-86) In 2011, the challenges and difficulties in pushing the envelope in supercomputing were underscored by [IBM's](/wiki/IBM) abandonment of the [Blue Waters](/wiki/Blue_Waters) petascale project.[[87]](#cite_note-87) The [Advanced Simulation and Computing Program](/wiki/Advanced_Simulation_and_Computing_Program) currently uses supercomputers to maintain and simulate the United States nuclear stockpile.

## Research and development trends[[edit](/index.php?title=(none)&action=edit&section=16)]

[thumb|Diagram of a 3-dimensional](/wiki/File:2x2x2torus.svg) [torus interconnect](/wiki/Torus_interconnect) used by systems such as Blue Gene, Cray XT3, etc.

Given the current speed of progress, industry experts estimate that supercomputers will reach 1 [EFLOPS](/wiki/Exascale_computing) (1018, 1,000 PFLOPS or one quintillion FLOPS) by 2018. The Chinese government in particular is pushing to achieve this goal after they briefly achieved the most powerful supercomputer in the world with Tianhe-1A in 2010 (ranked fifth by 2012).[[88]](#cite_note-88) Using the [Intel MIC](/wiki/Intel_MIC) multi-core processor architecture, which is Intel's response to GPU systems, SGI also plans to achieve a 500-fold increase in performance by 2018 in order to achieve one EFLOPS. Samples of MIC chips with 32 cores, which combine vector processing units with standard CPU, have become available.[[89]](#cite_note-89) The Indian government has also stated ambitions for an EFLOPS-range supercomputer, which they hope to complete by 2017.[[90]](#cite_note-90) In November 2014, it was reported that India is working on the fastest supercomputer ever, which is set to work at 132 EFLOPS.[[91]](#cite_note-91) Erik P. DeBenedictis of [Sandia National Laboratories](/wiki/Sandia_National_Laboratories) theorizes that a zettaFLOPS (1021, one sextillion FLOPS) computer is required to accomplish full [weather modeling](/wiki/Weather_forecasting), which could cover a two-week time span accurately.[[92]](#cite_note-92)[Template:Failed verification](/wiki/Template:Failed_verification) Such systems might be built around 2030.[[93]](#cite_note-93) Many [Monte Carlo simulations](/wiki/Monte_Carlo_method) use the same algorithm to process a randomly generated data set; particularly, [integro-differential equations](/wiki/Integro-differential_equation) describing [physical transport processes](/wiki/Transport_phenomena), the [random paths](/wiki/Random_walk), collisions, and energy and momentum depositions of neutrons, photons, ions, electrons, etc. [Template:AnchorThe](/wiki/Template:Anchor) next step for microprocessors may be into the [third dimension](/wiki/Three-dimensional_integrated_circuit); and specializing to Monte Carlo, the many layers could be identical, simplifying the design and manufacture process.[[94]](#cite_note-94)

## Energy use[[edit](/index.php?title=(none)&action=edit&section=17)]

High performance supercomputers usually require high energy, as well. However, Iceland may be a benchmark for the future with the world's first zero-emission supercomputer. Located at the Thor Data Center in Reykjavik, Iceland, this supercomputer relies on completely renewable sources for its power rather than fossil fuels. The colder climate also reduces the need for active cooling, making it one of the greenest facilities in the world.[[95]](#cite_note-95)

## In fiction[[edit](/index.php?title=(none)&action=edit&section=18)]

[Template:Main](/wiki/Template:Main)

Many Science Fiction writers depicted supercomputers in their works, both before and after such computers were actually constructed. Much of such fiction deals with the relations of humans with the computers they created and the possibility of conflict eventually developing between them. Some such scenarios can be found on the [AI takeover](/wiki/AI_takeover) page.

## See also[[edit](/index.php?title=(none)&action=edit&section=19)]

[Template:Commons category](/wiki/Template:Commons_category)

* [ACM/IEEE Supercomputing Conference](/wiki/ACM/IEEE_Supercomputing_Conference)
* [Jungle computing](/wiki/Jungle_computing)
* [Nvidia Tesla Personal Supercomputer](/wiki/Nvidia_Tesla_Personal_Supercomputer)
* [Parallel computing](/wiki/Parallel_computing)
* [Supercomputing in China](/wiki/Supercomputing_in_China)
* [Supercomputing in Europe](/wiki/Supercomputing_in_Europe)
* [Supercomputing in India](/wiki/Supercomputing_in_India)
* [Supercomputing in Japan](/wiki/Supercomputing_in_Japan)
* [Supercomputing in Pakistan](/wiki/Supercomputing_in_Pakistan)
* [Ultra Network Technologies](/wiki/Ultra_Network_Technologies)
* [Testing high-performance computing applications](/wiki/Testing_high-performance_computing_applications)

## Notes and references[[edit](/index.php?title=(none)&action=edit&section=20)]

[Template:Reflist](/wiki/Template:Reflist)

## External links[[edit](/index.php?title=(none)&action=edit&section=21)]

* [A Tunable, Software-based DRAM Error Detection and Correction Library for HPC](http://www.fiala.me/pubs/papers/libsdc11.pdf)
* [Detection and Correction of Silent Data Corruption for Large-Scale High-Performance Computing](http://www.fiala.me/pubs/papers/sc12-redmpi.pdf)

[Template:Parallel computing](/wiki/Template:Parallel_computing) [Template:Computer sizes](/wiki/Template:Computer_sizes)

[Template:Portal bar](/wiki/Template:Portal_bar)

[Template:Authority control](/wiki/Template:Authority_control)

[Template:DEFAULTSORT:Supercomputer](/wiki/Template:DEFAULTSORT:Supercomputer) [Category:Supercomputers](/wiki/Category:Supercomputers) [Category:American inventions](/wiki/Category:American_inventions) [Category:Cluster computing](/wiki/Category:Cluster_computing) [Category:Concurrent computing](/wiki/Category:Concurrent_computing) [Category:Distributed computing architecture](/wiki/Category:Distributed_computing_architecture) [Category:Parallel computing](/wiki/Category:Parallel_computing)