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High-Performance Computing: A Primer

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ABSTRACT: Computational science is well on its way to enter into the exascale era. High-performance computing emerged to meet the need of increasing demands for processing speed.
High-performance computers have evolved from MFlops to GFlops to PFlops scale over the past two decades. (Flop = floating-point operations per second). High-performance computing is fast computing using high-performance computers such as supercomputers. HPC has become determinants of industrial competitiveness and advanced research in several areas. This paper presents a brief introduction to high-performance computing.

KEYWORDS: high-performance computing, high-productivity computing, supercomputing, parallel computing

I. INTRODUCTION

High-performance computing or high-productivity computing (HPC) refers to the use of supercomputers and parallel processing techniques for solving complex computational problems. In general, HPC can either mean "high performance computing" or "high performance computer." In the latter sense, HPC is used as a synonym for supercomputer. HPC allows researchers to find a quick solution to complex, compute-intensive problems in science, engineering, and business.

HPC combines several technologies such as computer architecture, algorithms, VLSI, digital signal processing, and system software to solve advanced problems effectively and quickly. Based on the availability of powerful computing devices, new computing tasks have been designed and sseveral emerging technologies, such as grid computing, utility computing, services computing and cloud computing, have evolved from HPC. HPC is regarded as the leading edge of computing. High-performance x86 processors, augmented with functional accelerators and open source Linux software and associated toolkits now dominate advanced computing [1].

The major architecture for building HPC systems are clusters, vector processors, and parallel processing systems. Popular types of HPC systems include clusters, clouds, GPUs, and FPGAs. A cluster consists of a set of connected computers that work together to form a computing system. Cloud computing is offering new approaches for HPC as it provides scalable resources as a service over the Internet. The use of cloud infrastructures for HPC applications has generated considerable interest in the scientific community [2].

II. APPLICATIONS

HPC is often applied in solving advanced problems and performing research activities through computer modeling, simulation, and analysis. HPC facilities serve as infrastructure for solving demanding computational problems encountered in various disciplines. It is implemented in many areas including:

- *Smart power grid*: HPC can improve today's power grid operation functions like state estimation and contingency analysis and reduce the solution time from minutes to seconds, comparable to the supervisory control and data acquisition (SCADA) measurement cycles. HPC in grid operations is beginning [3].
- *Oil and Gas*: HPC plays a major role in data processing and interpretation of oil and gas geophysical exploration, which is a science that examines the underground geological distribution of minerals based on differences in the physical properties. The main computing task in the oil and gas industry modeling is processing that involves solving the data-intensive wave equations [4].

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- *Engineering simulations*: This is one of the most well-known fields that succeeded in taking advantage of the new skyrocketing HPC. Simulation is an indispensable tool for researchers to explore systems without having recourse to real experiments. It is now clear that modeling and simulation of artificial and natural systems is fundamental for the advancement of science. This has facilitated a broader and more effective application of numerical methods for differential equation such as finite difference time domain (FDTD), finite element method (FEM), and Monte Carlo method (MCM) [5].
- *Neuroscience:* The computational power, memory, and storage capabilities offered by HPC resources are suitable for neural circuit simulations. Performing even standard analysis on massive neurophysiology datasets will benefit from HPC systems. Harnessing the power of HPC resources to address "Grand Challenge Problems" will requires computational neuroscientists to collaborate with computer scientists [6].

The applications described here represent only a sampling of the most popular HPC applications available. Other applications are found across industry, academia, and government in diverse areas such as financial services, social networks, media and entertainment, climate modeling, biology, geographical data, high-energy physics, linguistics, life sciences, scientific computing, weather forecasting, medical sciences, transportation, electronic design automation (EDA), computer-aided engineering (CAE), and Homeland Security. Applications are becoming increasingly complex providing many opportunities to apply HPC in new ways.

III. ISSUES AND CHALLENGES

Although HPC presents many opportunities for research and advancement in a wide range of applications, it also presents significant challenges that must be addressed.

Security is a key component for all computing techniques as our life is more and more intertwined with information processing. Some of the traditional security techniques are not effective because they cannot keep up with the system [7]. There needs to be balance between security and convenience. Due to the convenience factor intrusion prevention is little bit harder on HPC systems and they are more vulnerable.

Performance, however, is always of primary concern in HPC. By definition, HPC systems are optimized for high performance and performance is defined as speed. To achieve higher performance, microprocessors vendors have increased the power and number of transistors every 18-24 months. As a result, keeping a large HPC system working properly requires continuous cooling of a large computer room, creating a large operational cost [8].

Power awareness is an important issue in HPC. Ignoring power consumption can lead to high operational cost, which can impact reliability and productivity. Modern parallel supercomputers are dominated by power hungry commodity machines that are capable of performing billions of operations per second. Breaking the exascale barrier requires overcoming several challenges related to energy costs, memory costs, communications costs, etc. [9].

While computer performance has improved dramatically, real productivity (defined
in terms of achieving mission goals) with these ever-faster machines has not kept pace. Indeed, researches are finding it increasingly costly and time-consuming to update their software to take advantage of the new hardware [10].

The energy efficiency of applications running on HPC platforms is hard to improve due to the lack of systems and tools that can provide accurate power consumption data of all major components including CPUs, DRAMs, disks, accelerators and coprocessors. Minimizing energy consumption of HPC requires novel energy-conscious technologies at multiple layers [11].

The adoption of cloud computing in HPC has become appealing within the enterprise and service providers. HPC clouds expand the application user base. But with cloud being an additional deployment option, HPC users have to deal with heterogeneous resources [12].

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IV. CONCLUSION

Today's leading-edge scientific research and scholarly activities heavily depend on HPC.However; history has repeatedly shown that the power of a 1980s-class supercomputer is now embedded in today's cellphones and common appliances. Hence today's HPC systems will become tomorrow's desktop systems [13].

To adequately prepare students for tomorrow's workforce, the educational institutions must incorporate computational thinking as an integral component in all disciplines starting from the K-12 years. Major needs in various disciplines drive demand for HPC professionals. This has led some institution to provide a new Computer Science minor for high-performance computing (HPC). This minor is usually available to students from all of the science and engineering disciplines [14].

Additional information on HPC is available in several books in Amazon.com and the journal, *The International Journal of High Performance Computing Applications*, which is exclusively devoted to providing information on HPC, covering various aspects of HPC.

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