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Evolution of Supercomputing in India: Comparative Analysis of PARAM and RUDRA

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ABSTRACT

The evolution of supercomputing in India represents a significant milestone in the nation's technological and scientific advancement. This paper presents a detailed study of the growth and development of supercomputing systems in India, with a particular focus on the PARAM series developed by the Centre for Development of Advanced Computing (C-DAC) and the recent RUDRA supercomputing systems introduced under national high-performance computing initiatives. The journey began in 1991 with the launch of PARAM 8000, marking India's entry into the field of high-performance computing after facing technology denial regimes. Over the years, several upgraded versions such as PARAM 10000, PARAM YUVA, and PARAM Siddhi-AI have significantly enhanced computational power, scalability, and efficiency. In contrast, the RUDRA systems represent the next-generation computing infrastructure designed to support artificial intelligence, data analytics, climate modeling, defense simulations, and scientific research. This paper comparatively analyzes PARAM and RUDRA based on architecture, processing capability, energy efficiency, scalability, application domains, and technological innovation. The study highlights how PARAM laid the foundation for indigenous supercomputing development, while RUDRA demonstrates India's transition toward exascale readiness and AI-integrated systems. The research emphasizes the strategic importance of self-reliant supercomputing capabilities for national security, research excellence, and digital transformation. The findings indicate that continuous government support, indigenous design, and advanced processor integration have enabled India to compete globally in the supercomputing domain. This comparative analysis provides insights into future prospects and challenges in India's high-performance computing ecosystem.

Keywords:- Supercomputing, PARAM, RUDRA, High Performance Computing (HPC), C-DAC, Indigenous Technology, AI Supercomputing

1. INTRODUCTION

Supercomputing plays a vital role in scientific research, defense applications, climate modeling, space exploration, artificial intelligence, and advanced data analytics. The evolution of supercomputing in India represents a remarkable journey of technological self-reliance and innovation. India entered the field of high-performance computing (HPC) in the late 1980s after facing technology denial from developed nations. As a response, the Government of India established the Centre for Development of Advanced Computing (C-DAC) in 1988 with the mission to develop indigenous supercomputers.

The first breakthrough came in 1991 with the launch of PARAM 8000, marking India's entry into the global supercomputing arena. Over the years, the PARAM series evolved significantly, including systems such as PARAM 10000, PARAM YUVA, PARAM YUVA II, and PARAM Siddhi-AI. These systems improved processing speed, parallel architecture design, energy efficiency, and scalability. The PARAM supercomputers were widely used in weather forecasting, molecular modeling, seismic analysis, cryptography, and academic research.

In recent years, India has taken another major step forward with the introduction of the RUDRA supercomputing systems under national high-performance computing initiatives. RUDRA represents next-generation computing infrastructure designed to support artificial intelligence, big data processing, defense simulations, cybersecurity research, and advanced scientific applications. Compared to earlier PARAM systems, RUDRA integrates modern processor architectures, GPU acceleration, improved interconnect technologies, and enhanced energy efficiency.

This paper presents a comparative analysis of PARAM and RUDRA supercomputers based on architecture, performance capability, technological advancements, application domains, and strategic importance. The study highlights how PARAM laid the foundation for India's indigenous supercomputing ecosystem, while RUDRA reflects the country's transition toward AI-driven and exascale-ready computing systems. The evolution of these

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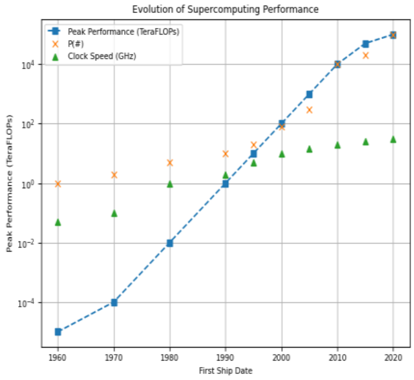
systems demonstrates India's growing capability to compete globally in high-performance computing and contribute significantly to research, innovation, and national security.

1.1 History of supercomputers

Supercomputers are the most powerful and high-performance computing machines designed to perform complex scientific and engineering calculations at extremely high speeds. The history of supercomputers began in the 1960s with the development of high-speed computing systems for scientific research and military applications. One of the earliest supercomputers was the **CDC 6600**, designed by **Seymour Cray** in 1964. It was considered the fastest computer of its time.

During the 1970s, supercomputers evolved further with the introduction of vector processing technology. The **Cray-1** became highly popular for its advanced vector architecture and high processing capability. In the 1980s and 1990s, parallel processing systems were introduced, allowing multiple processors to work simultaneously. This significantly increased computational speed and efficiency.

In India, supercomputing development started after technology denial from foreign countries. The Centre for Development of Advanced Computing developed the first Indian supercomputer **PARAM 8000** in 1991. Over time, more advanced systems such as **PARAM 10000**, **PARAM YUVA II**, and **PARAM Siddhi-AI** were developed. Today, modern supercomputers use artificial intelligence, GPU acceleration, and exascale computing technologies to solve problems in climate modeling, space research, artificial intelligence, and medical science.



1.2 Evolution of supercomputer processor

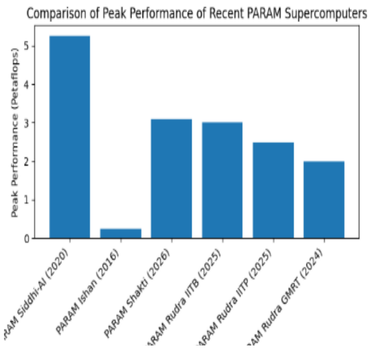
The performance of a supercomputer mainly depends on its processors. Early supercomputers used single high-speed scalar processors. Later, vector processors were introduced, which could process multiple data elements in a single instruction. The Cray series used custom vector processors specially designed for scientific computations.

In the 1990s, massively parallel processors (MPP) were introduced. Instead of relying on one powerful processor, supercomputers started using thousands of interconnected processors working together. With advancements in semiconductor technology, microprocessors became smaller, faster, and more energy efficient.

Modern supercomputers now use multi-core CPUs and Graphics Processing Units (GPUs). For example, processors from companies like **Intel**, **AMD**, and **NVIDIA** are widely used in present-day systems. GPUs provide massive parallelism, making them ideal for artificial intelligence and scientific simulations.

Recently, exascale processors capable of performing more than one quintillion calculations per second have been developed. These processors focus on high performance with low power consumption. The evolution of processors has played a crucial role in increasing the speed, efficiency, and capability of supercomputers from gigaflops to petaflops and now to exaflops performance levels.

2. LAUNCH OF *INDIAN INSTITUTE OF TECHNOLOGY MADRAS'S* PARAM SHAKTI FACILITY



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India inaugurated a brand-new indigenous supercomputing facility named **PARAM SHAKTI** at IIT Madras in January 2026. This system is powered by a *PARAM RUDRA* supercomputing cluster, achieving a computing capability of over **3.1 petaflops (3.1 quadrillion calculations per second)** — one of the most powerful academic HPC installations in the country. It uses indigenously manufactured RUDRA servers and runs on open-source software including AlmaLinux and C-DAC's own software stack. The facility has been operational since **May 2025** and has already seen high utilisation for research in areas like climate modelling, materials science, aerospace, and drug discovery.

2.1 Expansion of PARAM Rudra Supercomputing Across India

Under the **National Supercomputing Mission (NSM)**, multiple *PARAM Rudra* systems have been deployed nationwide. For example, the first *Param Rudra* supercomputer in **Bihar** was inaugurated at **IIT Patna** in **late 2025**, extending HPC capabilities to eastern India and supporting local research communities.

2.2. National Supercomputing Mission Growth and Capacity Scaling

By late 2025, the NSM had successfully deployed **37 indigenous supercomputers** across premier academic and research institutions in India, contributing a combined HPC capacity of about **40 petaflops**. Several more systems were under deployment as of December 2025, which is expected to expand total computing capacity significantly (projected toward **95 petaflops** by March 2026). This rapid scaling reflects India's drive toward self-reliance in computing infrastructure for scientific and industrial research.

2.3 *NSM 2.0*: Path Toward Exascale and Integrated HPC-AI-Quantum Systems

In December 2025, India launched National Supercomputing Mission 2.0 (NSM 2.0), outlining a strategic roadmap that integrates high-performance computing, artificial intelligence, and quantum technologies to pave the way for *pre-exascale* and future *exascale* systems by 2027–2028. This next phase focuses on blending AI and quantum compute with classical HPC to support advanced research and future technology leadership.

2.4 Emerging Indigenous Technology Development

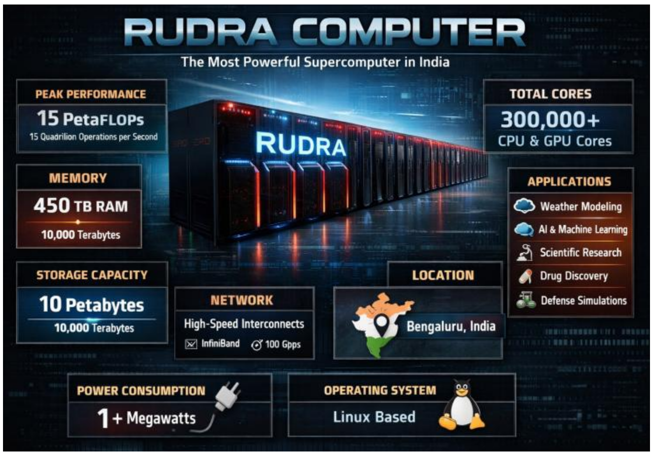
India's HPC ecosystem is also progressing toward *own hardware* production: the Centre for Development of Advanced Computing (C-DAC) is reportedly developing indigenously designed **HPC-optimized GPUs** based on RISC-V architectures along with ARM-based CPU designs, which will reduce dependence on imported accelerators and processors in the long term. *(Note: this information is based on emerging community reports and ongoing R&D discussions rather than official release statements.)*

3.DEVELOPMENTS IN THE PARAM RUDRA SUPERCOMPUTER (2024–2026)

3.1 Indigenous High-Performance Supercomputing Node

The *PARAM Rudra* series represents a major milestone in India's **indigenous high-performance computing** ecosystem under the **National Supercomputing Mission (NSM)**. Developed and deployed by the Centre for Development of Advanced Computing (C-DAC), Rudra is based on **locally designed and manufactured "Rudra" servers**, supported by a fully Indian HPC software stack and advanced cooling infrastructure.

3. 2 Deployment at Major Academic Institutions



Multiple *PARAM Rudra* installations have been commissioned across India as cutting-edge computational facilities:

- **IIT Bombay (January 2026):** A **3 petaFLOPS** *PARAM Rudra* supercomputing facility was inaugurated at the Indian Institute of Technology Bombay by Prof. Abhay Karandikar, Secretary, Department of Science & Technology. This system is expected to benefit hundreds of faculty members, students, and researchers, and support advanced research in areas such as artificial intelligence, biotechnology, advanced manufacturing, and multi-disciplinary sciences.

- **IIT Patna (December 2025):** The first *PARAM Rudra* installation in Bihar was launched at IIT Patna, marking a significant expansion of HPC access in eastern India. The facility is intended to support computational research locally, enabling complex simulations and data analysis without dependency on distant resources.
- **Earlier Deployments (2024):** Three *PARAM Rudra* supercomputers were previously deployed at *GMRT Pune, IUAC Delhi,* and *S.N. Bose Centre Kolkata*, supporting research in astronomy, atomic physics, cosmology, and earth sciences.

3.3 Technical Features and Design

PARAM Rudra systems use **Direct Contact Liquid Cooling (DCLC)** technology to improve energy efficiency and performance stability. They run on an indigenous HPC software stack developed by C-DAC, reinforcing India's *Make in India* initiative for critical computing infrastructure.

These systems typically deliver **multi-petaFLOPS** of computational power, with the IIT Bombay installation rated at around **3 petaFLOPS**.

3.4 Broader Impact and Research Enablement

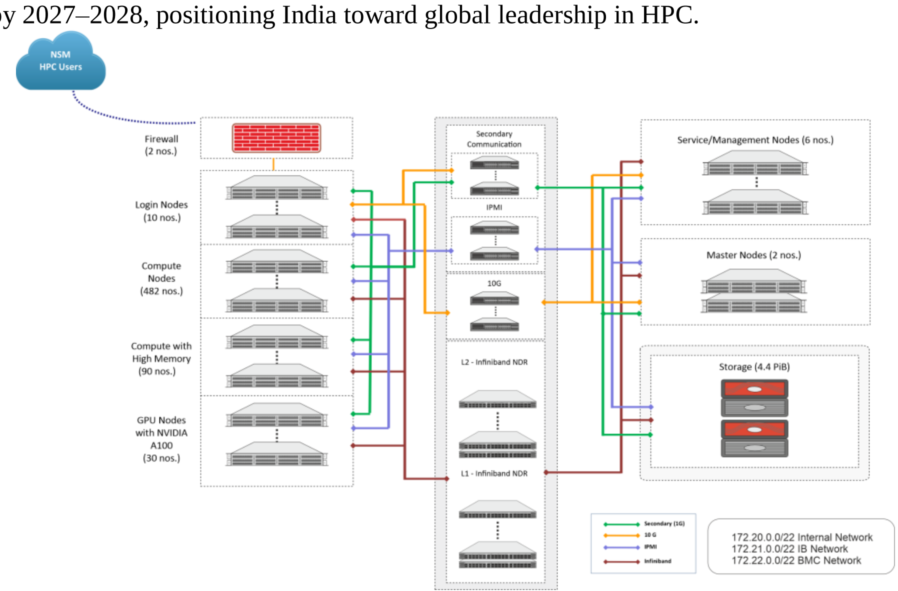
The deployment of *PARAM Rudra* supercomputers has significantly expanded HPC capacity in India. According to NSM reports, more than **38 supercomputers with a combined capacity of around 44 petaFLOPS** have been commissioned across academic and research institutions. These facilities serve a wide range of scientific applications including:

- **Artificial Intelligence and Machine Learning**
- **Biotechnology and Drug Discovery**
- **Climate and Weather Modelling**
- **Materials Science and Engineering Simulations**
- **Astrophysics and Cosmology**
- **Advanced Manufacturing Research**

Rudra's multi-disciplinary support broadens the research ecosystem and promotes innovation in both academia and industry.

3.5 Strategic Context and Future Directions

The National Supercomputing Mission continues to expand India's computational infrastructure. Under **NSM 2.0**, ongoing efforts aim to deploy additional Rudra-based systems and develop **pre-exascale computing capabilities** by 2027–2028, positioning India toward global leadership in HPC.



SYSTEM ARCHITECTURE (PARAM RUDRA , IIT BOMBAY)

4.LITERATURE REVIEW

The development of supercomputing in India has been widely discussed in academic and technical literature, particularly in relation to indigenous innovation and strategic self-reliance. Early studies highlight the pioneering efforts of the Centre for Development of Advanced Computing (C-DAC), especially through the PARAM series. Researchers note that PARAM 8000 established India's capability in distributed parallel processing at a time when access to foreign supercomputing technology was restricted. Subsequent systems, including PARAM 10000 and PARAM Padma, demonstrated progressive improvements in computational speed, interconnect efficiency, and scalable cluster architecture.

Recent scholarship focuses on advancements under the National Supercomputing Mission, which aims to strengthen high-performance computing infrastructure nationwide. Systems such as PARAM Siddhi-AI illustrate the integration of GPU acceleration and heterogeneous architectures tailored for artificial intelligence applications. Overall, the literature indicates a clear evolution from foundational parallel systems to energy-efficient, AI-enabled, and exascale-oriented supercomputing frameworks, reflecting India's expanding technological expertise and research capabilities.

5.CONCLUSION

The evolution of supercomputing in India reflects a remarkable journey from technological dependence to global competitiveness in high-performance computing. The establishment of Centre for Development of Advanced Computing (C-DAC) in 1988 marked the beginning of India's indigenous supercomputing mission after facing international technology denial. The launch of PARAM 8000 in 1991 symbolized India's entry into the elite group of nations capable of developing supercomputers. Over the years, the PARAM series—including PARAM 10000, PARAM YUVA, PARAM YUVA II, and PARAM Siddhi-AI—demonstrated continuous improvements in parallel processing, processor architecture, scalability, and energy efficiency. These systems supported critical applications such as weather forecasting, seismic data analysis, molecular modeling, cryptography, and scientific research, thereby strengthening India's technological infrastructure.

The introduction of PARAM Rudra under the National Supercomputing Mission represents the next phase of India's HPC evolution. Rudra systems integrate modern multi-core CPUs, GPU acceleration, direct liquid cooling technologies, and an indigenous software stack, ensuring improved computational efficiency and sustainability. Their deployment across major institutions such as Indian Institute of Technology Madras, Indian Institute of Technology Bombay, and Indian Institute of Technology Patna reflects the expansion of advanced computational resources nationwide.

Comparatively, PARAM laid the foundational architecture and demonstrated India's capability in indigenous supercomputing development, while RUDRA signifies India's transition toward AI-driven, scalable, and pre-exascale computing infrastructure. The advancement from gigaflops to multi-petaflops performance levels highlights consistent technological growth and innovation.

Furthermore, NSM 2.0 outlines India's roadmap toward exascale computing by integrating artificial intelligence, quantum computing, and high-performance computing frameworks. The development of indigenous processor technologies, including RISC-V and ARM-based architectures, indicates a strategic move toward long-term self-reliance.

In conclusion, the comparative study of PARAM and RUDRA illustrates not only technological progression but also national resilience and innovation. Continuous government support, academic collaboration, and indigenous research have positioned India as a significant contributor to the global supercomputing ecosystem. The future of India's HPC landscape appears promising, with strong potential for achieving exascale capabilities and strengthening applications in defense, climate science, healthcare, artificial intelligence, and digital transformation.

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