Case Study of Dr. Tassadaq Hussain Contribution

Title: A Platform for Supercomputing and Artificial Intelligence

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1. Summary

In a supercomputer system, thousands or even millions of processors work in parallel using advanced programming models and process the real-life scientific and engineering applications delivering power up to millions of times higher than of normal personal computer. With the integration of Artificial Intelligence (AI) based supercomputers, the machines allow scientist and engineers for simulation and data analysis that require a large amount of data in short period of time. Today supercomputers are considered as the main pillar of science and is an essential tool for accelerating countrys strength, overall growth, financial power, national security, defensive ability, and promote the timely development of the highly modern tool and technology. Therefore, a high-performance supercomputer platform and artificial intelligence framework are required in all fields of academia, research and industry, which give hardware/software design and development services and solutions to execute science and engineering problems using supervised and unsupervised techniques. The proposed and developed platform allows scientists, researchers, and engineers to easily exploit the power of supercomputing and generate intelligent applications that observe, understand, learn and recognize the world similar to human begins. It produces excellent levels of computing capability and skills to drive next-generation artificial intelligence applications, supporting researchers and scientists to dramatically diminish the time to train bigger, more complex application models.

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2. Supercomputing Systems Architectures and Trends

Big data is the oil of 21st Century which opens a new era in the data exploration and allows to take advance decisions by consuming vast amounts of information. Gartner [1] predicts that enterprise data in all forms will grow up to 650% over the next five years. According to IDC [2], the worlds volume of data doubles every 18 months. Digital information is doubling every 1.5 years and will exceed 1000 exabytes [3] till 2020, according to the MIT Centre for Digital Research. On the other side, the speed of digital computer systems to process the information has been increasing exponentially, therefore, become the cornerstone of much of the technological and scientific advancements that we have experienced over the past few decades.

With the increase of the number of processors on a chip, there has been a rapid growth in the deployment and application of computer clusters to expand the range of available system capabilities beyond those of conventional desktop and server platforms. By leveraging the development of hardware and software for these widely marketed and heavily used conventional computer systems, Supercomputers deliver an order of magnitude or more scaling of computational performance and storage capacity without incurring significant additional research and development costs. Heterogeneous Supercomputers exploit mass-market of graphics hardware and software in conjunction with cost-effective commercial network technology, provide users with the dual advantages of unprecedented price/performance and configuration flexibility for parallel computing.

Faster high performance systems allow us to solve larger Algorithms, Numerical Techniques, Big Data, Data Mining, Bioinformatics & Genomics, Business Intelligence & Analytics, Climate, Weather & Ocean Modeling, Computational Chemistry, Computer Vision & Machine Vision, Finance & Economics, Geoscience, Image Processing, Material Science, Medical Imaging, Molecular Dynamics, Neuroscience, Physics, etc. related problems, and to find solutions more quickly, with greater accuracy, and at a lower cost. Traditional high-performance clusters have proved their worth in a variety of uses from predicting the weather to industrial design, from molecular dynamics to astronomical modeling. Many of the todays problems require tremendous computational resources to be solved accurately. For example, interferon (IFN) response to virus infection , n-body problem to predict the individual motions of a group of objects, finding genes in DNA sequences, predicting the structure and functions of new proteins, clustering proteins into families, aligning similar proteins, and generating phylogenetic trees to examine evolutionary relationships all need complex computations. These ap-

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plications are computationally very intensive and require vast amounts of processing power and memory requirements. Therefore, to give accurate results, robust Supercomputer architecture is needed to reduce the execution time of applications.

In Pakistan, the research and development on Supercomputing started during the early eighties. Pakistan Atomic Energy Commission (PAEC) department is considered as the pioneer in the field of supercomputing. The PAEC started using supercomputing for processing complex applications. In the late nineties, Pakistan faces a ban on supercomputers which reduces the speed of development of supercomputing. The ban gets relaxations at the start of 21st century, the U.S. government eased regulations that applied to exporting high-performance computers to Pakistan. The current regulations allowed Pakistan to import supercomputer systems that are capable of processing information at a speed of 500 GFLOPS Later different universities and research centers have established their supercluster architectures. Some of the leading supercomputing groups and departments are ScREC NUST Islamabad, KUST Kohat, COMSATS, CIIT Islamabad, GIK Institute, KRL, UET Lahore, and NED Karachi.

Dr. Tassadaq Hussain [4] has built a Supercomputing Research Group (ScRG) [5] in collaboration with UCERD Private Limbed Islamabad [6] and Barcelona Supercomputing Centre Spain [7]. In January 2016, Dr. Tassadaq and his team of engineers have developed a GP-GPU based supercomputer architecture [8]. The system supports CUDA, MPI/LAM, OpenMP, OpenCL and OpenACC programming models. It also can solve larger algorithms, numerical techniques, big data, data mining, bioinformatics and genomics, business intelligence and analytics, climate, weather and ocean-related problems. He also proposed and developed Pakistan's 1st FPGA-Powered Supercomputer [9][10]. The FPGA-Powered Supercomputer uses an FPGA and ARM processor based compute nodes. The design system uses message passing interface libraries for communication between compute-nodes while AXI4-stream interfaces between ARM processor and FPGA inside a compute-node.

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3. Generic Supercomputing System

A supercomputer is a computer with a high-level computational capacity compared to a general-purpose computer. A super computer holds a group of computers that act as one collective machine capable of processing enormous amounts of data. For the best efficacy, the supercomputer system has high Performance processing architecture, easy Programmable programming models , Portability, and Scalable against scientific algorithms, Accessible by the users, Power Efficient and Low Cost. A generic supercomputing system contains five major groups (shown in Figure 1) which are the Scientists, the Programmers, the Hardware Experts, the System Manager and the Programming Tool Developers.

1. The scientist group responsibility is to propose and provide algorithms related to sciences and engineering e.g. linear, differential equations and filters for quick analysis, observation and decision.
2. The Programmers duty is to take a sequential algorithm and convert it into the parallel program which can execute efficiently on supercomputer architecture.
3. The Hardware Experts proposes hardware architectures which can execute parallel program generated by Programmers group and give high performance. There are three type of hardware architectures for the supercomputing system CPU-based, CPU, GPU-based and Embedded CPU-GPU based.
4. The Programming Tool Developers is to prove software solutions. The solutions can be used by the Scientists and Programmers to best utilize the resources of High Performance Computing. The Programming Tool Developers has to deal with, the hardware scalability issues by using Operating

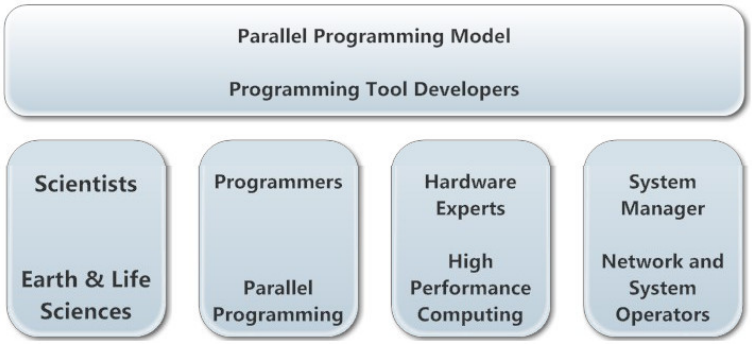

Figure 1: Different Sections of A Generic Supercomputer System

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Systems (OS). Suitability of the mainstream OS for Supercomputers with potentially hundreds and thousands of heterogeneous processing cores is one of the hottest debated subjects in the academic and research community. The OS supports, in a scalable manner, hundreds of heterogeneous processor cores. It follows the fundamental design principle, space sharing, support for heterogeneity, power efficiency, virtualization, and layering. The Programming Tool Developers has to propose and provide Programming Models. Real applications use SISD (CPU), SIMD (GPU), and MIMD (FPGA, Multi-core) architectures, executing the sequential parts on the SISD and compute intensive parts of the SIMD or MIMD cores. Supercomputer requires a practical programming model that facilitates parallel implementation and supports proper management of data delivery to the processing nodes. This is why the CUDA programming model, introduced by NVIDIA in 2007, is designed to support joint CPU-GPU (SISD-SIMD) architecture. The demand for supporting joint CPU-GPU execution is further reflected in more recent programming models such as OpenCL, OpenACC, and C++AMP.

5. The system manager has to deal with hardware maintenance issues, software installations, power management, and network management etc..

4. Innovation: Platform for Supercomputing and Artificial Intelligence

With the increase of information available in Big Data format and improvement in microprocessor technology, high performance, and low power Supercomputer architecture is required across all fields of research and academia. The Supercomputer architecture allows multiple processing resources to be accessible by different applications to processes datasets.

The Supercomputing Platforms harness the power of processing systems uses intelligent programming frameworks and provides the services to solve complex applications. The Supercomputing Platforms provide application services to solve scientific and engineering problems for academia, industry, and defense and gives them a productive environment. The Supercomputing programming frameworks allow developers, researchers and scientists communities to write compute and data intensive applications easily, solve problems in quick time and provide a guideline that improves their efficiency. It uses high performance processing cores to process compute and data intensive real and non real-time problems. The platform targets new computing processing architectures that are hardware optimized and give better support, artificial intelligence based programming environment

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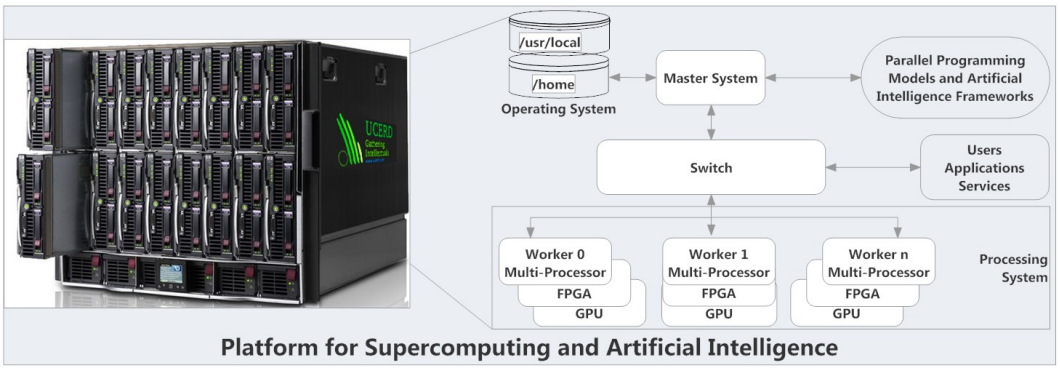

Figure 2: Platform for Supercomputing and Artificial Intelligence

and low power and high performance components to make supercomputer easily programmable, more energy efficient and high performance. A simple block diagram of the supercomputer design is shown in Figure 2

In 2015 Dr. Tassadaq Hussain [4] built a Supercomputing Research Group (ScRG) [5] in collaboration with UCERD Private Limbed Islamabad [6] and Barcelona Supercomputing Centre Spain [7]. The ScRG is one of the largest supercomputing research center in Pakistan. The ScRG can work on research, industry and defence projects, including big data processing, signal processing, and low power computing. In the past, Dr. Tassadaq has proposed supercomputing architecture [11] [12] [13] [14] [15] [16] that uses FPGAs based accelerators, DSP, GPU and RISC multi-core processing systems.

Considering the cost, power and performance, Dr. Tassadaq has proposed and developed three types of Supercomputing Platforms. The supercomputer architectures are the *CPU based Supercomputer*, the *CPU-GPU based Supercomputer* and the *FPGA based Supercomputer*.

4.1. CPU based Supercomputer

The *CPU-based Supercomputer* uses multiple CPUs having RISC architecture instruction set architecture. To program and execute the compute intensive applications architecture uses Python, CUDA, MPI/LAM, OpenMP, OpenCL and OpenACC programming models. It also can solve larger algorithms, numerical techniques, big data, data mining, bioinformatics and genomics, business intelligence and analytics, climate, weather and ocean-related problems.

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4.2. *CPU-GPU based Supercomputer*

The *CPU-GPU based Supercomputer* uses GPU hardware accelerators to execute applications. The supercomputer uses SIMD architecture having DSPs and the CUDA Fermi architecture ," the Tesla GPU Computing Modules. The OpenACC and CUDA for CPU-GPU based Supercomputer are used to program the applications. In January 2016, Dr. Tassadaq and his team of engineers have developed a GP-GPU based supercomputer architecture [8]. These dedicated accelerators have low footprint and low power consumption and provide high performance. SIMD architecture uses DSPs and the CUDA Tesla, Fermi, etc. architectures," the GPU Computing Modules. Low power ARM and high performance x86 multi-core processor systems are also used in the Super-Cluster system which allows system to execute most of the generic C/C++ applications. The proposed system is ideal for seismic processing, biochemistry simulations, weather and climate modeling, signal processing, computational finance, CAE, CFD and data analytics.

4.3. *FPGA based Supercomputer*

He also proposed and developed Pakistan's 1st FPGA-Powered Supercomputer [9][10]. The FPGA-Powered Supercomputer uses an FPGA and ARM processor based compute nodes. The design system uses message passing interface libraries for communication between compute-nodes while AXI4-stream interfaces between ARM processor and FPGA inside a compute-node. The *FPGA based Supercomputer* uses low power and low-cost real-time applications. Low power ARM and high performance x86 multi-core processor systems are used in the Supercomputer system which allows the system to execute most of the generic C/C++ applications with low power and low cost. A High level synthesis tool is used to program FPGA accelerators for specific applications. The system uses High-level synthesis tool is used to program FPGA accelerators for a specific application. The proposed supercomputer systems can execute a set of requirements for high-performance scientific applications related to earth, space, and medical sciences and give an opportunity of low-cost computing to research and academic groups. The proposed system is also facilitated by the availability of the Linux operating system, a robust Unix-like system environment.

4.4. *Objectives*

- The supercomputing platform provides a platform for high performance processing system and easy to use programming environment for complex and compute-intensive applications that help researchers to solve problems

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by analyzing the massive amount of data in a short period that will improve the quality of learning and research.

- The supercomputing project is an application of the design, the research team has already worked on and published relevant articles; it will strengthen the means of implementation and revitalize the local academic and industry partnership for sustainable development.
- Supercomputing platform promotes sustained, inclusive and sustainable economic growth, full and productive employment and decent work.
- The proposed platform improves the performance of application for data sciences, modeling, and simulation, security, health-care, real-time signal processing based system.
- The proposed platform solve medical health-care problems. Therefore, it will contribute to ensure healthy lives and promote well-being for all of all ages.
- The project gives high performance and intelligent programming support that can support security and surveillance application which grow human resources and give comprehensive safety.

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Table 1: Available Super-Computer System Architectures in Pakistan

Institute	Peak Performance	Power Consumption
NUST, Islamabad	132 TFLOPS	N/A
UCERD System	112.91 TFLOPS	10.35 K Watts
KUST, Kohat	0.416 TFLOPS	N/A
COMSATS	0.158 TFLOPS	N/A
CIIT, Islamabad	0.05 TFLOPS	N/A
GIK Institute	N/A	N/A
KRL	N/A	N/A
UET Lahore	N/A	N/A
NED Karachi	N/A	N/A

5. Contributions

The supercomputing contributions are subdivided into Achievements, Awards and Workshops.

5.1. Achievements

In Pakistan, different universities have established their super computer architectures. Some of the leading universities are NUST Islamabad, KUST Kohat, COMSATS, CIIT Islamabad, GIK Institute, KRL, UET Lahore, and NED Karachi. If we compare those universities with our proposed architecture with Peak Performance and Power Consumption, then we get the summary as shown in Table 1. The results show that the proposed Super-Computer architecture lies at the 2nd position while comparing the performance [8][17]. While comparing the Performance per Watt, our system ranks at 1st place.

5.2. Awards

The Platform for Supercomputing and Artificial Intelligence secured 1st runner-up position in Professional Categories of DICE 2017 Mega Innovation and Entrepreneurship Event at MUST [5].

5.3. Workshops

Following are the workshops conducted on Supercomputing and Artificial Intelligence.

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- One Day CBT PEC workshop on Supercomputing and Artificial Intelligence on 18th of December 2017 at Riphah University Islamabad.
- A Workshop on High Performance Computing Chenab Group of Collages Gujrat Pakistan on 12th of August 2016
- Low Power Low Cost Supercomputing System International Conference on Energy for Environmental and Economic Sustainability (ICEEES2016) Lahore (PK) on 22nd of October 2016
- Supercomputing System Architectures and Trends University of Lahore, Gujrat Campus 2nd International Multidisciplinary conference (IMDC 2016), on 19th of December 2016
- Supercomputing System Architecture for High Performance Applications Department of Electrical Engineering, Capital University of Science and Technology Islamabad, on 1st of February 2017.
- Supercomputing and Artificial Intelligence at Mirpure University of Science and Technology and DICE Mega Event of Innovation and Entrepreneurship December 2017.

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