Breaking the Limits: Exploring the Frontiers of High-Performance Computing in Africa

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***Abstract*— HPC has been widely adopted worldwide, but its use in Africa has been limited by challenges such as inadequate infrastructure, high maintenance costs, and a lack of skilled personnel. However, there is a growing interest in bringing HPC to Africa to boost its technical and scientific capabilities. This study examines the state of HPC in Africa, highlighting its technological advancements, challenges, and potential. It discusses the potential for cutting-edge technologies, such as quantum computing and neuromorphic computing, to revolutionize HPC. The study also emphasizes the value of HPC in Africa and the opportunities it offers for development, innovation, and collaboration. The study discusses initiatives aimed at building African knowledge and infrastructure, such as the African School on Electronic Structure Methods and Applications (ASESMA), CApic-Ace, KENET, and regional HPC facilities. The results show that, by using HPC to tackle problems, African scientists can advance knowledge and innovation in science, collaborate internationally, and help address pressing issues such as climate change, public health, and food security.**

Keywords*— *High performance Computing, cloud computing, challenges, Opportunities, Research groups, collaboration, supercomputers, infrastructure, scalability

I. INTRODUCTION

High-performance computing (HPC) has revolutionized research and development across various fields by using advanced computing systems to solve complex scientific, engineering, and data-intensive problems. While HPC makes use of supercomputer and computer cluster technologies, its applications are mainly categorized into two types, which they are closely coupled applications and loosely coupled applications (Peterson J. S, 2011). Supercomputers are transistorized to handle large numbers of computations. They are capable of processing huge amounts of calculations for complex jobs. To run these HPC applications it requires costly hardware, and users have to wait to make use of the shared memory. With the advent of Cloud Computing and the benefits of Infrastructure as a service (IaaS) and Platform as a service (PaaS), scientists and engineers are able to deploy their HPC applications in the cloud without worrying about the costs associated with infrastructure and other costs (Sindhu M., and Sanjay P. A., 2012). Moreover, there are different applications that are running in the cloudlike Molecular modeling, Genome analysis, oil, Gas, Computer science, etc. Cloud computing is captivating to scientists in the small research groups in the fields of computational science and engineering.

While HPC has been widely adopted globally, its presence in Africa has been limited due to challenges such as infrastructure limitations, maintenance costs, scalability, the need for advancements in hardware and software technologies and limited expertise. However, there is a growing interest in bringing HPC to Africa to enhance scientific and technological capabilities such as quantum computing and neuromorphic computing. The study emphasizes the importance of HPC in enabling African researchers to process large amounts of data quickly, collaborate globally, and contribute to addressing critical challenges such as climate change, public health, and food security. It discusses initiatives such as the African School on Electronic Structure Methods and Applications (ASESMA), CApic-Ace, KENET and regional HPC centers that aim to develop expertise and infrastructure in Africa. The research work highlights the significance of HPC in Africa and the opportunities it presents for innovation, collaboration, and development. By addressing challenges and leveraging the power of HPC, African scientists can contribute to global scientific knowledge and innovation.

II. LITERATURE REVIEW

In 2002, South Africa's President Thabo Mbeki highlighted ICT as a crucial element in economic development and recommended the establishment of an ICT University, highlighting its central role in promoting development in the country. The Centre for High Performance Computing (CHPC), a Meraka Institute component, has secured funding for a three-year high performance computing initiative from 2006-2008 (Adam R, 2006).

The University of Cape Town will host the CHPC facility, utilizing South Africa's scientific computing capabilities. The facility will include experts in computational chemistry, grid computing, climate modeling, bioinformatics, and machine vision. South Africa plans to establish regional nodes to enhance its HPC knowledge and enable regional research initiatives.

The CHPC has provided computational resources and temporary storage to ASESMA participants in African schools, with the South African government's support. ASESMA has trained African scholars in materials science, with support from host governments and international institutions. Regional initiatives in Africa have established small HPC facilities for local researchers and graduate students, with support from the Chinese government. In Kenya, The Kenya Education Network is assisting a special interest group, Computational Modeling and Materials Science, by offering workshops on HPC resource usage and proposal writing (KENET, 2023).

The African School on Electronic Structure Methods and Applications (ASESMA) introduces computational modeling to African academia, researchers, and graduate students, with biannual series planned from 2010 until 2020 (Chetty N., etal, 2010). The 2010 series was held in Cape Town, with those in 2012, 2015 and 2016 taking place in Eldoret (Kenya), Johannesburg (South Africa), and Accra (Ghana), respectively. (Amolo G., and Martin R. H, 2015) The initial focus was on materials science, with physics and chemistry as the fundamental subjects, but has grown to involve biological systems and applied sciences such as materials engineering. The CHPC now has a much larger user base that includes drug design and astronomy, among others.

TABLE 1: AFRICAN COUNTRIES THAT HAVE HAD HPC IN RECENT YEARS.

S/N	HPC FACILITIES IN AFRICA		
	SERVER MODEL	**BRANDS**	**COUNTRIES**
1	AMD Operon-based IBM e150 (Has eight nodes equipped with clear speed accelerator card)	IBM	South Africa
2	IBM Blue Gene/Prack	IBM	South Africa
3	Hybrid Sun Machine (SPARC 64 VII M700)		South Africa
4	4 Computing Nodes 2.5 Teraflops, Linux, Red hat OS	Brand Unknown	Tanzania
5	Dell PowerEdge 2950 Headnote and 1950 computer node	DELL	Nigeria
6	Four (4) Computer Nodes	Brand Unknown	Nigeria

The National Agency for Science and Engineering Infrastructure (NASENI) is a government agency in Nigeria, also implemented HPC in its laboratory which caters to both internal scientists and engineers for carrying out their research activities which involve simulations and modeling (Oladapo O. A, 2015). Moreover, CApIC-ACE in Nigeria aims to develop indigenous African scientists with bioinformatics, molecular biology, and engineering skills for research in malaria, prostate, breast cancer, and personalized medicine. Collaborating with institutions in Nigeria, West Africa, Germany, France, the US, and the UK. (CApIC-ACE, 2023).

In Africa, there are several challenges that researchers in Africa face when it comes to HPC adoption, and this research will discuss these challenges.

One of these challenges is scalability. Scalability challenges in HPC systems, requiring efficient resource management, prompt the development of new programming approaches incorporating machine learning and artificial intelligence techniques. According to (Tiziana C., et al, 2020), Data analysis infrastructure with a mix of general-purpose computational power, multi-threading, and large memory nodes is efficient and affordable.

Another challenge is the need for specialized hardware and software that can handle the unique requirements of scientific computing. Specialized processors, memory systems, and networking technologies are being developed to provide high bandwidth and low latency for scientific applications, surpassing those available in desktop computers and servers (Tiziana C., et al., 2020). HPC systems are rapidly evolving with new architectures and hardware, and in some cases, the hardware interfaces are proprietary, such as the Cray interconnect (Dan H., et al. 2022).

Infrastructure (Limited access to HPC resources): One of the biggest challenges facing African scientists is limited access to HPC resources, (Dan R., 2022) Market and cost pressures have shifted users and centers towards clustered systems, leading to high maintenance costs, inactivity, and abandonment of specialized supercomputers (Amolo G., 2018). HPC requires a reliable data infrastructure, including CPUs and GPUs, fast networks, and data storage systems. Many African nations lack the necessary infrastructure for large-scale simulations and data processing in modern supercomputer systems (Dan R., 2022).

Limited technical expertise: Limited technical skill in Africa makes HPC systems challenging for scientists to utilize. Ineffective resource management negatively impacts efficiency and cost, leading to expensive or omitted functions. (V. P. Nzanzu et al. 2022).

Funding constraints: Many African nations struggle to invest in high-performance computing (HPC) systems due to high costs. Without government support, supercomputers could shape the next generation of computing products, reducing reliance on foreign countries.

Recently, African nations are increasingly embracing High-Performance Computing (HPC) to enhance their technical and scientific capabilities, enabling efficient data processing, simulation, and execution of advanced algorithms, and promoting research and development (Amolo G.,2018). HPC technology could lead to innovations in the energy, healthcare, and agriculture industries. However, it must be used to tackle climate change, public health, data security, and food security. More likely, It is widely used in various technologies such as IoT (internet of things), Artificial intelligence, and 3D evolutional images solving complex problems. All these applications use a large amount of data exponentially. HPC is a fast-computing application, so we can use it parallel with CPU and GPU. Moreover, HPC has revolutionized research in fields

like weather forecasting, drug discovery, genomics, and physics, enabling breakthroughs in various fields by simulating complex systems and analyzing vast data.

III. Methodology

African scholars can support international efforts by learning about HPC concepts, attending conferences, workshops and networking. Regional initiatives by groups in various parts of Africa that have, through their own governmental resources and support from international institutions, set up small HPC facilities that have enabled local researchers and graduate students to engage in simulations of materials of interest.

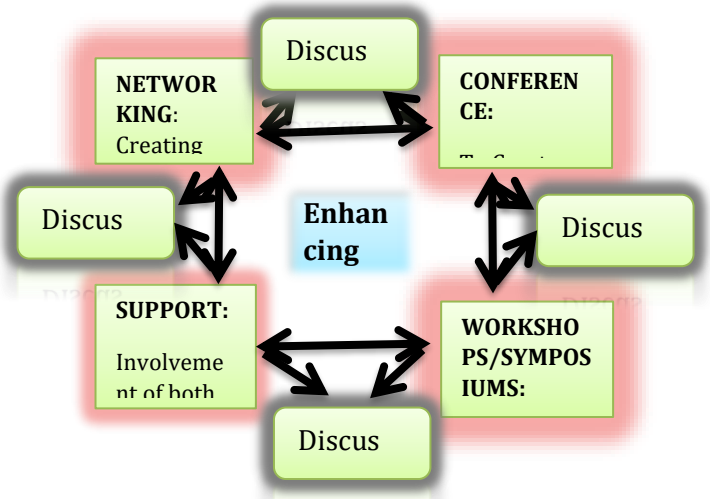

Figure 1: Enhancing HPC growth in Africa

IV. Results

According to (Amolo G., 2018), The lack of infrastructure in Africa hinders the adoption of High Performance Computing (HPC), leading to extended inactivity and abandonment. However, expertise in this field allows for high-quality research using fundamental science principles. To overcome this, regional HPC centers are established, African researchers are educated, and partnerships between African and foreign universities are formed.

Additionally, another significant challenge facing HPC is scalability. HPC faces scaling challenges due to big data combined through memory layers, making resource management more challenging. Novel programming strategies, including artificial intelligence and machine learning, have been developed. This study compares in-memory computing on two platforms, focusing on end-to-end performance, usability, portability, and resilience. Through deep analysis of these metrics, it could identify the design and scalability challenges and opportunities.

Another area of active challenge in HPC is the development of new hardware technologies, which is a similar approach is to use processor partitioning for network processing and to reduce resource contention issues in many-core systems, (Uhlig V., 2004) uses a dynamic locking approach while (Brecht T., et al, 2006) side core approach, on the other hand, presents an alternative to using functional partitioning and dedicated cores to reduce locking contention. (Huang, Liu, and Panda, 2006) and (Youseff L., 2006) have already demonstrated acceptable overheads as experienced by scientific MPI applications executing on top of Xen. More advanced technology would be better since there is more big data to compute using quantum computing and neuromorphic computing. These emerging technologies have the potential to revolutionize HPC by providing new ways to perform computations and handle data.

V. Impact of HPC on the Development of Africa

a) Increases processing speed to handle more calculations per second and power through the most difficult analyses for the most demanding applications, such as engineering design.

b) The ability to envision and begin working on engineering designs and models that have been taught conceptually in the classroom empowers young and incoming engineering students at all levels — undergraduate and postgraduate.

c) Opens up a new era for computational science education and parallel computing across the country.

d) When professionals in the scientific and engineering community have access to the HPC facility for executing time-saving, robust, and thorough simulations throughout their inquiry, this sparks the nation's top engineering ideas.

e) It is a cost-effective alternative to earlier engineering techniques that led to the failure of crucial machine parts and electronic components by forcing the planned equipment to function under unanticipated real-world circumstances, such as environmental impacts (Temperature, Pressure, etc.). HPC resources may be used to effectively imitate such environmental conditions.

f) Allows for the adaption of local technologies to ongoing economic issues.

g) Our future transition to cloud computing will be built on this new, cost-effective service-oriented architecture.

VI. Conclusion

h) The acceleration of scientific discovery through High-Performance Computing (HPC) in Africa faces both challenges and opportunities. As researchers push boundaries, new challenges emerge, but also opportunities for innovation and development. African scientists can contribute to global knowledge and innovation. To start, familiarize yourself with HPC concepts through courses, workshops, and networking.

i) Another important consideration in the introduction of HPC to Africa is the need to ensure that this technology is used to address the most pressing challenges facing the continent, such as climate change, public health, data security, and food security. By harnessing the power of HPC, African researchers can contribute to global efforts to tackle these and other critical issues. The practical implications of cloud computing are vast and transformative, offering organizations scalable and cost-

effective access to computational resources, storage, and services. This technology enables increased agility, flexibility, and innovation, allowing businesses to adapt swiftly to changing demands. However, challenges such as data security, privacy concerns, and regulatory compliance must be carefully addressed to fully harness the benefits. Future research in cloud computing should focus on advancing security measures, optimizing resource allocation algorithms, exploring sustainable and energy-efficient solutions, and enhancing interoperability standards. Additionally, investigating the societal and economic impacts of widespread cloud adoption, along with addressing ethical considerations, will be crucial to shaping the future landscape of this rapidly evolving technology.

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