

### 3.Supercomputer – Science & Technology

Supercomputers are powerful systems using parallel computing to solve massive calculations, a field where India is advancing through its National Supercomputing Mission. As Europe launches its first exascale machine, JUPITER, it highlights the global race for computational dominance in science, defense, and AI.

#### Introduction – A New Era in European Computing

Recently, JUPITER in Germany was inaugurated, marking a significant milestone as Europe's first exascale supercomputer. This development highlights the rapid advancements and growing importance of high-performance computing worldwide.

#### Supercomputers

**Definition** – A supercomputer is a highly advanced computing system engineered to perform extremely large-scale, complex, and calculation-intensive tasks that are beyond the capabilities of ordinary computers.

**Core Principle – Parallel Computing** – Instead of using a single processor, supercomputers employ thousands to millions of processors (CPUs and GPUs) that work simultaneously. This parallel computing architecture allows a complex problem to be broken down into smaller portions, which are solved independently and simultaneously. The results are then aggregated for a much faster and more efficient final computation.

#### Structure and Components

Supercomputers are intricate systems built from several specialized components working in unison.

**Processors** – They use a combination of Central Processing Units (CPUs) for general tasks and Graphics Processing Units (GPUs), which are highly efficient at handling the repetitive mathematical operations common in scientific simulations.

**Nodes** – Processors are grouped with memory to form nodes, which act as small, individual computing units. A supercomputer contains thousands of these nodes.

**High-Speed Network** – All nodes are interconnected via ultra-fast data links, enabling seamless and rapid data exchange between them, which is crucial for parallel processing.

**Memory and Storage** – Each node has its own local memory. Additionally, supercomputers are equipped with massive, large-scale storage systems capable of handling petabytes of data, ensuring that read/write operations across thousands of nodes occur in an orderly fashion.

**Cooling Systems** – The immense computational work generates enormous heat. Advanced cooling solutions like liquid immersion, intricate water pipe systems, or powerful refrigeration units are essential to prevent overheating and maintain operational stability.

**Power Supply** – These machines are power-intensive, consuming megawatts of electricity—often equivalent to the power needs of a small town. This requires a robust and efficient power distribution infrastructure.

#### Software, Performance, and User Interaction

##### 1. Software and Task Management –

**Parallel Programming** – Specialized languages like Message Passing Interface (MPI) and OpenMP are used to write code that can schedule tasks effectively across millions of processors.

**Load Balancing** – Sophisticated algorithms ensure that the computational workload is distributed evenly among all processors, preventing any from being idle while others are overloaded.

**Job Scheduling** – Users do not interact with the machine directly. They submit job scripts remotely, specifying their computational needs. A scheduler then assigns these tasks to available nodes, optimizing the overall efficiency of the system.

**Performance Metrics** – Performance is measured in flops (floating-point operations per second). The most powerful supercomputers, known as exascale machines, can perform over an exaflop—a quintillion (10<sup>18</sup>) operations per second.

## 2. User Interaction –

**Remote Access –** Scientists and researchers access supercomputers via secure networks, typically using terminal interfaces rather than a graphical user interface (GUI).

**Data Output –** The results of the computations are stored in the supercomputer's file system. Users can then download this data for detailed analysis and visualization.

### Difference Between Supercomputers and Normal Computers

Feature	Normal Computer	Supercomputer
<b>Purpose</b>	Daily tasks like browsing, typing, or gaming.	Large-scale scientific, industrial, and defence computations.
<b>Processing</b>	Single or few processors.	Thousands to millions of processors working in parallel.
<b>Speed</b>	Billions of FLOPS.	Exaflops (quintillions of operations per second).
<b>Memory &amp; Storage</b>	Gigabytes (GBs) to Terabytes (TBs).	Petabytes (PBs) with specialized high-speed file systems.
<b>Cooling</b>	Standard air cooling (fans).	Advanced liquid cooling, water pipes, or refrigeration.
<b>Electricity Use</b>	Minimal (watts).	Megawatts, equivalent to a small town.
<b>User Access</b>	Direct, GUI-based.	Remote, terminal-based, managed by a job scheduler.

### India's Journey in Supercomputing

**Origins –** India's journey began in the late 1980s after being denied access to high-end supercomputers by Western nations. This led to the establishment of the Centre for Development of Advanced Computing (C-DAC) in 1988 to spearhead indigenous development.

**The PARAM Series –** In 1991, India launched PARAM 8000, its first homegrown supercomputer, which was a pioneer in using parallel computing architectures.

**National Supercomputing Mission (NSM) –** Launched in 2015 by the Department of Science and Technology (DST) and the Ministry of Electronics and Information Technology (MeitY). Its goal is to establish a network of over 70 High-Performance Computing (HPC) facilities across the country.

### Key Installations –

**AIRAWAT-PSAI –** India's AI-focused supercomputer at C-DAC, Pune, which has been ranked among the world's top 100 most powerful systems.

**Pratyush & Mihir –** Twin supercomputers installed at IITM (Pune) and NCMRWF (Noida) respectively, dedicated to weather forecasting, climate modeling, and other earth science simulations.

**Technological Collaboration –** India is fostering indigenous capabilities through partnerships with IISc, IITs, and private vendors to develop hardware like Rudra servers and AUM HPC nodes.

### Significance and Need for Supercomputers

#### Significance –

- Scientific Advancement –** Enables complex simulations in fields like cosmology, molecular dynamics, and climate change.
- Defence & Security –** Crucial for war-game simulations, nuclear research, and strategic planning.
- Technological Leadership –** A symbol of national innovation and technological prowess, boosting global competitiveness.
- Disaster Management –** Aids in accurate monsoon prediction, flood modeling, and earthquake simulations, which can save lives.

#### Need –

- Data-Intensive Research –** Modern science generates massive datasets that require high-performance computation for analysis.
- AI and Machine Learning –** Training large neural networks and complex AI models is only feasible on HPC platforms.
- Climate and Weather Forecasting –** Accurate and timely predictions depend on high-speed simulations and real-time data analysis.

4. **Global Competitiveness** – Nations with advanced supercomputing capabilities have a significant edge in strategic, economic, and scientific domains.

#### Global Initiatives and World Best Practices

**Exascale Computing** – The new frontier, with machines like JUPITER (Germany), which not only achieve over 1 exaflop but also focus on using renewable energy.

**Neuromorphic Computing** – Brain-inspired architectures that integrate processing and memory on a single chip, leading to dramatic improvements in speed and energy efficiency.

**Quantum Computing Integration** – Future simulations may be offloaded to quantum systems, which could solve certain problems far more efficiently, reducing hardware and energy demands.

**International Collaborations** – Partnerships like PRACE (Partnership for Advanced Computing in Europe) and INCITE (USA) promote global access to supercomputing resources and foster scientific collaboration.

Source – <https://www.thehindu.com/sci-tech/technology/how-different-are-supercomputers-to-normal-computers/article70076989.ece>

